EVALUATION OF IMPACTS OF WATER, SANITATION AND HYGIENE (WASH) ACTIVITIES TO THE ENVIRONMENT IN THE UPPER MARA BASIN USING THE WEAP MODEL

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Evaluation of Impacts of Water, Sanitation and Hygiene (WASH) Activities to the Environment in the Upper Mara Basin Using the WEAP Model

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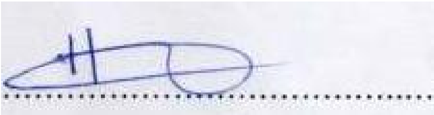
DECLARATION

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

Signature  Date 6/11/2014.

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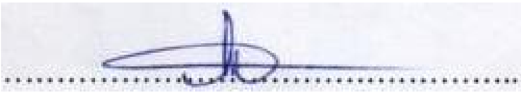
Signature  Date 6/11/2014

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DEDICATION

I dedicate this work to all who endeavor to do good without malice or selfishness and all who strife to make the world a better place for all creatures to live in.

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ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
BOD	Bio-chemical Oxygen demand
CFAs	Community Forest Associations
CGIAR	Consultative Group on International Agricultural Research
DHI	Danish Hydraulic Institute
DO	Dissolved oxygen
DST	Decision Support Tool
EMB	Eosin Methylene Blue
EMCA	Environmental Management and Coordination Act
EPA	Environment Protection Authority
EPHC	Environment Protection and Heritage Council
ER	Environmental Reserve
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agriculture Organisation
FDEP	Florida Department of Environment protection
GDP	Gross Domestic Product
GIS	Geophysical Information System
GLOWS	Global Water for Sustainability
GPS	Geographic Positioning System
ICF	International Classification of Functioning, Disability and Health
IEA	Institute of Economic Affairs
ILCA	International Livestock Centre for Africa

IWRM	Integrated Water Resources Management
JMP	Joint Monitoring Programme
KDHS	Kenya Demographic Health Survey
KNBS	Kenya National Bureau of Statistics
KWQR	Kenya Water Quality Regulation
LQI	Land Quality Indicators
LVBC	Lake Victoria Basin Commission
Ma.s.l	Meters above sea level
MCM	Million Cubic Meters
MDG	Millennium Development Goal
MF	Membrane Filter
MOPHS	Ministry of Public health and Sanitation
MOWI	Ministry of Water and Irrigation
MPN	Most Probable Number
MRB	Mara River Basin
MRWUA	Mara Waters Users Association
NEMA	National Environmental Management Authority
NGOS	Non-Governmental Organizations
NRC	National Research council
OECD	Organisation for Economic Development and Co-Operation
PES	Payment for ecosystem services
PSR	Pressure- State - Response
RUSLE	Revised Universal Soil Loss Equation.

SEI	Stockholm Environmental Institute
SPSS	Statistical Package for Social Science
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UNCHS	United Nations Conference on Human Settlement
UNDP	United Nations development Programme
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
USEPA	United States Environmental Protection Agency
VIP	Ventilated Improved Pit
WARMA	Water Resources Management Authority
WASH	Water, sanitation and hygiene
WEAP	Water Evaluation and Planning
WHO	World Health Organization
WNW	Wadi- Nar Watershed
WREM	Water Resources and Energy Management
WRMA-RO	Water Resource Management Authority Regional Office
WUAs	Water users associations
WWF	World Wide Fund for Nature
WWF-ESARPO	WWF-Eastern and Southern Africa Regional Programme Office

ABSTRACT

Provision of reliable and safe water supplies is an essential element in improving the quality of life for mankind and is critical component for sustainable development. World Wide Fund for Nature (WWF) and Global Water for Sustainability (GLOWS) are working in the Mara basin to improve adequate water supplies, and to ensure sustainable development and conservation of the natural resources in the Mara-Serengeti ecosystem. This study was undertaken to assess public access to water, sanitation and hygiene (WASH) services and to evaluate the impacts of WASH activities on the environment in the upper Mara River basin.

Operational 38 water supply projects, 16 waste water disposal projects and 22 solid waste disposal sites were identified by observations, review of literature and interviews to water users and stakeholders for impact evaluation. Impacts on land and environmental quality for the identified projects were assessed using Land Quality Indicators (LQI); water quality, solid and liquid waste generation and management and soil erosion.

Water Evaluation and Planning (WEAP) model was used to carry out scenario projections of impacts of WASH activities to the water quality and quantity in the Upper Mara Rivers. The projections started with the reference scenario of the current status followed by scenarios with alternative assumptions about future developments and management.

Water and sanitation accessibility and water quality data was analyzed using descriptive statistics, SPSS and Genstat software. GIS maps were developed to show distribution of major impacts of the WASH developments in the Upper Mara basin.
On average, 63% of the household obtained water from unimproved sources and only 23.4% of the sampled water sources were found suitable for domestic water use according to the Kenya Water Quality regulations. About 38% of the resident lacked human waste disposal facilities. A positive correlation (r = 0.37) was found between *E. coli* in open water sources and percentage of households within divisions lacking human waste disposal facilities.

Bomet municipal stabilization pond discharged poorly treated wastewater (BOD_5=644mg/l) into Nyangores river thereby posing a pollution threat to the environment. Soil erosion was observed around 17% of the sampled water supply projects shared between humans and livestock while poorly disposed solid waste defaced urban centers.

WEAP model predicted inadequate supply of water demanded in the upper Mara especially along Amala River in future. For instance, in February of year 2030 the total demand for Longisa hospital, Mulot town and Ndakaini farm would be unmet by 95.34m^3(0.88%), 47. 13m^3 (0.6%) and 924.17m^3 (0.89%) respectively in the current hydrological, climatic, water demand and population growth rate (2.44%) scenario.

The results indicated inadequacy of WASH services in the basin. The expansion of coverage of these services to reduce the vulnerability of the residents to contaminated water sources is recommended. Also, alternative sources of water particularly rainwater harvesting and underground water sources should be explored to avoid over abstraction from rivers in the scenarios that water demand in the catchment increased or if river flows reduced in the future

All effluents should be treated effectively before discharging it to the environment and solid waste generated in the basin should be collected and disposed off efficiently to reduce environmental pollution. Measures to conserve soil at water points should be done to reduce degradation of these sites.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The Mara River is particularly important because it is a trans-boundary watercourse with 65% of its catchment in Kenya and 35% in Tanzania (O'Keeffe *et al.,* 2007). In addition to water; Mara River basin (MRB) provides food, important plants, fertile soils, and critical habitat to people and wildlife. The river is the primary domestic water source for nearby towns and settlements, water for livestock, agricultural irrigation, tourist hotels and other industries (LVBC & WWF-ESARPO, 2010). The MRB supports some of the most profitable economic activities in Kenya and Tanzania including tourism, agriculture and mining which collectively contribute between 10-15% to their Gross Domestic Product (GDP) (LVBC, 2012).

Within the upper catchment of the Mara Basin, there are extensive tea plantations, large holdings of irrigated wheat; maize and French bean farms (O'Keeffe *et al*, 2007). On lower plains, livestock rearing is the principal activity with large herds of cattle, sheep and goats using free range grazing (Gathanju, 2009). Mineral resources of the Mara Basin are substantial with active mining of gold, slates and sand in the lower Mara at Buhemba and Nyamongo, Tanzania. Tourism in the MRB earns over 650 million Kenya shillings within the Masai Mara game reserve alone representing 8% of Kenya's overall tourism income while in Serengeti National Park in Tanzania revenues are nearly a billion Tanzanian Shillings per year (LVBC, 2012). The tourism industry is not only big business in terms of returns on investment from overseas visitors but it is also a major employer.

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. These specifically include: Soil erosion and high sediment loads, deforestation, declining water quality and quantity, wildlife-human conflicts and pollution (WREM, 2008).

Water supply, sanitation and hygiene (WASH) programs are undertaken to address a number of key concerns, including public health, water quality and quantity, water source protection, drainage, and disease vector control (Edmond *et al*., 2013). While WASH programs vary widely, there are a few core areas that capture a majority of the activities: Community and household water supplies, Sanitation which entails excreta disposal, solid waste management, storm water drainage and Hygiene promotion comprising awareness raising and education, behavior changes in personal and household hygiene practices (Edmond *et al*., 2013; Wetlands International, 2010).

In spite of concerted efforts to improve access to safe drinking water, an estimated 1.1 billion people in the world lack access to an improved water source. Over three million people, mostly children, die annually from water-related diseases globally. Almost two million of these deaths are the result of diarrhoeal diseases, which are caused by the ingestion of water contaminated by feacal matter, as well as by inadequate sanitation and hygiene (UNICEF, 2008).

Impact evaluation pertains to the effect which a project has on the recipient population and on the development of the sector and the country as a whole (UN-Habitat, 1987). Water supply and sanitation activities can have far-reaching positive and negative impacts. These include impacts on the environment, health and the economy (World Bank, 2006). Currently, 90% of the developing world's sewage is discharged untreated into rivers. Excessive withdrawals and water diversion are threats to rivers, lakes and aquifers (WASH advocates, 2010). In addition, water supply points often attract excessive numbers of nomads and livestock leading to defoliation, deforestation, erosion and consequent desertification especially in arid and semiarid regions (UN-Habitat, 1987).

The main WASH stakeholders were: Ministry of Water and Irrigation Bomet, Transmara and Narok South District offices, Ministry of Northern Kenya and Arid lands, Transmara District office, World Vision Kenya, Kirindon office, Free the Children Bomet, World Gospel Mission, Municipal Council of Bomet, County Council of Bomet, hotels and lodges, KTDA tea factories and Mara River Water Users Association, (GLOWS, 2011). However, there is little coordination and collaboration among the several WASH actors involved in the basin (Wamalwa, 2009).

While the Mara River and its tributaries are the dominant water source within the basin, other water sources include springs, rainwater, wells, and boreholes (Hoffman, 2007). In the Mara River basin, sanitation is mainly by use of pit latrines. However, more than half of households in Transmara and Narok districts in Narok County lacked toilets (KNBS, 2006).

The Water Evaluation and Planning System (WEAP) is a modeling computer tool for water planning, allocation and evaluation developed by the Stockholm Environment Institute (SEI) (Sieber and Purkey, 2011). It has a global user base and it is designed around a scenario approach, where scenarios reflect alternative changes in water allocation, water supply infrastructure, water management, land use, climate, and other water-related variables.

1.2 Statement of the Problem

Stakeholders in the Mara River Basin are increasingly facing water shortages as well as problems with poor water quality (WWF-Kenya, 2010). Random sampling of water quality conducted in the MRB showed that most of the water sources including shallow wells are polluted and the water was not fit for human consumption (Mbuya, 2004). Water pollution in the Mara River, is mainly caused by unregulated wastewater discharges, especially from poor sanitation facilities (WREM, 2008). Solid waste generated from the urban centres, industrial centres, hospitals and agricultural activities, is poorly managed thus a major source of pollution (WRMA-RO, 2011).

In addition to water quality, water quantity is also a major concern within the in MRB, especially during the dry season when the threat of drought is high (Mbuya, 2004). Adding to the challenge, the water abstraction system within the basin is poorly planned and loosely monitored, causing abstractions to occur in an uncontrolled manner and often times without permits (Hoffman, 2007).

Water shortages and poor water quality in MRB are further aggravated by the weak and poorly enforced water related laws and regulations, and water resources management institutions with inadequate technical and financial capacity to monitor and ensure compliance with established standards and regulation (WREM, 2008). In addition, there are uncoordinated water resources planning and management processes in the MRB due to lack of a comprehensive cooperative framework for trans-boundary water resources management (Wamalwa, 2009).

WASH directly impacts environmental conditions. Poorly planned WASH projects, which incorrectly collect and dispose of human excreta, wastewater, solid waste and sludge, can negatively impact communities and ecosystems downstream (UN Water, 2010). Not enough attention has been given so far to the environmental sustainability of rural water supply and sanitation programmes. More environmentally integrated approaches to rural water supply and sanitation are needed, especially in the context of integrated water resource management (OECD, 2012).

WASH and environmental sustainability are mutually reinforcing and interdependent. However, donor interest and commitment for WASH and environmental sustainability have not traditionally been integrated and environmental issues are not often addressed in WASH programs (WASH advocates, 2010). This may be due to misunderstanding of and resistance to such initiatives among WASH project managers and key stakeholders who may argue that addressing environmental issues is too time consuming, too costly or simply not important (Pailler and Thompson, 2010). Actually, the 'last word' on the environmental impact of water points on African rangelands is still a long way from being written (Sandford, 1983). This study assessed WASH accessibility and evaluated the impacts of WASH to the environment in the upper Mara basin

1.3 Justification of the study

WASH is imperative for health, and is also an important part of the livelihood of any household. Health is also affected by environmental management in that, disposal of domestic and other water borne wastes is the cause of many water borne diseases such as diarrhoea (Wetlands International, 2010).

Decision-makers, project designers and even communities still often neglect the need for integration between WASH and environmental sustainability (WASH advocates, 2010). In addition, environmental impacts of WASH projects have been relegated to second priority in the past (UN-Habitat, 1987) and the linkage between contamination of water sources by poorly planned sanitation activities is not always recognized by WASH practitioners (Wetlands International, 2010). This is probably because environmental sustainability is generally not enshrined in WASH policies and legislation in most countries (Bonnardeaux, 2012).

In the MRB, World Wide Fund for Nature (WWF) and Global Water for Sustainability (GLOWS) are working with water users, local communities, water managers and decision-makers to better manage the Mara River so as to improve adequate water supplies, and to ensure sustainable development and conservation of the natural resources in the Mara-Serengeti ecosystem. They aim to gather and disseminate appropriate information on conditions and threats to the Mara River Basin, document best practices and failures including water and sanitation projects to promote an integrated water resource management strategy (WWF-Kenya, 2010).

There is a growing need to integrate WASH services with conservation and environmental protection (WASH advocates, 2010). This integration will reduce the impact of pollution associated with WASH activities on the watershed and the ecosystem goods and services (Edmond *et al*., 2013).

Impact studies on WASH often indicate a lack of information on contextual factors which limit use of such information for improving policies and implementation of WASH projects. Limited availability of quality data, and the limited use of such empirical information, are significant constraints on the effectiveness of policy in this sector (OECD, 2012). Therefore, it is important to determine the access to water and sanitation in a given watershed and evaluate WASH activities to demonstrate if a particular WASH activity yields environmental sustainability or degradation (World Bank, 2006).

The focus of this study was to determine the access to water and sanitation, then carry out an environmental impact evaluation of WASH activities in the upper MRB. This was to determine whether the activities caused particular impacts on the land

and water qualities of the upper MRB. The study aimed at providing appropriate and contextual information concerning these activities which can influence policy and lead to implementation of sustainable WASH projects

1.4 Research Questions

This research aimed to provide answers to the following questions:

i. What percentage of the population in the upper Mara basin has access to improved water and sanitation services?

ii. What are the impacts of WASH activities to the environment in the Mara basin?

iii. What are the long term effects of WASH activities to the upper Mara Rivers?

1.5 Research Objectives

The main objective of this study was to evaluate the environmental impacts of WASH activities in the upper Mara River basin.

1.5.1 The Specific Objectives

1. To determine public access to Water and Sanitation services in the upper Mara River basin.
2. To identify the impacts of WASH activities to the environment in the upper Mara River basin.
3. To simulate long term effects of water supply and sanitation activities on the upper Mara Rivers using the WEAP model.

CHAPTER TWO

2.0 STUDY AREA

2.1 Location

The trans-boundary Mara basin covers a total area of 13,750 km^2. Originating from the Napuiyapui swamp in the Mau Escarpment in the highlands of Kenya, the 395 km long Mara River drains into Lake Victoria at the Mara Bay near Musoma in Tanzania and consequently forms part of the upper catchment of the Nile. The Basin is located roughly between longitudes 33^{o}47'E and 35^{o}47'E and latitudes 0^{o}38' S and 1^{o}52' S and the altitudes range from 2,932 m above sea level at its source to 1,134 m above sea level at Lake Victoria, (Figure 2.1). The basin is bordered by the Loita hills to the east (Mutie *et al*., 2006).

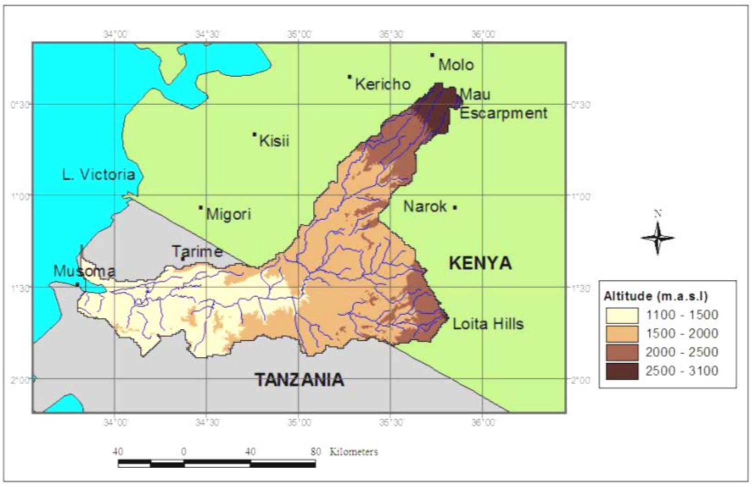


Figure 2.1: The location and relief of the trans-boundary Mara basin and the surrounding urban centers

2.2 Drainage

The main perennial tributaries of Mara River are the Amala and the Nyangores, which drain from western Mau escarpment. Other prominent tributaries include the Talek River, which starts from the Loita plains and joins the Mara in the Maasai Mara Game Reserve, the Engare Engito originating from the Ilmotyookoit Ap Soyet ridges and the Sand River, which is the last main tributary, joining the Mara at the Kenya-Tanzania border in the Serengeti plains, (Figure 2.2). The Mara then flows through Mosirori Swamp, finally draining through the Mara bay into Lake Victoria at Musoma in Tanzania (Hoffman, 2007).

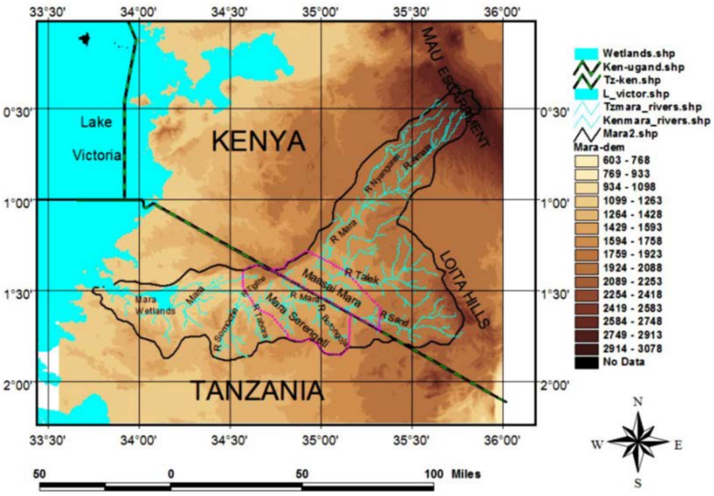


Figure 2.2: The trans-boundary Mara basin, the game reserves and the main tributaries of Mara river (Source: Kiragu, 2009)

2.3 Topography

The upper half of Mara River basin is mountainous and hilly characterized by an undulating topography while the lower half consists of gently sloping plains. The upper catchment decreases from 2920 m above sea level (m a.s.l) to below 2000 m a.s.l within 100 km, (Figure 2.3) (Gathenya, 2011). At approximately 50 km before reaching Musoma, the river passes through an expansive Mosirori wetland measuring about 20 km in length, ending at an altitude of 1,134 m a.s.l (Machiwa, 2001).

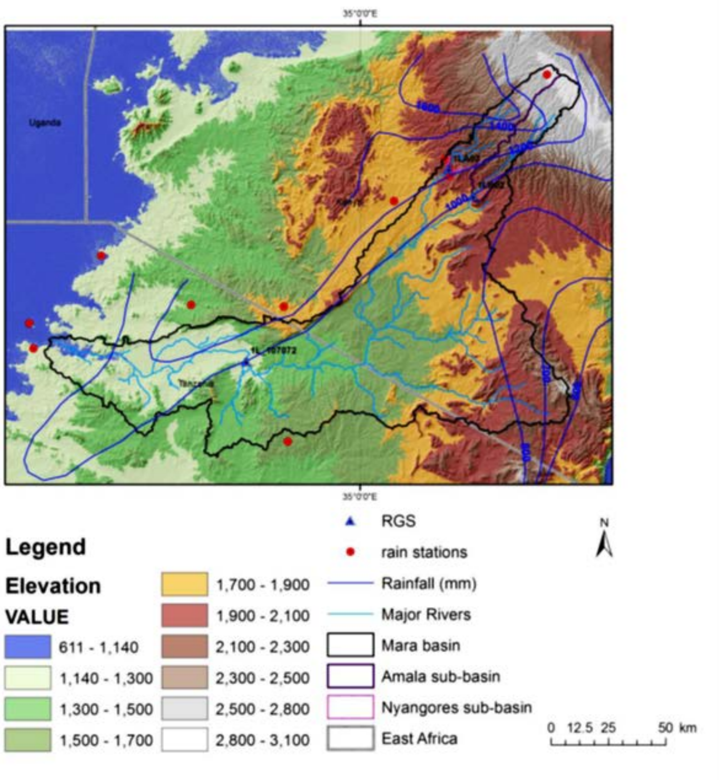


Figure 2.3: Digital Elevation Model of Mara basin showing the relief, rainfall stations and the river gauging stations (source: Gathenya, 2011)

2.4 Climate

Rainfall varies with altitude in the basin. Mean annual rainfall ranges from 1,000-1,750 mm in the Mau Escarpment, 900-1,000 mm in the middle rangelands to 700–850 mm in the lower Loita hills and around Musoma. Rainfall seasons are bi-modal, falling between April and September, and again between November-December (Mutie *et al.*, 2006). The Nyangores sub-basin receives more rainfall than Amala sub-basin. The average mean temperature is about 18º C in the highlands and 25ºC in the lowlands. The mean annual potential evapotranspiration is 1500 mm in Upper Mara basin and above 1700 mm in the lowlands (Gathenya, 2011).

2.5 Soils

The type and distribution of soils in the Mara River basin are determined by geology, topography and rainfall (Gereta *et al.,* 2001). Andosols are found in the forested highlands of the Mara watershed on the Kenyan side (FAO, 1997). Andosols are deep, well drained fertile soils of volcanic origin, very porous and generally form good aquifers, however, very susceptible to serious erosion when left bare through cultivation or overgrazing (Muchena *et al*., 1988).

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 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 (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).

2.6 Land Use

The upper part of Mara basin consists of protected forest and woodland within the gazetted area of Mau Forest Complex. Some of the areas which were originally forest have been cleared for cultivation. The middle part consists of grassland and bush land which is in the Maasai Mara National Reserve in Kenya and Serengeti

National Park in Tanzania. Some of it is also under large-scale farming or ranching or small scale agriculture. The lower part in Tanzania also consists of agricultural land (LVBC, 2013).

The dominant land use activity in the MRB is crop farming. About 62% of the households are smallholder farmers (Aboud *et al*., 2002) with livestock rearing being the second dominant activity. Tourism and wildlife are important economic activities as exemplified by the Maasai Mara Game Reserve on the Kenyan side and the Serengeti National park on the Tanzanian side.

2.7 Population

According to the Kenya 2009 population census (Republic of Kenya, 2010) the Upper Mara basin had approximately 891,333 people of whom 445,389 are male and 445,944 were female. The annual population growth rate was 2.44% for the period from 1999-2010 (KNBS, 2006). It was projected that the population of Mara will be 1,066,699 in 2020 and 1,356,705 in 2030 (LVBC/WWF-ESARPO, 2010). Bomet Central division was the most populated while Mulot was the lowest (Figure 2.4). Tinet forest division is a protected area therefore had no human settlement.

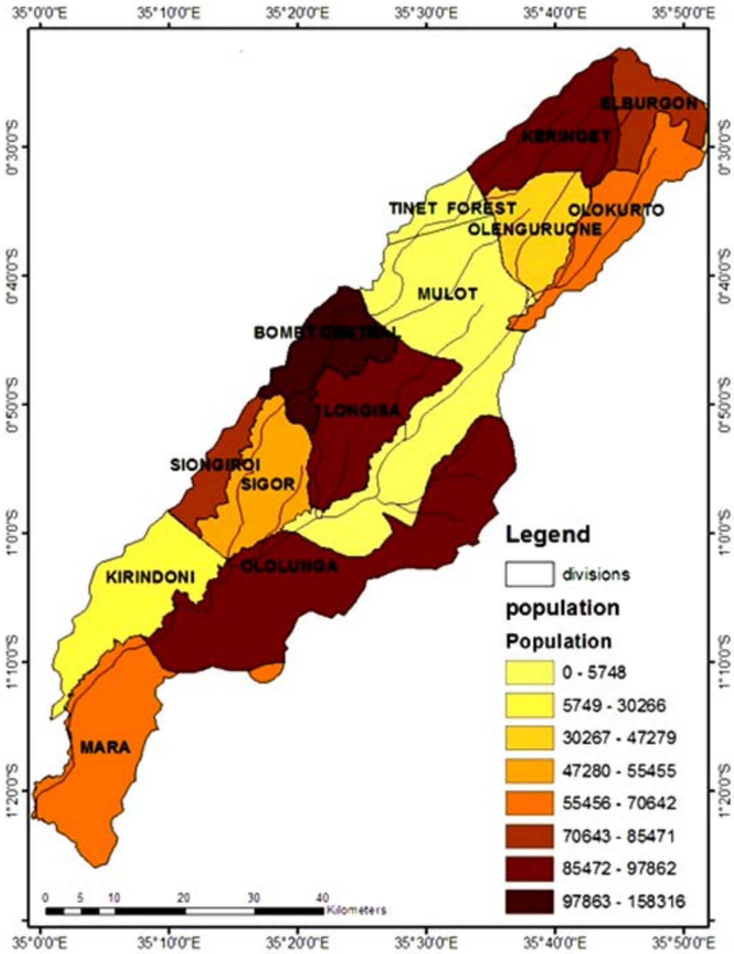


Figure 2.4 A Map of Population distribution per division in the upper Mara basin by 2009

CHAPTER THREE

3.0 LITERATURE REVIEW

3.1 Access to Water and Sanitation

Access to water is a fundamental human right and every individual has a right to a potable source of water. The third target under Millennium Development Goal (MDG) 7 on environmental sustainability, seeks to improve access to sustainable water and improved sanitation (WHO, 2000).

Access to domestic water sources is the availability of at least 20 liters of water per person per day (L/capita-day) from a source within one kilometer of the user's dwelling (WHO, 2000). It is estimated by the percentage of the population using improved drinking water sources

Improved drinking water technologies are those more likely to provide safe drinking water than those characterized as unimproved. Improved drinking water sources include: Household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection. While unimproved drinking water sources include: unprotected well, unprotected spring, rivers or ponds, vendor-provided water, bottled water and tanker truck water. Bottled water is not considered improved due to limitations in the potential quantity, not quality of the water (WHO and UNICEF, 2004).

Howard and Bartram (2003) described four service levels of access to water (Table 3.1). They include optimal, intermediate, basic and no access service levels. The service levels are described using indicators such as distance the consumer travels or the time spent collecting water, quantity collected and level of health concern associated with each service level. For instance, basic access will provide minimum health protection, and users of this service level will have access to 5-20 L/capita-day. Any members of a given community at no access service level travel more than 1km to obtain less than 5 L/ capita-day and the health concerns associated with this level are high since the water will probably be of low quality.

Table 3-1: Service level descriptors defined by distance and travel time to water source, quantities of water collected and the level of health concern (Source: Howard and Bartram, 2003)

Service level	**Distance to source (m)**	**Time of travel (minutes)**	**Quantity collected (L/capita-day**	**Level of health concern**
Optimal access	Water taps at home		100-300	Low (good water quality is available)
Intermediate access	A stand pipe outside house.		50	Low (good quality water available in stand pipe)
Basic access	100 – 1000	5-30	5-20	Medium (reliability and water quality questionable)
No access	Over 1000	Over 30	Less than 5	High (poor water quality. Poor Hygiene).

Access to sanitation is estimated by the percentage of the population using improved sanitation facilities. Improved sanitation facilities are those more likely to ensure privacy and hygienic use. A household is classified as having an improved sanitation facility if the facility is used only by members of one household and if the facility separates the waste from human contact. Improved sanitation facilities include: Connection to a public sewer, connection to a septic system, pour-flush latrine, simple pit latrine, ventilated improved pit (VIP) latrine. While unimproved sanitation facilities include: Public or shared latrine, open pit latrine and bucket latrine (WHO and UNICEF, 2004).

3.1.1 Global Water and Sanitation accessibility

By the end of 2011, 89% of the world population used an improved drinking-water source, and 55% enjoyed the convenience and associated health benefits of a piped supply on premises. An estimated 768 million people did not use an improved source for drinking water, including 185 million who relied on surface water to meet their daily drinking water needs. By the end of 2011, 83% of the population without access to an improved drinking-water source lived in rural areas (WHO, 2013).

In 2011, almost two thirds (64%) of the world population relied on improved sanitation facilities, while 15% continued to defecate in the open. The majority (71%) of those without sanitation lived in rural areas, where 90% of all open defecation takes place. Since 1990, only 1.9 billion people have gained access to an improved sanitation facility (WHO, 2013).

3.1.2 Water and Sanitation in Kenya

Estimates from the WHO and UNICEF joint monitoring programme ((JMP) for water supply and sanitation show that, in 2011 61% of Kenyans (83% in urban areas and 54% in rural areas) had access to improved drinking water sources. 20% of Kenyans had access to piped water through a house or yard connection. Access to improved water sources in urban areas decreased from 87% in 2000 to 83% in 2011. In rural areas, however, access increased from 43% to 54% during the same period. Countrywide estimates for 2011by the JMP indicated that 29% Kenyans had access to private improved sanitation. Open defecation was estimated to be practiced by 14% of the population (WHO, 2013).

According to an assessment report carried out in 2009, there were 43 wastewater treatment plants in 15 towns of Kenya serving a total population of 900,000 inhabitants. The operation efficiency of these wastewater treatment plants was estimated at around 16% of design efficiencies due to inadequate maintenance. In Kenya, the estimated connection rate is 19% (Gakubia *et al.*, 2010) and of the wastewater that enters the sewer network, only about 60% reaches the treatment plants due to leakages (MOWI, 2010). Mixing industrial effluent and domestic sewage in mixed sewer system often causes poor performance in waste water treatment systems (Institute of Economic Affairs, 2007). Sewer leakages and poorly treated wastewater pollutes the environment and the receiving waters.

3.1.3 Water and Sanitation in the Mara Basin

The main water sources in the Mara basin are rivers, boreholes, springs, water pans, earth dams, and shallow wells. Commercial enterprises in Bomet town and other growing rural market centres such as Longisa, Mulot, and Kapkimolwa fetch water directly from the rivers, utilizing both human and draught animal power. The most important sources of water for households in the upper and middle Mara basin during the wet season are unprotected springs. During the dry season the major source is the Mara River (WREM, 2008).

Some households get their domestic water supplies from protected springs and open shallow wells, while others harvest rain water from their roofs. Water pans are particularly important sources of water to pastoralists for their livestock. This water is also used for domestic purposes in some areas especially by the pastrolist community (WREM, 2008).

In the Mara River basin, sanitation is mainly by use of pit latrines. However, by 2005 more than half of households in Transmara and Narok districts lacked toilets (KNBS, 2006). The latrine coverage in Bomet central was much higher compared with the other districts but Bomet town had no sewerage facilities. Other towns and rural markets in the basin lacked sewerage facilities (WREM, 2008).

Solid waste handling capacity of the mushrooming urban centers along the Mara River such as Bomet and Mulot are relatively poor or inexistent leading to accelerated dumping of domestic wastes along streets, residential areas, side ditches, river banks and into the river (Majule, 2010). Such indiscriminate dumping leads to unpleasant odors and create fertile breeding grounds for flies, mosquitoes, and other disease carrying vectors (Majule, 2010). Furthermore, this practice resulted in blockage of drainage systems, impairment of soil permeability, and surface water and groundwater pollution through pollution leaching (WREM, 2008).

3.2 Environmental Impacts of WASH projects

Water supply and sanitation systems can impact environment in many ways. Studies have shown that energy and chemicals consumption in production of potable water cause global environmental impact (Mohapatra *et al.,* 2002; Vince *et al.,* 2008).

The impacts on human health linked to the lack of access to improved water and sanitation range from water-borne diarrheal diseases such as typhoid, giardia and cholera to water washed diseases such as roundworm, trachoma and scabies; and from water-based diseases such as bilharzia and guinea worm to vector-borne diseases such as malaria and river blindness (Wetlands International, 2010). However, the impacts resulting from the preparation and construction of WASH infrastructure cannot be overlooked; they include destruction of riverine habitat, filling of wetlands, alteration of drainage patterns, erosion and sediment run-off; all affecting wildlife populations and ecosystem functions (Bonnardeaux, 2012).

3.2.1 Positive environmental impacts of WASH activities

Water and sanitation projects have the potential to create positive environmental impacts. If wastewater systems are designed to remove a range of pollutants, including microorganisms and nutrients, they can improve water quality. Solid waste management programs can also improve environmental conditions if they are designed to minimize environmental impacts and maximize opportunities such as integrate composting and recycling elements into solid-waste management plans (Navaratne *et al*., 2010).

Improved water management, is a key factor for maintaining ecosystem integrity. Adequate treatment and disposal of excreta and both household and industrial wastewater contribute to less pressure on freshwater resources. Furthermore, improved sanitation reduces flows of human excreta into waterways and reducing the respective health and environmental risks (Bonnardeaux, 2012). Well-planned sanitation infrastructures minimize the risk of acquiring water-borne diseases resulting in a healthier and more vibrant community and healthy ecosystem.

3.2.2 Adverse environmental impacts of WASH activities

While water and sanitation projects are intended to improve environmental and public health, when managed ineffectively they may cause adverse impacts that can offset or eliminate these intended benefits (USAID, 2013). The impacts of poorly designed and operated water supply and sanitation infrastructure include increased water borne and water related diseases, depletion of reservoirs, reduction in stream flow, lowering of water tables, discharge of polluting effluents, contaminated runoff and nutrient enrichment (Bonnardeaux, 2012).

Water supply and sanitation projects may cause increased incidence of infectious water-borne diseases such as cholera, non-infectious disease such as arsenic poisoning, and water-enabled diseases such as malaria, schistosomiasis or bilharzia. Contamination may be caused by poorly designed, operated or maintained sanitation facilities (Warner, 2000). Failure to test new sources of water, especially groundwater, for possible natural or industrial chemical contaminants, such as arsenic, mercury, fluoride and nitrate, can have devastating consequences (Warner and Abate, 2005)

Depletion of fresh water sources can occur when WASH projects do not adequately assess the quantity of available surface and groundwater and when there are poor mechanisms for regulating withdrawals and use of water. Depletion of surface water sources damages aquatic life, reduces economic productivity, diminishes downstream use, and curtails recreational possibilities (USAID, 2013). Over pumping of groundwater can cause subsidence of land and saline ingress in many coastal aquifers (Mohapatra, 2009). In the case of the Mara River, higher rates of water abstraction are threatening to severely degrade the riverine ecosystem and adversely affect the basic water needs of people living along the river (LVBC and WWF-EARPO, 2010).

Discharge of sewage into sea causes microbial pollution of beach water. Infiltration of wastewater into aquifer increases nitrate concentrations in groundwater beyond permissible value (Mohapatra, 2009). The majority of urban residents especially those living in informal settlements use pit latrines, bucket toilets or other sub-standard facilities which increases the chances of untreated human excrement disposal in surface drains and water bodies (Gelinas *et al.*, 1996). Inadequate provision of safe drinking water, coupled with poor sanitation culminates in widespread infectious water borne diseases which afflict millions of urban residents (Gelinas *et al.*, 1996).

Contamination of receiving waters with human excreta can cause nutrient enrichment, depletion of dissolved oxygen and other changes that disturb natural ecosystems and reduce the vigor, abundance, and/or diversity of plants and animals that live either in the water or on land (Warner, 2000).

Poor design, operation and/or maintenance of water supply improvements can lead to pools of stagnant water near water taps, water pipes and storage tanks. Improper or ineffective practices for disposing of excreta and solid waste make this problem worse. These pools form an excellent breeding place for disease vectors (mosquitoes that carry malaria, etc.). They can also increase transmission of water-related diseases, especially when the wet spots are clogged or contaminated with solid waste or excreta (Warner and Abate, 2005).

Indiscriminate disposal of solid waste is detrimental to health because it increases breeding habitats of disease carrying agents like rodents and insects. Poorly disposed solid waste block sewers overflow into streets and open spaces, which provide suitable grounds for disease pathogens, (Economic Commission for Africa, 1996). While greenhouse gases emitted from solid waste landfill site have global warming effect and landfill leachate causes groundwater pollution (Mohapatra, 2009).

Water supply points often attract excessive numbers of nomads and livestock leading to defoliation, deforestation, erosion and consequent desertification especially in arid and semiarid regions (UN-Habitat, 1987).

3.3 Evaluation of Environmental Impacts of WASH Activities

The key focus of impact evaluation is its ability to measure the causes of outcomes (The World Bank, 2006). An impact evaluation measures a project's progress by tracking indicators of the projects's inputs and results (Bosch *et al*., 2000; Prenusshi *et al*., 2000). Water and sanitation systems are assessed through a set of performance indicators.

3.3.1 Environmental Quality Indicators

An indicator is an observed value representative of a phenomenon of study. In general, indicators quantify information by aggregating different and multiple data. The resulting information is therefore synthesized. In short, indicators simplify information that can help to reveal complex phenomena (Gabrielsen and Bosch, 2003). Prenusshi *et al*. (2000) define a good indicator as: traceable, relevant to project objectives, varying across areas over time, sensitive to changes in policies, programs, and institutions and not easily diverted or manipulated.

Environmental indicators are essential tools for tracking environmental progress, supporting policy evaluation and informing the public. Organisation for Economic Development and Co-Operation (OECD) which is made up of 34 member countries namely; Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and United States, has developed key environmental indicators that inform the public and provide key signals to policy makers on important environmental issues and trends as shown in Table 3.2.

3.3.1.1 Water Quality Indicators

Water quality parameters are a means to describe the chemical, physical and biological characteristics of water usually in respect to its suitability for particular purposes (Grillas, 1996). The quality of water can be determined using a combination of biological indicators, nutrient concentrations and physico-chemical parameters (Sidneit *et al*., 1992). Presence of coliform bacteria and their relative abundance can also be used as an indicator of water quality (USEPA, 2002). The main water quality indicators are described in table 3.3.

Table 3-2: OECD set of key environmental indicators (Source: OECD, 2008)

Pollution issues		
	Available indicators	**Medium term indicators**
Climate change	CO_2 emission intensities, index of greenhouse gas emissions	Index of greenhouse gas emissions
Ozone layer	Indices of apparent consumption of Ozone depleting substances (ODS)	Aggregation into one index of apparent consumption of ODS
Air quality	SOx and NOx emission intensities	Population exposure to air pollution
Waste generation	Municipal waste generation intensities	Total waste generation intensities, indicators derived from material flow accounting
Freshwater quality	Waste water treatment connection rates	Pollution loads to water bodies
Natural resources and assets		
Freshwater resources	Intensity of use of water resources	Subnational breakdown
Forest resources	Intensity of use of forest resources	Intensity of use of forest resources
Fish resources	Intensity of use of fish resources	Closer link to available resources
Energy resources	Intensity of energy use	Energy efficiency index
Biodiversity	Threatened species	Species and habitat or ecosystem diversity. Area of key ecosystem

Table 3-3: Water quality indicators and their descriptions

Water quality indicator	Description
Dissolved Oxygen	The amount of dissolved oxygen in water bodies is dependent on the water temperature, the quantity of sediment in the stream and the amount of organic solids dissolved and suspended in water. sewage is the major contributor of organic matter; which lead to a significant reduction in dissolved oxygen in the water during microbial breakdown (APHA, 1992)
Total suspended solids	It is a measure of the level of suspended solids in water, which may be mineral or organic material. They enter water bodies through urban surface runoff, agricultural runoff, through pavement wear, atmospheric deposition as result of abrasive action (Wagener and La Perriere, 1985).
Total Dissolved Solids	Any minerals, salts, cations or anions dissolved in water (Sansalone *et al*., 1998). They come from sources runoff from urban areas, fertilizers and pesticides, leaves, silt, plankton, and domestic waste such as sewage (APHA, 1998).
Dissolved nutrients in water	Excessive concentrations of nutrients, however, can over stimulate aquatic plant and algae growth (Benneh *et al*., 1993). They may result from discharge of sewage, use of detergents, urban runoff, erosion, and animal and plant matter (La Valle, 1975).
Coliform bacteria	Total coliforms are found in water polluted with fecal matter. *E. coli*; one of the coliform groups is always found in faeces and is, therefore, a more direct indicator of feacal contamination and the possible presence of enteric pathogens (USEPA, 2002). These bacteria enter a water

	body through storm drains and faulty sewage systems or receptacles, such as a public sewage overflow or a septic tank leakage. Grazing animals can defecate in or near rivers, which can contribute to a high concentration of faecal bacteria (Majule, 2010)
Biochemical oxygen demand	It is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period, it is used as a gauge of the effectiveness of wastewater treatment plants (USEPA, 2002).

3.4 WEAP model

WEAP applications include several steps: First, the study definition sets up the time frame, spatial boundary, system components and configuration of the problem. Secondly, the Current Account, which is viewed as a calibration step in the development of an application, provide a snapshot of actual water demand, pollution loads, resources and supplies for the system. Key assumptions may be built into the Current Accounts to represent policies, costs and factors that affect demand, pollution, supply and hydrology. Thirdly, scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (Sieber and Purkey, 2011).

WEAP tracks water quality, including pollution generation at demand sites, waste removal at wastewater treatment plants, effluent flows to surface and groundwater sources, and water quality modelling in rivers (Sieber and Purkey, 2011). The basic relationship in water quality modelling states that the weighted average mixed concentration from all supplies must not exceed the maximum allowed concentration illustrated by equation 3.1 and 3.2.

$$Q_1C_1 + Q_2\,C_2 + \cdots)/(Q_1 + Q_2 + \cdots) \leq C_{max} \tag{3.1}$$

This can be transformed into;

$$Q_1\left(1 - \frac{C_1}{C_{max}}\right) + Q2\left(1 - \frac{C_2}{C_{max}}\right) + \cdots > = 0 \tag{3.2}$$

Where;

Q_1 = the flow into the demand site from source 1, $C_{1=}$is the concentration of source 1in the previous time step and C_{max} = the maximum allowed concentration

WEAP can also model the concentration of water quality constituents in a river using simple mixing, first-order decay, and built-in temperature, BOD and DO models. In simple mixing, the initial concentration of a pollutant at the point of injection into the stream is calculated from a mass balance (Eqn 3.3):

$$C_1 = \frac{Q_w C_w + Q_r C_r}{Q_w + Q_r}$$

(3.3)

Where:

C_1 = the new concentration (mg/l), Q_w =the flow of wastewater discharged (m^3/time), C_w =the concentration of pollutant in the wastewater (mg/l) and Q_r= the flow of receiving water (m^3/time)

In BOD and DO models, the oxygen saturation OS for each segment is estimated as a function of water temperature T, as in equation 3.4.

$$OS = 14.54 - (0.39T) + (0.01T^2)$$

(3.4)

Comparing WEAP and other water evaluation and planning models such as MIKE II and Visual MODFLOW, WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation (Sieber and Purkey, 2011). MIKE 11, is a one dimensional computer program developed by the Danish Hydraulic Institute (DHI), that simulates flow and water level, water quality and sediment transport in rivers, flood plains, irrigation canals, reservoirs and other inland water bodies (Eisakhani, *et al*., 2012). Water quality simulations in MIKE 11 are undertaken by use ECOLab system using pre- or user-defined templates describing the actual processes to investigate (DHI, 2009). Visual MODFLOW is a three-dimensional software used primarily to simulate groundwater flow and contaminant transport (Waterloo Inc., 2011). The design of WEAP is guided by a comprehensive planning framework it includes a hydrological model and links to the groundwater model MODFLOW and the water quality model QUAL2K (Yates *et al*., 2005).

With WEAP, Current Accounts are first created of the water system under study. Then, based on a variety of economic, demographic, hydrological, and technological trends, a "reference" or "business-as-usual" scenario projection is established, referred to as a Reference Scenario. One can then develop one or more policy scenarios with alternative assumptions about future developments. These scenarios may be viewed simultaneously in the results for easy comparison of their effects on the water system (Sieber and Purkey, 2011). In addition, WEAP is unique in its capability of representing the effects of demand management on water systems per demand site thus priorities for allocating water for particular demands or from particular sources may be specified by the user.

3.4.1 Modelling Water Management Using the WEAP model

3.4.1.1 Assessing Future Water Demands Using WEAP in the Niger River, Niger Republic

Water resources management in Niger River basin was an issue of very high significance because of great socio-cultural, ecological and economic values (Mounir *et.al*, 2011). Niger River basin crosses the nine basin countries including Guinea, Cameroon, Mali, Niger, Nigeria, Côte d'Ivoire, Burkina Faso, and Chad (ABN, 1999). WEAP was applied to investigate scenarios of future water resource development in the Niger River Basin in Niger Republic. Therefore, the investigation consisted on the use of water consumption for human needs, for agriculture and industries in the cities of Niamey and Tillabéry (Mounir *et.al*, 2011).

Scenario modeling consisted of three steps. First, a current accounts year was chosen to serve as the base year of the model; two a reference scenario was established from the current accounts to simulate likely evolution of the system without intervention; and thirdly "what-if" scenarios created to alter the "reference scenario" and evaluate the effects of changes in policies and/or technologies. The data used in modeling for current accounts, ranged for the period of (2009-2030). For allocation of available resources a number of option were tested by developing several scenarios and future water demands were projected. The study confirmed that there would be unmet water demand in Niger in future as long as mechanisms of management were not in place to retain the phenomena of rapid population increase and climate change. It recommended a hydro-electric dam on the Niger River to control the flows of water fall and low water levels on river and to find adequate drinking water for two growing cities Niamey and Tillabéry (Mounir *et.al*, 2011)

3.4.1.2 Modeling Wastewater Management Options using WEAP for Wadi Nar Watershed, West Bank, Palestine

There is a critical lack of sanitation in the West Bank with only 45% of the Palestinian population connected to a sewer network; the majority of households dispose of domestic sewage into unlined cesspits. There is currently only one operational wastewater treatment plant (WWTP) in West Bank, so most of the sewage is directly discharged to the environment without treatment (Almasri and Hindi, 2008).

WEAP was used for mapping the management options related to wastewater reuse in Wadi Nar Watershed (WNW), West Bank Palestine. The watershed extends from the eastern hills of Jerusalem and drains into the Dead Sea. The model simulated and analyzed various treated wastewater reuse scenarios in relation to the availability of land fit for irrigation. The scenarios were; reuse of wastewater from a centralized treatment plant for wastewater generated from all the Palestinian communities linked to WNW and reuse of wastewater from separate treatment plants for the wastewater for East Jerusalem and the rest of Palestinian communities linked to WNW (Klawitter *et al.,* 2007). All scenarios assumed a water consumption rate of 140 l/capita/d starting from the outset in year 2010 to 2034 and that all communities would be connected to the sewerage network at a percentage of 95%.

The model estimated of land area available for the wastewater reuse would increase from about 3300m^2 in 2010 to 8000m^2 in 2034 for a centralized WWTP and it would increase from about 2300m^2 to 6000m^2 for separated WWPTs during the same period due to water losses (Almasri and Hindi, 2008).

3.4.1.3 Application of WEAP to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa

The Olifants River is a tributary of the Limpopo River, an international river shared by South Africa, Botswana, Zimbabwe and Mozambique. Different water users including domestic, mining, irrigated agriculture, forestry, industrial and power generation are present in the catchment and there is an inequity issue in the access to water. There are several natural reserves that demand special protection, and environmental flows are needed to preserve ecosystems (Arranz and McCartney, 2007).

WEAP was applied to assess the impacts of possible water demands on the water resources of the Olifants catchment by 2025 in a scenario analysis approach. A set of scenarios were developed to account for possible changes in the evolution of the water demands, the implementation of the Environmental Reserve (ER), water conservation programs and infrastructural development.

The study concluded that as a consequence of the application of the ER, which is intended to ensure the sustainability of the resource base, there would be more water flowing in the rivers, but less water available to meet direct human demands. At the most downstream location, the total reserve requirement was estimated to be 394 Milllon m^3. Hence, if fully implemented in the near future, shortages in other sectors would increase. In addition, the storage capacity in the South African side of the Olifants catchment was less than the mean annual naturalized flow. As a consequence of this, during the wet periods the reservoirs were rapidly filled and the excess water was spilled. The mean annual volume flowing into Mozambique equated to between 60 percent and 75 percent of the mean annual naturalized flow for the different scenarios analyzed (Arranz and McCartney, 2007).

3.4.1.4 Use of WEAP for Developing a Sustainable Water Use Plan: Case Study of Ruiru-Ndarugu Basin, Kenya.

WEAP model was calibrated and validated as a tool for water allocation in Ruiru, Thiririka and Ndarugu sub-basins and used to simulate effect of future water use change scenarios in Ruiru, Thiririka and Ndarugu sub-basins and propose water use management strategy. The study modeled 5 scenarios namely; High population growth rate, area under irrigation is reduced by a half, a reservoir is added along the river, Environmental flow requirement and Irrigation water quality constraint. The study projected the water demand in the study will grow from 75.1 Million M^3 in 2010 to 96.3 Million M^3 and 129.2 Million M^3 in 2020 and 2030 respectively. The unmet demand was 0 Million M^3 in 2010 and 0.6 Million M^3 and 7.2 Million M^3 in 2020 and 2030 respectively with the surface water storage strategy (Thubu, 2010).

CHAPTER FOUR

4.0 RESEARCH METHODOLOGY

This study used both primary and secondary data. Secondary data collection involved review of existing reports while primary data collection involved field sampling and testing, laboratory tests and interviews.

4.1 Reconnaissance visit

A preliminary visit was made to the study area during which the major stakeholders were identified. The stakeholders were identified by use of the snow ball technique during which key informers, WASH project implementers and beneficiaries, relevant government bodies were consulted as well as review of literature. In addition, the roles of each individual or group interested or involved in WASH activities in the upper Mara basin was described (Appendix 1). WASH activities evaluated in this study included community and household water supply projects, Sanitation projects, that is, excreta disposal and solid waste management projects.

4.2 Data collection

4.2.1 Determining Water and Sanitation accessibility

Access to water and sanitation in the upper Mara basin was determined by analyzing the latest secondary data available. The Kenya Demographic and Health Survey 2008-2009 report was analyzed to provide the average country access (KNBS, 2010) while the 2009 census report by the Kenya Bureau of Statistics provided per division household water and sanitation access (Republic of Kenya, 2010). District public health offices reports for 2011/2012 from Bomet, Narok South and Transmara Districts were analyzed to obtain the latrine coverage per division in the Basin.

4.2.2 Determination of environmental impacts of WASH activities

Impacts of the WASH activities on land and environmental quality were assessed using the following indicators as applicable;

- Water quality supplied to residents
- Waste water quality discharged to the environment
- Characteristics of Solid Waste disposed to the environment
- Amount of Soil erosion around water points

An inventory of all completed and water supply projects in the upper Mara was done (Appendix 2) by interviewing the WASH stakeholders. A purposive sampling of accessible water supply (Appendix 5) and sanitation projects was done for impact evaluation. The sampled projects had to be developed and/or managed by known stakeholders to be held accountable for the impacts of the project to the environment. The projects included rainwater harvesting projects, water abstraction and supply projects, solid waste and waste water management projects.

Baseline data on sampled WASH projects including their type, location, developer and condition was obtained from developers' records, observations and interviews. Data was recorded in the inventory (Appendix 2).

4.2.2.1 Analyzing Water Quality Supplied

The physical, chemical and biological characteristics of the water obtained from the sampled water supply projects were determined. This was done to assess their suitability for domestic water supply as stipulated in the Kenya Water Quality Regulations of 2006, (Republic of Kenya, 2006)

4.2.2.1.1 Sample Collection

Out of the 50 completed water supply projects inventoried (Appendix 2), water was sampled in triplicates from 38 water supply projects (Appendix 5). These were the only accessible water supply projects developed and/or managed by known stakeholders who could be held accountable. The water was analyzed for physical-chemical and bacteriological parameters. Water samples from Nyangores, Amala, Mara, Amalo, Cheptwetch, Ilmolelian, Kipsinoi, Tinet and Mukuki rivers were also collected in areas where they were the only accessible source of domestic water (Figure 4.1).

Water samples for physical- chemical analysis were collected directly from sources and stored in sterile plastic sample bottles while samples for bacteriological analysis were collected using sterile 250ml glass bottles, stored in cold ice-packed boxes and delivered to the laboratory within six hours of collection for isolation of faecal coliforms. Seven of the bacteriological analysis samples were done at Longisa District Hospital microbiology laboratory while the rest 40 were analysed at the Ministry of Water and Irrigation laboratory in Bomet.

4.2.2.1.2 Measurement of Physical-Chemical and Nutrient Parameters

Dissolved oxygen, conductivity, turbidity, pH, temperature of the water samples were measured *in situ* at point of sampling in replicates of three using a multi parameter Hach meter model HMP6P and a Hach Calorimeter DR 800 model. Nitrates, total suspended solids and fluorides in the water samples were also measured using the Hach calorimeter model DR 800 using standard procedures as described by the American Public Health Association (APHA, 1998).

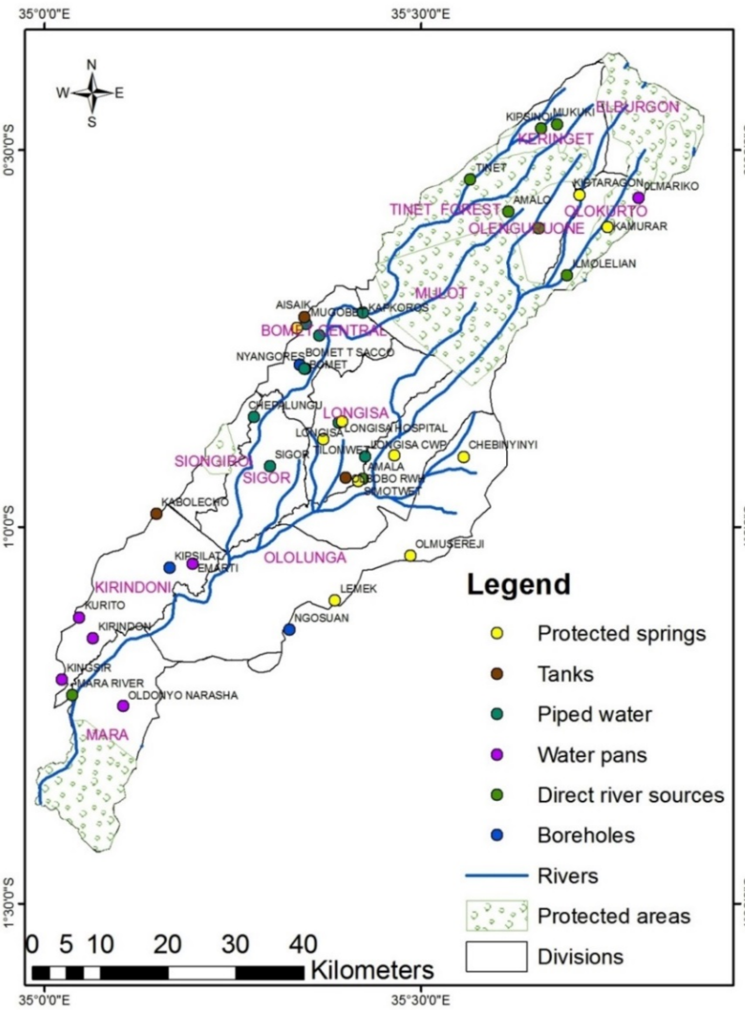
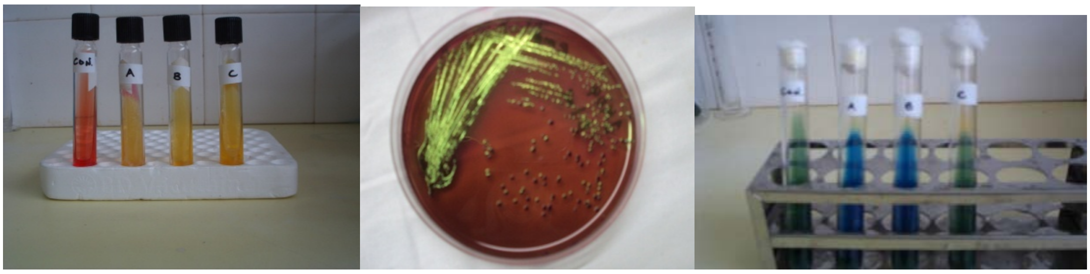


Figure 4.1 A map of the upper Mara Basin showing, location and type of sampled water points for water quality analysis

4.2.2.1.3 Coliform Testing

Coliform analysis was done using Most Probable Number (MPN) procedure which detects the coliform bacteria as indicator for faecal contamination (APHA, 1998). The technique involved three successive steps, namely, presumptive test, confirmed test and complete test (Tharannum *et al.*, 2009). In the presumptive test, 10mls of McConkey G broth purple were added into each of the 3 sets of 25ml tubes. The tubes were then inoculated with a ten-fold difference of water samples' inoculum volumes, i.e., 0.1ml, 1ml, and 10ml per tube and incubated at 370˚C. After 24 hours, the tubes were examined for acid and gas production. Change in colour from purple to yellow indicated acid production (Plate 4-1a), (APHA, 1998). Each set was scored for the number of positive tubes and the score of all the three sets recorded and used with the standard MPN table to determine the probable number of coliforms in the water samples.

The presumptive test was followed by the confirmative test and the complete test. The confirmative test was performed by streaking a sample from positive presumptive tube onto eosin methylene blue agar (EMB agar) and incubated at 44.50˚ C for 24 hours. A positive confirmative test was indicated by the presence of green metallic sheen colonies on EMB streaked from a positive presumptive test, (Plate 4-2b). The complete test was performed by inoculating a tube of McConkey G purple broth with green sheen colonies from positive confirmative tests (Plate 4-2 c). A sterile loop of colony was streaked onto a slant of nutrient agar. Both tubes were incubated at 370˚C for 24hrs. The culture on the nutrient agar was analysed by Gram staining.



(a) (b) (c)

Plate 4-1 Coliform testing using the MPN method (a) test tubes showing positive presumptive test, (b) A petri dish showing positive confirmative test, (c) test tubes prepared for complete test

4.2.2.2 Analyzing waste water discharged to the environment

This involved analyzing the quality of liquid matter discharged to the environment from waste water managing projects in upper Mara basin. Waste water generating activities in the study area included; KTDA Kiptagich, Kapkoros and Tirgaga tea factories, Kapsimotwa and Bomet slaughter houses, Tenwek and Longisa hospitals, Fairmont Mara safari club, Mpata safari hotel, Olonana Hotel and Bomet Municipal council stabilization pond. The Municipal pond received waste water generated in Bomet town

4.2.2.2.1 Sample Collection

Waste water effluent samples were collected from Kapsimotwa and Bomet slaughter houses, Tenwek hospital, Olonana hotel and Bomet Municipal pond. Fairmont Mara safari club and Mpata safari hotel discharged their waste into septic tanks which were emptied and discharged into Narok Municipal waste water treatment while Longisa hospital disposed its waste water into septic tanks emptied to Bomet Municipal pond.

Waste water from the KTDA tea factories was treated by screening and stabilization before it was allowed to seep into tree plantations thus there was no visible effluent to be collected. Plate 4.2 shows some of the wastewater sources.

(a) (b) (c) (d)

Plate 4-2: Various wastewater sources in the Upper Mara a) Bomet Municipal stabilization pond b) Stabilization pond at Tirgaga tea factory c) effluent from Bomet slaughter house d) constructed wetland at Olonana hotel.

4.2.2.2.2 Waste water quality analysis

The 5 samples were tested for dissolved oxygen (DO), Biochemical oxygen Demand (BOD_5), fluorides, total dissolved solids and total suspended solids. DO, fluorides, total dissolved solids and total suspended solids were measured using Hach calorimeter model DR 800 at the Ministry of Water and Irrigation laboratory at Bomet. The BOD test involved preparation of dilution water where 1000 ml of water, 1ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solution was added, before bringing it to 20 ^{o}C and aerating it thoroughly

The sample was determined for first day DO. Three dilutions were prepared to obtain about 50% depletion of D.O. using sample and dilution water. The samples were incubated at 20 ^{o}C for 5 days and the 5^{th} day D.O was noted using the oximeter. A reagent blank was also prepared in a similar manner. BOD_5 was calculated as in equation 4.1 (APHA, 1998).

$$BOD_5 = ((DI - D2) - (BI - B2) * F)/P \quad \text{(Eqn: 4.1)}$$

Where:

D_1 = 1^{st} day DO of diluted sample, D_2 = 5^{th} day DO of diluted sample P - decimal volumetric fraction of sample used. $B_{1=}1^{st}$ day DO of control and B_2 =5^{th} day DO of control

4.2.2.3 Characterization of Solid Waste disposed to the environment

Solid wastes disposal methods within 22 sites in the upper Mara basin including, all urban centres, hotels and hospitals were observed and documented at points of disposal. Methods of disposal and management were identified by observation and interviewing the waste managers. Estimation of solid waste compositions in Bomet town (the main urban centre in the Upper Mara) was done using field sampling and analysis. In total 3 samples of 15kg each were collected from Bomet dumpsite and sorted out into different components including polythene bags, paper, plastics, textile, Manila paper, leather, food waste, and others. The separated waste was put into buckets for the volume estimation.

4.2.2.4 Estimating amount of Soil erosion around water points

Among the sampled water supply points, observations were made to identify any evidence of soil erosion. The volumes of gullies observed at four sites; Chebinyinyi, Tilimiet and Oljoro protected springs as well as at Kirindon water pan were estimated.

Gully volumes were determined from the average end area method (Poeson, 1993). The average end area calculation was used to calculate volume between two cross sections i.e., two cross sectional areas were averaged and multiplied by the length (distance) between two cross sections to get the volume (Poeson, 1993) (Figure 4.2, Eqn. 4.2). The cross sectional area was determined by measuring the cross section of the gullies (Appendix 3). The coordinates of the gully were determined with a hand held Garmin Etrex global positions system (GPS) receiver. The distance between cross-sections was measured using a 50 m long surveyor's tape.

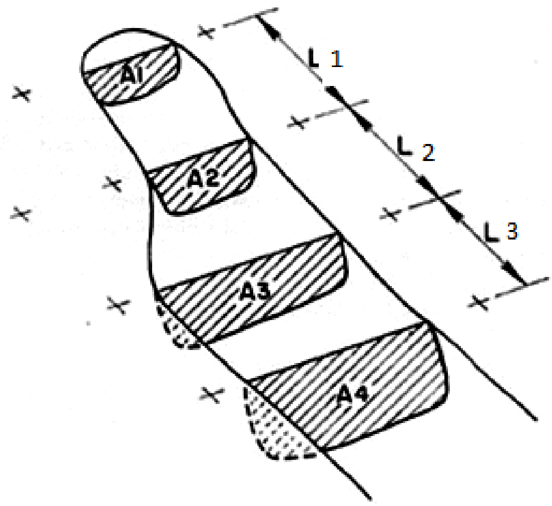


Figure 4.2 : An illustration showing a gully cross sectional areas and the lengths between two cross sections

$$\text{VOLUME} = \sum \left(\frac{A1 + A2}{2} * L1\right) + \left(\frac{A2 + A3}{2} * L2\right) + \cdots$$

(Eqn 4.2)

4.3 Modeling long term effects of WASH activities using WEAP model

4.3.1 Creating a schematic area in WEAP

A schematic area of the upper Mara (Figure 4.3) was created in WEAP by adding an arc-GIS shape file of the catchment delineated from the Kenya river basins map from World Resource Institute, **(**http://www.wri.org), using the 'add vector layer' function of the model. The shape file included the catchment boundary, rivers, demands sites, point pollution sources and river gauging stations.

4.3.2 Data collection

Major water demand sites, their GPS coordinates and permitted abstraction rates in m^3/day were obtained from the Water Resources Management Authority (WRMA) (Appendix 4), Lake Victoria South sub-regional office at Kericho town. Average monthly water quality data: water temperature, TSS, TDS and DO for the years 2006 to 2012 at gauging stations 1LB02 on Amala River, 1LA03 on Nyangores and 1LA04 on the Mara were obtained from Water Resources Management Authority, Lake Victoria regional office at Kisumu. The water quality data was used as the baseline for model calibration and water quality modeling.

Average monthly stream flows for the years 2004-2012 for gauging stations 1LB02, 1LA03 and 1LA04 were obtained from the Water Resources Management Authority, Lake Victoria South sub-regional office at Kericho. Monthly flow data for the year 2004-2006 was used to calibrate WEAP while the flow data for the years 2007-2009 was used to validate the model. Flow data for the year 2012 were used to create the current account in WEAP for scenario analysis. Climatic data required for water quality modeling in WEAP: average monthly temperature, humidity and wind speed was collected from Bomet weather station. Wastewater quality data; TSS, TDS, DO and BOD_5 analyzed earlier for Tenwek hospital, Olonana hotel and Bomet Municipal stabilization pond was used as a baseline for waste water pollution modelling.

4.3.3 Entering Elements into the Schematic

The rivers and demand sites were drawn into the schematic by clicking on the "River" and "Demand" symbols in the element window of the model and holding the click as the symbol was dragged over to the map. To satisfy the demand sites they were connected to a supply resource by creating a Transmission Link from the Rivers to each demand site.

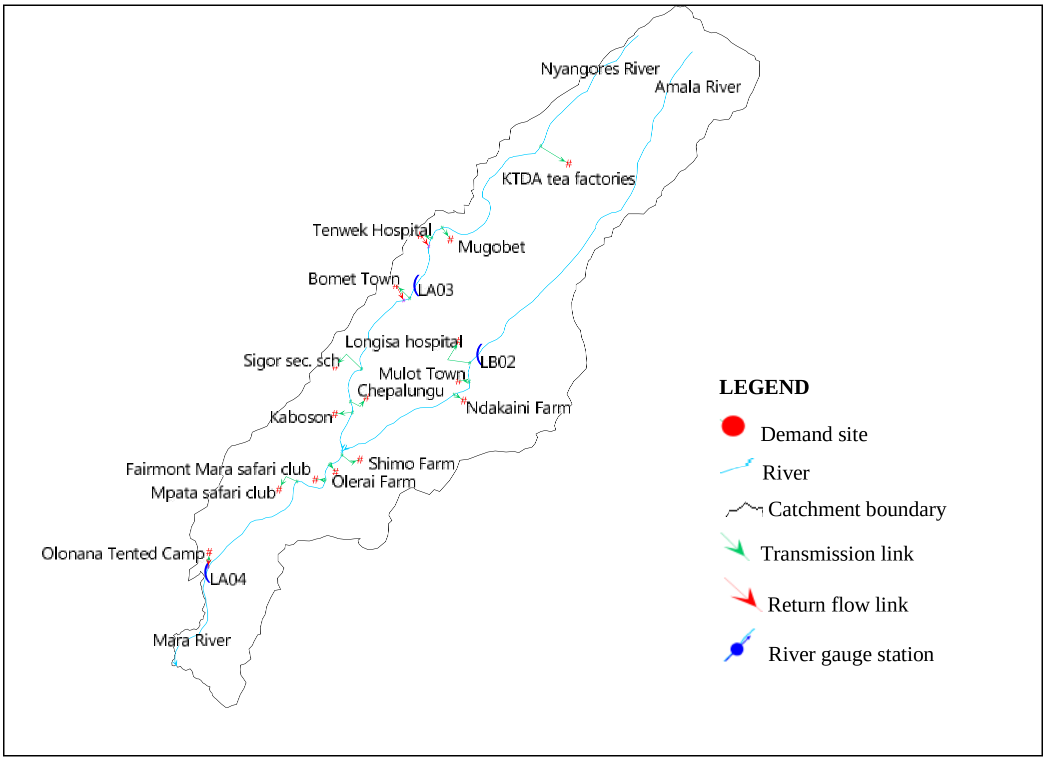


Figure 4.3: A schematic area in WEAP showing the Upper Mara catchment boundaries, rivers, major demand sites, transmission links, return flows and the river gauging stations

4.3.4 Model Calibration and Validation

4.3.4.1 Hydrological calibration and validation

The Hydrological calibration and validation was done using available stream flow data for 2004 to 2009 as shown in Table 4-1. Monthly stream flow data for 2004-2006 for gauging stations 1LB02 and 1LA03 were used to calibrate the model. The model was then used to simulate monthly flows for the years 2007-2009 using the water year method. Model validation was based on regression analysis of the simulated and observed monthly flows for the years 2007-2009 (Ronald and Raymond, 1989).

Table 4-1: Summary of Hydrological Calibration and Validation Period

Name of River	River Gauging Station	Calibration Period	Validation Period
Amala	1LB02	2004 - 2006	2007 – 2009
Nyangores	1LA03	2004 - 2006	2007 – 2008

4.3.4.1.1 Water Year Method

Using the water year method average annual rainfall data for Bomet weather station for the years 2004-2011 was used to explore the effects of changes in hydrological patterns to the river flows. The water year method projected future inflows by varying the inflow data from the current accounts year according to the water year sequence and definitions specified in the hydrology section of the model. Hydrologic fluctuations were entered as variations from a normal water year. A water year type characterized the hydrological conditions over the period of one year. The five types defined by dividing the years into five broad categories based on relative rainfall amounts were normal, very wet, wet, dry, and very dry. The water year method required data for defining standard types of the above water years (water year definition), as well as defining the sequence of those years for a given set of scenarios (water year sequence).

4.3.4.1.2 Water Year Definition and Sequencing

To define each non-normal water year type (Very Dry, Dry, Wet, Very Wet), specifications of how much more or less water flowed into the system in that year relative to a Normal water year were made as in table 4-2. These fractions were derived from a statistical analysis of total annual rainfall data for Bomet weather station for the years 2003-2011 (Table 4-3). The years were grouped into five groups (quintiles), each quintile separated from the previous quintile by 20% annual rainfall difference. To sequence the water year types, first the average annual rainfall for the period was calculated then computations of how each annual rainfall varied from the average were made. If a given annual rainfall varied from the average by more than -40% the year was defined as very dry, if by -39 to -20% it was defined as dry. If it varied by -19 t0 20% it was defined as normal, if by 21% to 40% it was defined as wet, more than 40% was assigned as very wet (Sieber, and Purkey, 2011). These data were entered at: Data View, Branch: Hydrology \ Water Year Method, Tab: Definitions\ Sequence in the WEAP model

Table 4-2: Water year definitions of different climate regimes

Climate regime	Definition value
Very Dry	0.6
Dry	0.8
Normal	1
Wet	1.2
Very wet	1.4

Table 4-3: Annual rainfall data from Bomet weather station for various years and their climate regime definition

Year	Total annual rainfall (mm)	% deviation from the average annual rainfall	Definition
2003	806	9.4	Normal
2004	703	-4.6	Normal
2005	441	-40.2	very dry
2006	1059	43.7	very wet
2007	711.9	-3.4	Normal
2008	619	-16.0	Normal
2009	580	-21.3	Dry
2010	799.8	8.5	Normal
2011	920.4	24.9	wet
Average	737		

4.3.4.2 Water Quality Calibration and Validation

WEAP models the concentration of water quality constituents in a river using simple mixing, first-order decay, and built-in temperature, BOD and DO models, The water quality calibration and validation was done using available water quality data for

DO, TSS and TDS for years 2006 to 2012 as shown in table 4.4. Available average monthly water quality data for 2006-2008 for gauging stations 1LB02 and 1LA03 on Amala and Nyangores Rivers respectively was used for calibration. The model was then used to simulate DO, TSS and TDS at the same gauging stations for the years 2009-2012. Model validation was based on regression analysis of the simulated and observed monthly flows for the years 2009-2012 (Ronald and Raymond, 1989).

Table 4-4: Summary of Water Quality Calibration and Validation Period

Name of River	River Gauging Station	Calibration Period	Validation Period
Amala	1LB02	2006 - 2008	2009 - 2012
Nyangores	1LA03	2006 – 2008	2009 - 2012

4.3.5 Simulating future scenarios in the river basin

Using WEAP, a set of scenarios was developed to account for theoretical possible changes in the evolution of the water demands, supply and management (Table 4-5) in the upper Mara. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions (Sieber, and Purkey, 2011). The assumed scenarios were used to assess possible long term effects of WASH activities on the water quantity and quality of the upper Mara Rivers. All scenarios started from year 2012, for which Current Accounts data was established

Table 4-5: Summary of scenario analysis

No	Description of the scenario	Implications
1	Reference Scenario	System business as usual status: Current scenario; current demand, current link water quality, current river flows and quality
2	Demand increases by 10% each year	If abstractions increases in volume by 10% each year creating an increase in water demand scenario: probably caused by increase in population growth rate or change of lifestyles in case water closet toilets were to be used .
3	River flows reduces by 10% each year	If river flows in the three upper Mara rivers reduces by 10% each year creating decrease in water supply scenario: probably caused by climate change or catchment destruction.
4	Bomet Town wastewater treatment plant added	If all wastewater draining in Nyangores river from Bomet town is fully treated by establishing a waste water treatment plant in Bomet town.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSION

5.1 Water and Sanitation accessibility in the Upper Mara Basin

5.1.1 Access to Water

Access to water As shown on figure 5.1, on average 49% of the households in the upper Mara obtained water directly from streams, 32% collected from springs, wells and boreholes, only about 1% had piped water into their houses and about 1% used rain harvested water.

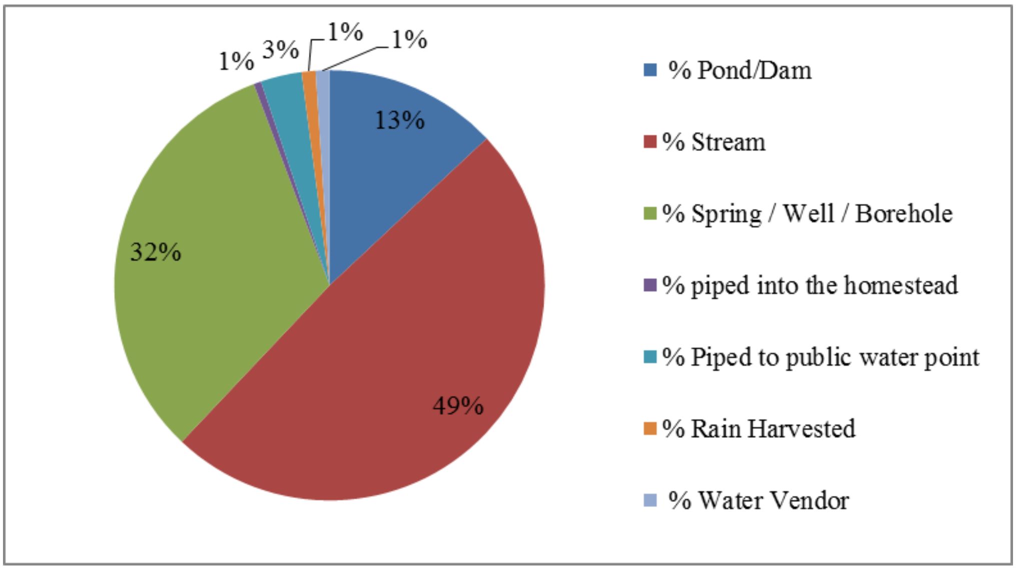


Figure 5.1: Average percentage of household access to domestic water sources in Upper Mara

The source of drinking water is an indicator of whether the water is suitable for drinking or not in terms of quality. Improved drinking water concerns access, use of water and its safety (Prüss-Üstün *et al*., 2008). Moreover increasing access to water has incremental and multiple beneficial impacts on health (Howard and Batram, 2003). Improved drinking water technologies are those more likely to provide safe drinking water than those characterized as unimproved. Improved drinking water sources include: Household connection, public standpipe, borehole, protected dug well, protected spring, rainwater collection while unimproved drinking water sources include: unprotected well, unprotected spring, rivers or ponds, vendor-provided water, bottled water and tanker truck water (WHO and UNICEF, 2004).

From the above data, about 63% of households in the upper Mara basin obtained water from unimproved sources of streams, ponds and water vendors while 32% households obtain water from springs, wells or boreholes, only 4% had piped water supply and only 1% used rain harvested water. Therefore, 63% of the household in the Upper Mara basin are vulnerable to using contaminated water from unimproved sources.

As per divisions, Kirindon division recorded the highest percentage of household accessing water from unimproved sources of 86% followed by Siongiroi at 83% while Elbergon recorded the highest percentage of household with piped water at 13% as in figure 5.2. Therefore, efforts to provide improved sources of water should be increased in the divisions with the highest number of households obtaining water from unimproved sources such as Kirindon and Siongiroi.

5.1.2 Access to Sanitation

A household is classified as having an improved sanitation facility if the facility is used only by members of one household and if the facility separates the waste from human contact. Improved sanitation facilities include: Connection to a public sewer, connection to a septic system, pour-flush latrine, simple pit latrine, ventilated improved pit (VIP) latrine. While unimproved sanitation facilities include: Public or shared latrine, open pit latrine and bucket latrine (WHO and UNICEF, 2004).

Results indicate that none of the households was connected to a main sewer. Up to 58% of the households used pit latrines while 38% disposed their human waste in bushes. The rest used septic tanks and ventilated improved pit (VIP) latrines as figure 5.3.

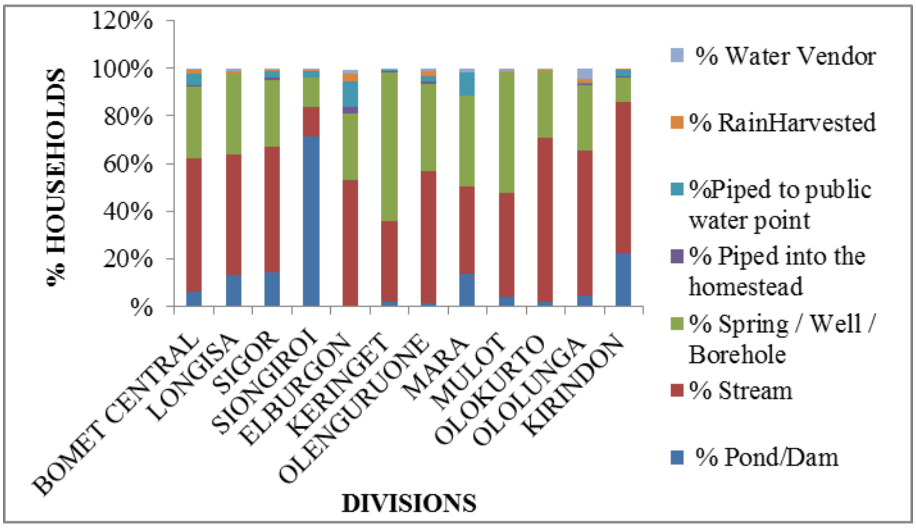


Figure 5.2: Average % household domestic water sources in Upper Mara per division

Open defecation causes pollution to the open water sources causing waterborne disease such as cholera. According to WHO, diarrheal diseases are the second leading cause of death in low-income countries and are the fifth leading cause of death globally (WHO, 2013). WASH-related diseases constitute 9.1% of the total disease burden in terms of disability-adjusted life years (Pruss *et al*., 2002). An estimated 94% of the diarrhoeal burden of disease is attributable to the environment and associated with risk factors such as unsafe drinking water, lack of sanitation and poor hygiene (Prüss-Üstün and Corvalán, 2006).

Improved access to sanitation in the form of nearby latrines reduces the travel time to areas where open defecation is practiced. Latrine use reduces the incidence of diarrheal disease, which reduces time caring for sick households, sick days and clinic or hospital visits (Walter, 2013). Therefore efforts to provide improved sanitation facilities to the residents of the upper Mara should be increased to render the catchment open defecation free (ODF).

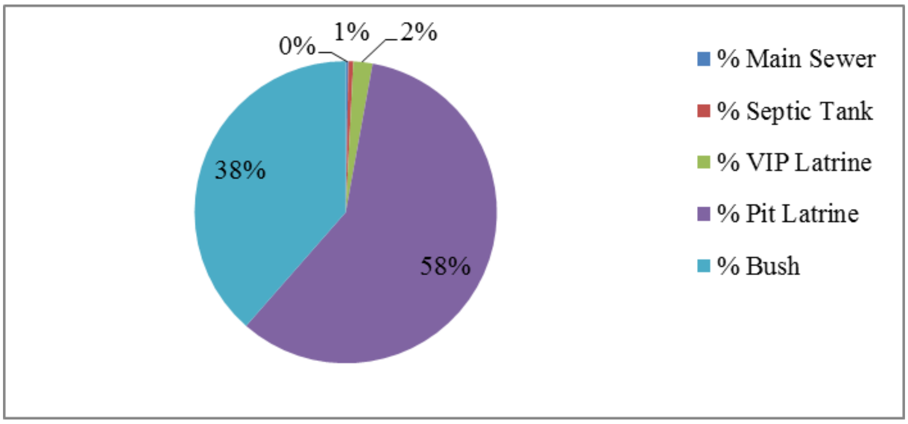


Figure 5.3: Average % household access to sanitation in the Upper Mara

Mara division recorded the highest percentage of household open defecating at 84% followed by Kirindon at 83%, Ololunga at 54% and Olkurto at 50% while Olenguruone recorded the lowest % of household disposing human waste in bushes at 2% as shown in figure 5.4.

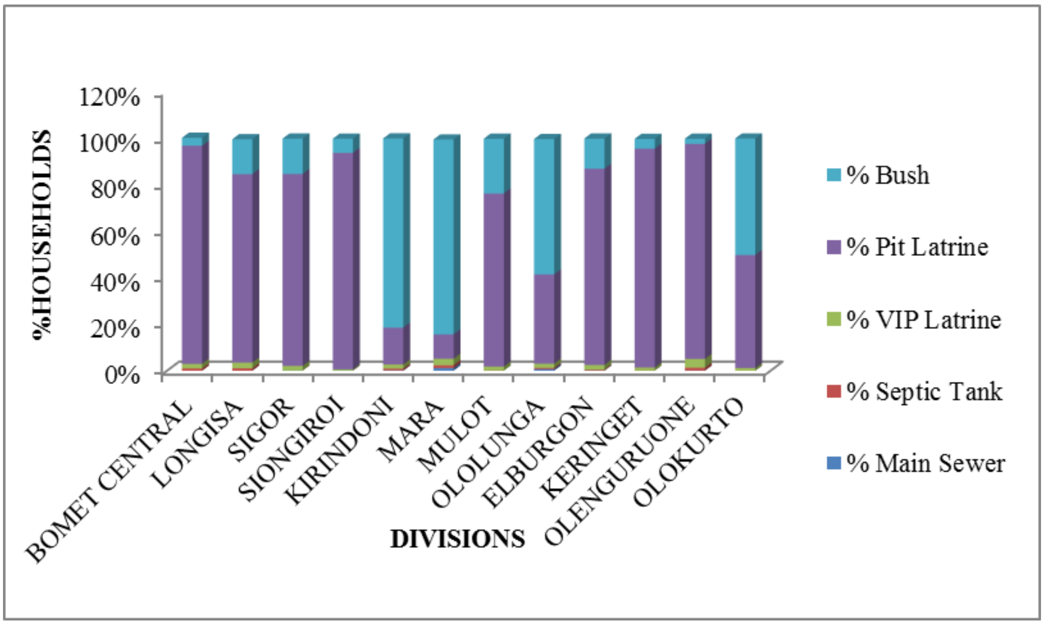


Figure 5.4: Average % household access to sanitation in the Upper Mara per division

5.2 Impacts of WASH activities to the environment in the Upper Mara

The impacts of WASH activities were presented using indicator such as water quality supplied by water sources, waste water quality discharged to the environment by sewage treatment projects, waste disposal methods and characteristics and soil erosion eroded around water points

5.2.1 Water quality supplied to the residents

Only 23.4% of the sampled water sources were found suitable sources for domestic water sources according to the Kenya 2006 water quality regulations (Republic of Kenya, 2006) (Appendix 5).

While groundwater was generally of much higher microbiological quality than surface water sources in the upper Mara, most (about 76%) of sources and systems used by people for domestic water were not adequately protected from faecal contamination. The scale of the problem of water quality in the upper Mara was found greater since it was clear that even of the existing improved sources such as boreholes and piped water projects were not providing water of adequate quality for domestic purposes.

Safe water is a precondition for health and development and a basic human right, yet it is still denied to hundreds of millions of people throughout the developing world (UNICEF, 2008). The consequences of poor water quality go beyond health. Chronic bouts of water-related diseases impose significant social and economic burdens both on victims themselves and society as a whole. Poverty alleviation and the other Millennium Development Goals will be difficult to achieve without improvements in water quality (Rottier and Ince, 2003). For the sampled boreholes, 80% had higher fluoride levels than the minimum allowed of 1.5 mg/l (Table 5-1).

Table 5-1 Nitrates, Fluoride, TSS and *E. coli* counts in sampled boreholes in the Upper Mara

BOREHOLES	**NITRATES mg/l**	**FLUORIDE mg/l**	**TSS mg/l**	***E. coli* count/10**
KIPLOKY	1.6	1.16	4	Nil
BOMET T SACCO	1.9	2.3	5	Nil
KIPSILAT	1.3	2.23	4	Nil
LEMEK	1.3	1.87	7	Nil
NGOSUAN	1.7	1.57	11	Nil
KWQR STANDARD LIMIT	**10**	**1.5**	**30**	**Nil**

Fluoride is one of the most serious chemical contaminants that occur naturally in drinking water. While the most common source of fluoride in drinking water is geological, considerable amounts may also be contributed from industrial sources or impurities in phosphorus fertilizers (Janssen and Knaap, 1989). Ingestion of water containing more than 1 mg/L F can lead to dental fluorosis, characterized by staining or pitting of dental enamel, in children under 6 years of age. At higher concentrations skeletal fluorosis may occur, involving stiffness and pain in joints in severe cases, ligaments can calcify and bone structure may change, causing pain and impaired mobility or crippling (Fawell, 2006).

Kenya water quality regulation (KWQR) guideline value for fluoride is set at 1.5 mg/L (Republic of Kenya, 2006) because of the increased risk of dental fluorosis above this level and of skeletal fluorosis at higher levels. From the data, 80% of the boreholes in the upper Mara contained fluoride levels higher than the set minimum levels. Therefore, without defluoridation water from these boreholes was unfit for human consumption and residents using these sources were vulnerable to dental fluorosis.

Ingestion of 14 mg/day F poses a clear risk of skeletal fluorosis, and there is evidence suggestive of increased risk at 6 mg/day. It is thought that fluorosis affects tens of millions of people across the world, with dental fluorosis being much more prevalent than the more serious skeletal form (NRC, 1999)

About 76.8% of the direct river water sources especially in the lower altitudes were found to be unsuitable due to high levels of suspended solids and presence of *E. Coli* (Table 5-2)

The indicator organism *Escherichia coli* (*E. coli*) is used to assess the bacterial quality of water (Nataro and Kaper, 1998). The bacterial quality of water is satisfactory if the *E. coli* concentration is less than one organism per 100 ml (WHO, 2006). Except for a few strains, *E. coli* is not a disease-causing organism (pathogen). It is found in very high numbers in the gut of all warm-blooded animals. Fresh faeces always contain *E. coli*, although it may not survive in the environment as long as some pathogens do. When *E. coli* is detected in water it shows that the water has been in contact with faeces: this means that pathogens may also be present in the water. The types of pathogen and their concentrations will depend on the nature of the organisms infecting the animals or humans that are the source of the faeces, and the number of animals or humans that are infected (FDEP, 2013).

Table 5-2 Nitrates, fluorides, TSS and *E.coli* counts in sampled rivers in the Upper Mara

RIVER	NITRATES mg/l	FLUORIDE mg/l	TSS mg/l	*E. coli* count/100ml
NYANGORES AT BOMET BRIDGE	10.6	0.95	108	63
MUKUKI	4.8	0.65	50	Nil
KIPSINOI	2.0	0.95	36	Nil
TINET	2.3	0.56	23	15
MARA RIVER	6.4	0.76	65	250
AMALA AT MULOT MK	8	0.14	88	170
ILMOLELIAN	2.8	1	64	11
CHEPTWETCH	1.0	0.77	36	Nil
KWQR STANDARD LIMIT	**10**	**1.5**	**30**	**Nil**

Suspended solids in drinking water cause turbidity or cloudiness. High levels of suspended solids can shield pathogens from disinfectants (JMP, 2008), so effective disinfection requires that TSS is less than 30mg/l (Republic of Kenya, 2006); Most water pans (88.9%) had presence of *E. Coli,* high levels of suspended solids and nitrates concentration more than the minimum levels allowed of 10mg/l (Table 5-3).

The main health concern regarding nitrate is methaemoglobinaemia, or “bluebaby syndrome”, which can lead to death by asphyxiation amongst bottle-fed infants when contaminated water is used to prepare formula or where infants drink contaminated water directly. When ingested, nitrate can oxidize blood haemoglobin (Hb) to methaemoglobin (metHb). MetHb cannot transport oxygen, and the oxygen-poor blood causes development of a blue colour in tissues (cyanosis) (Howard, *et al.*, 2003). Kenya water quality regulation guideline value for nitrate is set at 10mg/l (Republic of Kenya, 2006); to protect against methaemoglobinaemia in bottle-fed infants. The Main source of nitrate in drinking water is when nitrogen fertilizer is applied to crops, nitrate (NO_3) can filter into shallow aquifers or be washed into surface waters. However disposal of human or animal waste can also be a major source of nitrate (UNICEF, 2008).

The principal cause of concern for water quality in upper Mara basin was microbiological contamination, especially from faeces. The study showed a positive correlation (r=0.38) (Appendix 6) of the *E. Coli* per 100ml of water sampled from open water sources in various divisions and percentage households open defecating

Table 5-3 Nitrates, Fluoride, TSS and *E.coli* counts in sampled water pans in the Upper Mara

WATER PAN	**NITRATES mg/l**	**FLUORIDE mg/l**	**TSS mg/l**	***E. coli* count/100ml**
0LMARIKO	2.3	0.37	29	Nil
KIRINDON	22.8	1.66	90	7
DIKIRR	10.2	1.58	66	Nil
KINGSIR	9	1.16	79	425
EMARTI	11.1	0	81	150
KURITO	7	0.89	26	30
ILDUGISHO	6	1	32	15
EMBOLE NAIBOR	13	1.13	115	34
OLDONYO NARASHA	8	0.69	93	221
KWQR STANDARD LIMIT	**10**	**1.5**	**30**	**Nil**

Most of the suitable water sources were found in the upper catchment as seen in figure 5.5 which had a corresponding low percentage of households open defecating (Figure 5.6). On the contrary, the highest percentages of percentage household open defecating were recorded in the lower divisions of the basin, that is, Kirindoni, Ololunga and Mara (Figure 5.6) where all the water sources except Lemek borehole were found unsuitable for domestic water supply. Therefore open defecation was the most likely source of microbial water contamination. In addition, the lower divisions were occupied by pastoralist community and feacal coliforms from grazing animals would cause microbial water contamination of the open water sources

About 55% of the community piped water projects supplied poor water quality due to higher suspended solids than the standard limit of 30mg/l and presence of *E. Coli* (Table 5-4)

Table 5-4 Nitrates, Fluorides, TSS and *E.coli* counts in community piped water projects in the Upper Mara

WATER PROJECT	NITRATES mg/l	FLUORIDE mg/l	TSS mg/l	*E.coli* counts /100ml
TENWEK HOSPITAL	2.5	0.89	2	Nil
SIGOR	1.2	0.4	1	Nil
MUGOBET	5.7	0.07	78	Nil
KAPKOROS	2.3	0.68	10	Nil
SERGUTIET	1.2	0.92	22	5
BOMET	6.1	0.73	13	Nil
LONGISA COMMUNITY	6.3	0.69	60	180
LONGISA HOSPITAL	3.1	1.1	2	6
CHEPALUNGU	6.3	0.24	39	Nil
KWQR STANDARD LIMIT	**10**	**1.5**	**30**	**Nil**

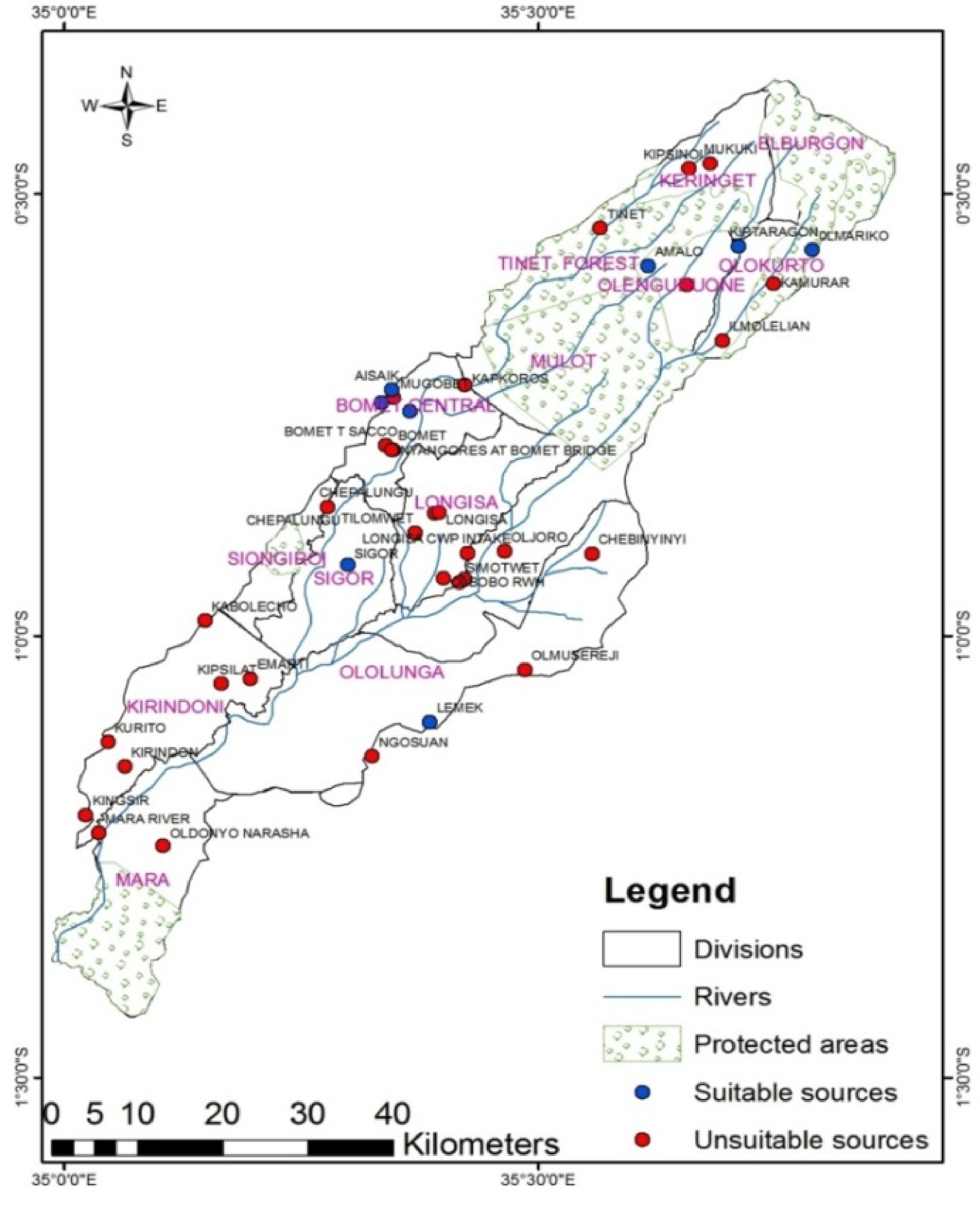


Figure 5.5: A Map of the Upper Mara showing the geographical distribution of the sampled water supply projects by suitability for domestic water supply

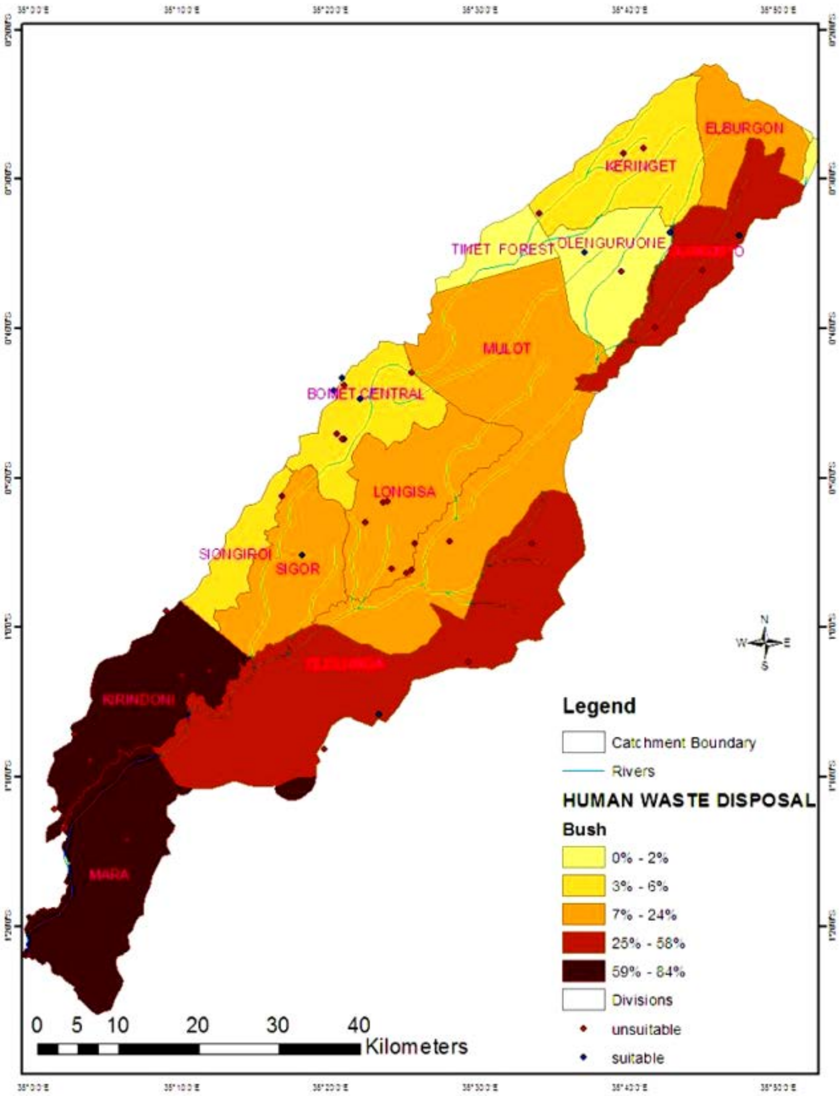


Figure 5.6: A map of the Upper Mara showing the geographical distribution household % open defecating per division and location of water points and their suitability for domestic water supply

5.2.2 Waste water quality discharged to the environment

The characterization of wastewater from the five generating sources was as in table 5-5. Based on the parameters analyzed, the BOD_5 level of wastewater from Bomet Municipal stabilization pond was recorded as 644 mg/l, TSS and TDS levels were

1076mg/l and 3910mg/l respectively. Bomet slaughter house recorded BOD_5 at 1514mg/l, TSS at 1067mg/l and TDS at 3910mg/l while for Kapsimotwa slaughter house waste water BOD_5 level was 398 mg/l, TSS at 897mg/l and and TDS levels of 1842 mg/l. According to the Kenya water quality regulations of waste water discharged to the environment (Republic of Kenya, 2006) where BOD_5 is set at 30mg/l, TSS as 30mg/l and TDS to be 1200 mg/l, waste water from these three sources was poorly treated thus sources of pollution to the environment in the Upper Mara basin. Olonana tented camp utilized a constructed wetland treating the waste satisfactorily while Tenwek hospital treated its waste water to standards using a series of physical, biological and chemical processes.

Table 5-5: Wastewater quality analysis from Various Source

Sample / Parameter	Kapsimotwa slaughter house	Tenwek hospital	Bomet municipal pond	Bomet slaughter house	Olonana hotel	**KWQR Standard for effluent discharged**
pH	6.86	7.62	7.66	7.56	7.47	**6.5-8.5**
BOD_5 mg/l	398	28	644	1514	23	**30**
Fluorides mg/l	0	0.68	0	0.6	1.35	**1.5**
TSS mg/l	897	14	1076	1067	30	**30**
TDS mg/l	1842	394	3910	945	484	**1200**

Wastewater quality indicators are used to assess suitability of wastewater for disposal. Tests measure physical, chemical, and biological characteristics of the wastewater. Solid material in wastewater may be dissolved, suspended, or settleable. Total dissolved solids or TDS is measured as the mass of residue remaining when a measured volume of filtered water is evaporated. The mass of dried solids remaining on the filter is called total suspended solids (TSS) or non-filtrable residue (APHA, 1975).

Dissolved or suspended oxidizable organic material in wastewater will be used as a food source for microorganism. Finely divided material is readily available to microorganisms whose populations will increase to digest the amount of food available. Digestion of this food requires oxygen, so the oxygen content of the water will ultimately be decreased by the amount required to digest the dissolved or suspended food. Oxygen concentrations may fall below the minimum required by aquatic animals if the rate of oxygen utilization exceeds replacement by atmospheric oxygen (Goldman and Horne, 1983)

Since all natural waterways contain bacteria and nutrient, almost any waste compounds introduced into such waterways will initiate biochemical reactions. Those biochemical reactions create what is measured in the laboratory as the biochemical oxygen demand (BOD). A BOD test is a measure of the relative oxygen-depletion effect of a waste contaminant. It has been widely adopted as a measure of pollution effect. The BOD test measures the oxygen demand of biodegradable pollutants. The 5-day BOD measures the amount of oxygen consumed by biochemical oxidation of waste contaminants in a 5-day period (Tchobanoglous *et al.*, 2003).

The contaminants in domestic sewage can be divided into three categories: suspended solids (SS), organic matter (chemical oxygen demand or biochemical oxygen demand), and nutrients (nitrogen and phosphorus) (Xiaochang *et al.*, 2007). In general, organic and inorganic substances in the domestic sewage may include both suspended and dissolved fractions, and the suspended fraction can be easily removed by physical and/or physiochemical processes under most conditions. However, some dissolved substances may attach on to the suspended particles. Therefore, as long as the suspended particles can be effectively removed, the originally dissolved matter may also be removed substantially (Semerjian *et al.*, 2003; Ødegaard, 1992)

Slaughterhouse wastewater has been classified by Environmental Protection Agency (EPA) as one of the most harmful to the environment (Walter, 1974). It typically contains high levels of organic matters which generally arise from paunch, fecal matter, fat, lard, undigested food, suspended materials, urine, and loose meat. These contents tend to form a mixture of suspended solution at the end (Sarairah and Jamrah, 2008). It also contains high inorganic load, high suspended solids content, dark color and offensive odor indicating poor bacteriological standards. Therefore, discharging slaughterhouse wastewater without treatment contributes to greatly degrading the aquatic environment and pollution of water bodies (Michael, 1988). For the treatment of this type of wastes, conventional biological processes do not offer the solution to satisfy environmental requirements. As an alternative to more efficient treatment process for treating highly loaded effluents, the anaerobic process is particularly designed to effluents discharged at high concentrations of BOD_5 and other biodegradable components (Speece, 1999).

5.2.3 Solid Waste Characterization and Disposal

Analysis of solid waste to establish its composition revealed that polythene bags were the most dominant (49%) by volume and commonly encountered waste at Bomet town dumpsite. Additional waste included: recyclable office paper (17%), plastic bottles (10%), textile/torn clothing (8%), manila bags/ropes (3%), leather (3%), food waste (6%) among other waste like broken glass, tins/cans, sponge, rotting wooden pieces and ceramic waste (4%), (Figure 5.7).

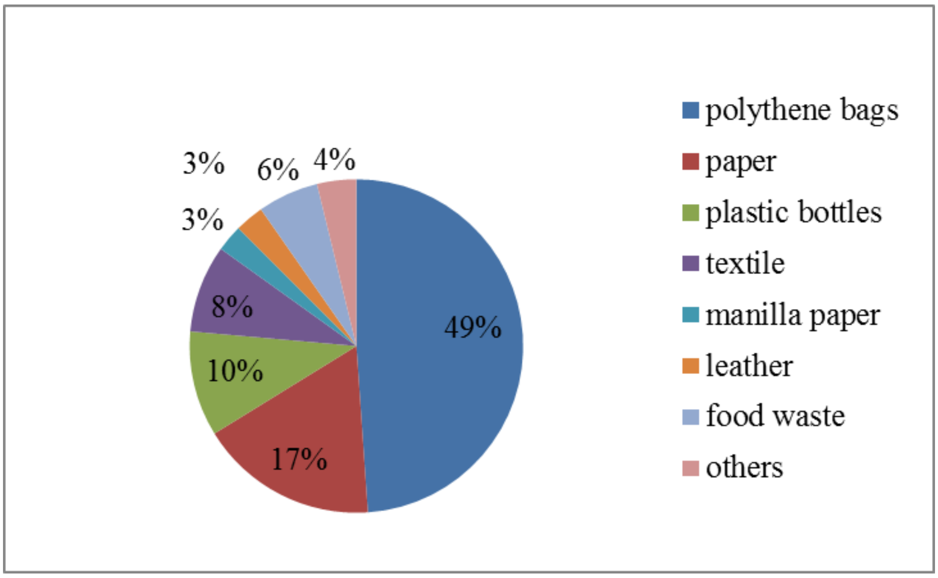


Figure 5.7: Solid waste characterization by volume at Bomet town dumpsite

According to Environment Protection and Heritage Council (EPHC) (2002), the problem of plastic bags emanates from their relatively cheaper cost compared to other packaging materials. In addition, some of the polythene bags are too thin and fragile to be re-used, while polythene bags in most cases are given out for free upon purchase of a commodity in supermarkets and shops across the country. Such factors encourage excessive usage of plastic bags, and trigger a general tendency by locals to misuse and dispose of carelessly. Most of the plastic bags encountered along Bomet towns probably originated from supermarkets, shops and markets in the area.

Plastic bags and plastic bottles/containers are a threat to public health as they may collect water during rainfall and retain it, creating suitable breeding grounds for disease vectors like mosquitoes, flies and cockroaches as well as rodents like rats which can lead to the spread of diseases (Ngwuluka *et al.*, 2009). In addition, polythene bags can be detrimental to animal health and worse still lead to their death if consumed (Singh, 2005). This is the case in of the urban cities of the Upper Mara basin.

Most of the solid waste in the upper Mara was disposed by open burning and dumping especially in urban and market centers (Figure 5.8). Olonana, Fairmont and Mpata safari hotels separated solid waste and practiced compositing, recycling and incineration of different waste. Tenwek and Longisa hospitals burned all medical waste in incinerators (Plate 5-1). Solid waste management in urban centres and markets Itembe, Silibwet, Tenwek and Longisa Market center was poor; solid waste was collected weekly and burned openly in the market centers. In Bomet town a tractor hitched with an open trailer was used for garbage transport to a dumping site. The municipal council of Bomet (major town center in the catchment) had no license to operate a dumpsite. There was no separation of wastes from the source and the dumping site is open. The council normally collected 12 tons of wastes generated per day.

Open burning of plastic waste by residents could result in air pollution with associated health problems due to heavy metal additives (Ketibuah *et al*., 2004). Carelessly disposed waste, emits unpleasant odor, contributes to blockage of drainages (Plate 5-2a), defaces urban habitations and pollutes adjacent aquatic systems (Halden, 2010).

Poor waste disposal and collection efficiency in the urban centers of the upper Mara has given rise to huge amounts of waste which seem to have outstripped the capacity of local authorities to collect, manage and dispose solid waste correctly (Wetherall, 2003). Domestic wastes add large amounts of organic and inorganic substances into aquatic systems (Bashir and Kawo, 2004), which in turn increases turbidity, suspended and dissolved solids into the river water.

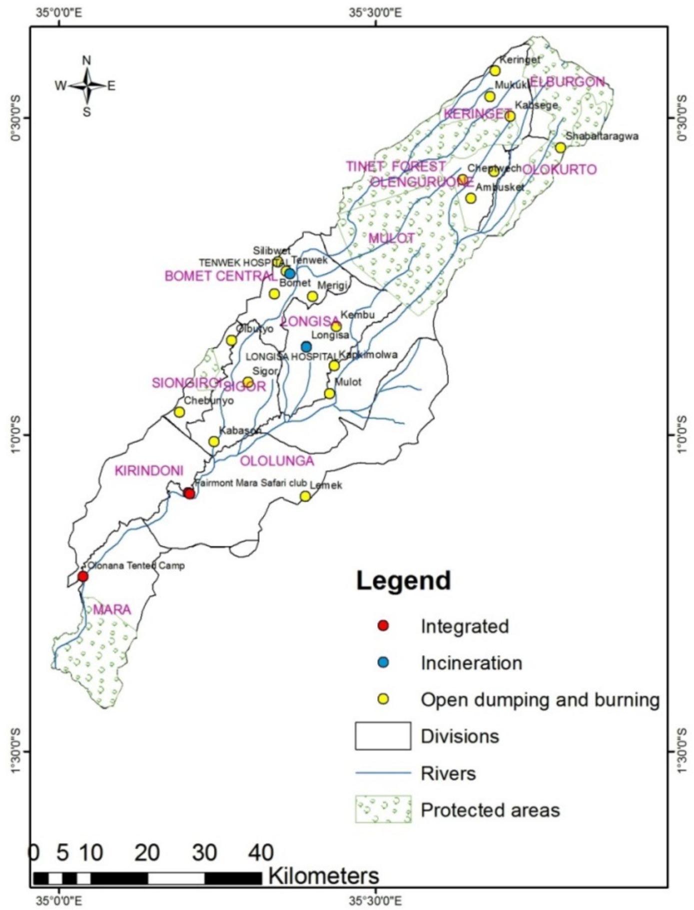


Figure 5.8: A map of the Upper Mara basin showing location of solid waste disposal sites and method of disposal employed

(a) (b) (c) (d)

Plate 5-1: Various solid waste disposal methods in the Upper Mara a) Compositing and b) Incineration at Olonana Hotel c) Open burning at Mulot town d) Open dumping at Bomet town

According to a United Nations Conference on Human Settlement report, one third to one-half of solid waste generated within most towns in low- and middle-income countries, are not collected, and usually end up as illegal dumps on streets, open spaces, and water bodies (UNCHS, 1996). Urban environmental problems in Africa of which liquid and solid waste disposal is a part have been justified on the grounds that most of the countries in sub-Saharan Africa lack adequate funding and suffer from rapid population growth (Porter *et al*, 1997; Onibokun and Kumuyi, 1999). Waste disposal practices of the authorities have also encouraged improper attitudes regarding waste management programmes (Kendie, 1999) and big changes will be needed to re-orient the mindset of the riparian populations regarding their perception of waste and its disposal.

The growth of urban areas has resulted in increased consumption of resources to meet the growing demands of urban population and industry, leading to the generation of large amounts of waste in urban centers. Due to weak institutional policies and lack of resources; both human and capital, management of wastes, hygiene and sanitation in many cities on the African continent are in very poor conditions (UNEP, 1999). Between 20% and 80% of solid waste is disposed of by dumping in open spaces, water bodies, and surface drains in African cities due to factors like inadequate infrastructure (UNEP, 1999).

Dumpsites in close proximity to rivers and streams as observed at some sections along the two perennial tributaries of Mara River were subjected to open burning, further polluting the environment through noxious gases and fumes. Ashes from burnt waste would easily be swept into the river by storm water during heavy rains, further polluting the aquatic system (Beukerung, *et al*., 1990).

Open dumpsites containing standing water fosters the growth of pathogens contained in the waste it also substantially increases the risk of groundwater contamination and provides breeding habitat for insect disease vectors. Open solid waste dumpsites located in proximity of 20m from residential houses, hospital wards and shops (Figure 5-2 b) increases the risk that pathogens contained in waste would contaminate food.

(a) (b)

Plate 5-2: Domestic solid waste, (a) in storm drainages leading into Amala tributary and (b) next to human dwelling

5.2.4 Soil erosion around water points

The study showed that, 17%, (Figure 5.9) of the sampled water supply projects sites, were eroded as shown by changed levels of soils around them. This erosion was probably caused by overstocked livestock sharing water points with the humans causing degradation of the environment around the water points. It was observed that 36% (Figure 5.9) of the sampled water points were shared with livestock.

A Chi Square test performed to determine if livestock-human sharing related with erosion at water points (Appendix 7), indicated that there was a significant relationship, (X^2 (1) = 6.599, P = .010 (at an alpha level of .05) between livestock sharing water point with humans and soil erosion occurring at those sites, this could probably be caused by overcrowding livestock at the water points which loosen the soils by their hooves making it more erodible.

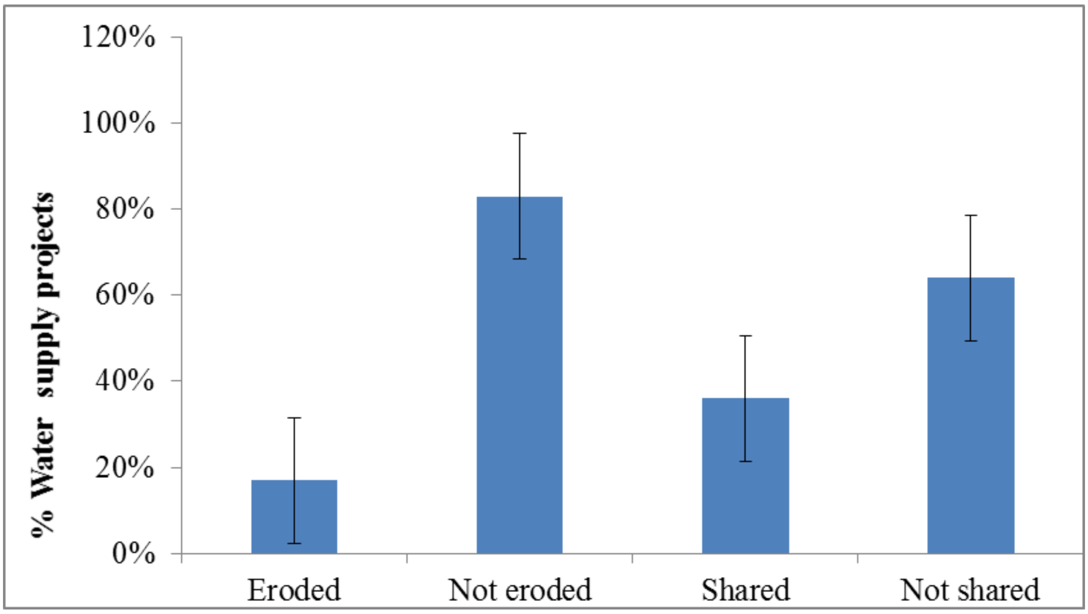


Figure 5.9: Percentage of eroded and livestock – human shared water supply points in the Upper Mara.

Unrestricted livestock access to waterways, stream-beds and water points may cause environmental disturbance through the loss of natural fringing vegetation, compacted soils, erosion and poor water quality. Livestock tend to concentrate around water sources. This activity can lead to reduced vegetative cover and increased manure concentration in and around water sources. The water source can become polluted with sediment, nutrients, and fecal coliform and streptococcus bacteria, leading to impaired water quality (Machiwa, 2002). Helland (1980) found out that water development in areas of uncontrolled grazing may alleviate overstocking resulting in range degradation around watering points. The most conspicuous effects of range degradation are found around permanent wells and boreholes (Helland, 1980). According to Dregne (1986), overgrazing in the Sahel was made worse by the drilling of additional wells that provided drinking water for livestock throughout the year. Without the rest period that intermittent water supplies previously assured, forage conditions deteriorated around the wells where water was no longer a limiting factor in livestock survival. Local authorities did not or could not impose a control system that would allow forage plants to recover from heavy grazing. Accelerated water erosion has been especially serious on overgrazed rangelands.

Figure 5.10 shows the distribution of the water points in relation to erosion. It was noted that, most of the eroded water points were found in the lower parts of the catchment which is predominantly occupied by pastoralists.

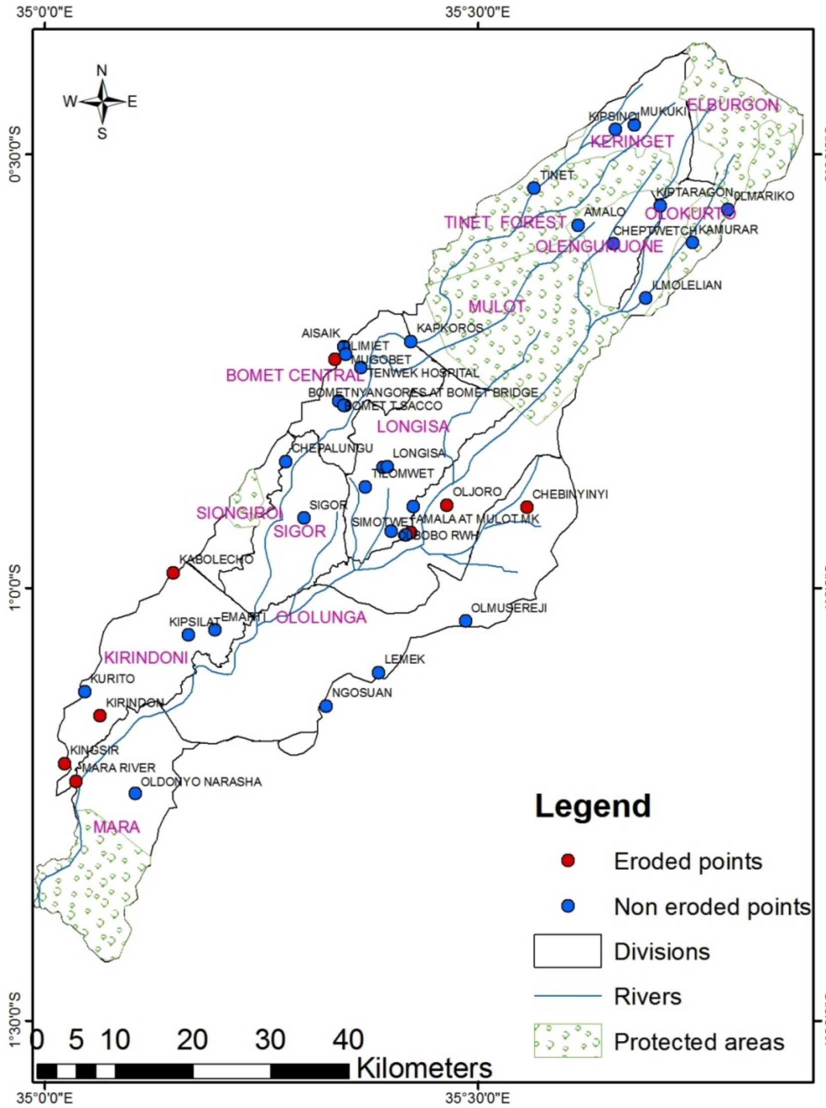


Figure 5.10: A map of the Upper Mara basin showing location of eroded water points

5.2.4.1 Gully volumes

Among the eroded water projects, gullies were observed at four sites the rest had evidence of sheet and rill erosion. Soil lost from gullies at Chebinyinyi, Tilimiet and

Oljoro protected springs as well as at kirindon water pan (Plate 5-3) was estimated as recorded in table 5-6.

Table 5-6: Gully volumes at various water points

Water point	**Gully volume (m^3)**
Tilimiet springs	186.5
Chebinyinyi springs	527.6
Kirindon water pan	85.9
Oljoro springs	296.8

Most soil had been lost around Chebinyinyi spring followed by Oljoro spring, Tilimiet spring and kirindo water pan. All these water points were public water points shared between livestock and humans shared. Therefore, gullies were formed on livestock trails along hillsides to the watering points. This is because the livestock traffic on them compact the soil and reduced the water holding capacity. Sunken footpaths made up- and-down the slope became the focus of concentrated flow that eventually turned into gullies (NBI, 2012). Soil eroded from gullies caused siltation of waterways suspended sediments, which may have attached nutrients and pesticides, can adversely affect water quality and aquatic life.

Erosion around water points usually reduces the service period of the supply point by undercutting concrete aprons, well covers, and pump footings (USAID, 2013). It often leads to stagnant water around the supply point. In addition, llivestock sharing a water point with humans easily results in contamination of water with livestock feaces & body fluids; it may also attract disease vectors (particularly flies) which are a source of contamination.

Plate 5-3: Eroded land around water points a) Tilimiet spring, b) Chebinyinyi spring, c) path to Kirindon water pan, d) Oljoro spring

Therefore, the emphasis in water development must be on the continuing use of traditional watering practices for which the labour and social organization required act as a constraint on range utilization (Helland, 1980). For instance, by using carefully spaced water points or by centripetal watering where herding livestock is done as far from water points as possible at the start of the dry season, when the vegetation is green and the days are cool, and gradually bringing them closer as the vegetation dries out and the days become hotter (Hudson, 1993).

Plate 5-4 shows overcrowded livestock at a water point and a livestock-human shared water pan.

(a) (b)

Plate 5-4: a) Overcrowded livestock at Embole Naibor water pan in Ololunga division, b) A livestock – human shared water pan in Kirindon

5.3 Modelling the long term effects of WASH activities using WEAP model

5.3.1 Model Calibration and Validation

5.3.1.1 Hydrological Calibration and Validation

Hydrological calibration and validation was done by comparing the simulated and measured monthly flows for 1LB02 and 1LA03 stream flow gauges. The calibration parameters were catchment area, River lengths as measured in Arc-GIS 10 (Table 5-7) and annual precipitation for Bomet weather station (Table 5-8). Figure 5.11 shows the observed and simulated flows at 1LB02 during calibration. The regression coefficient (R^2) between the simulated and observed stream flow were assessed for the 2 gauging stations. For station 1LB02, an R^2 of 0.87 was obtained during calibration (Figure 5.12) and an R^2 of 0.78 for 1LA03. The simulated and observed mean monthly flow at 1LB02 and 1LA03 differed by 0.52 m^3/s and 0.34 m^3/s respectively (Table 5-9) during calibration. Figure 5.13 shows the observed and simulated flows at 1LB02 during validation. During the validation process, station 1LB02, had R^2 of 0.89 (Figure 5.14) while an R^2 of 0.83 was attained for 1LA03. The simulated and observed mean monthly flow at 1LB02 and 1LA03 differed by 0.22m^3/s and 0.6m^3/s respectively (Table 5-10) during validation.

Table 5-7: Catchment area and river lengths used for model calibration

Catchment Area	3389.57 Km^2
River Length	
Nyangores	85.67 Km
Amala	89.49 Km

Table 5-8: Annual Rainfall Data for Bomet Weather Station used for Model Calibration

Year	Total annual rainfall (mm)
2003	806
2004	703
2005	441
2006	1059
2007	711.9
2008	619
2009	580
2010	799.8
2011	920.4

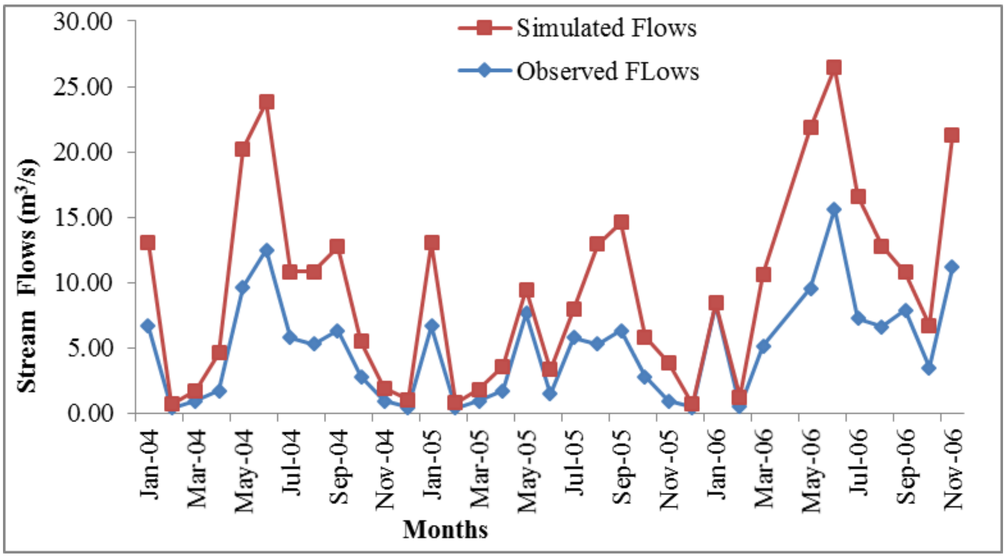


Figure 5.11: Observed and simulated monthly stream flows for Amala River at gauging station ILB02 during calibration

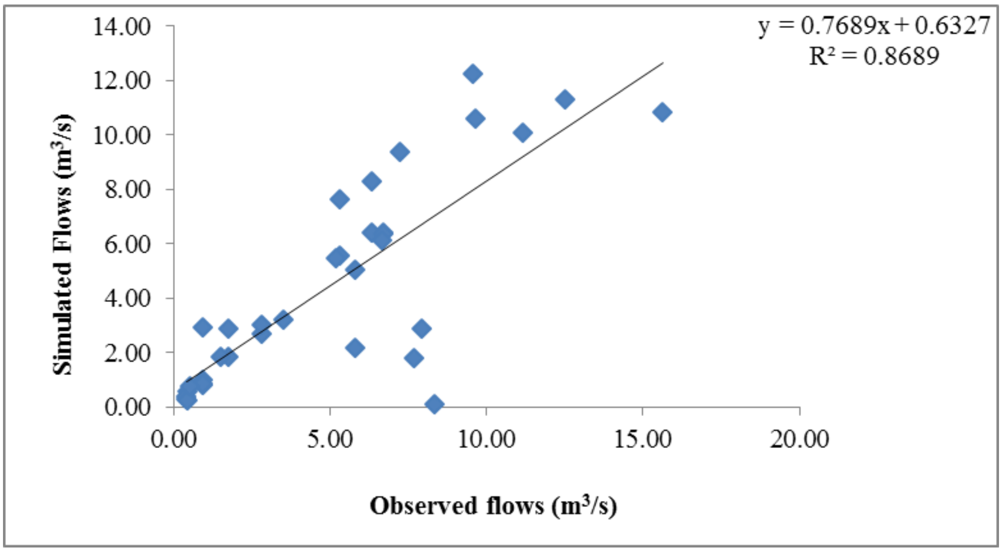


Figure 5.12: A scatter plot showing the R^2 during stream flow calibration at gauging station

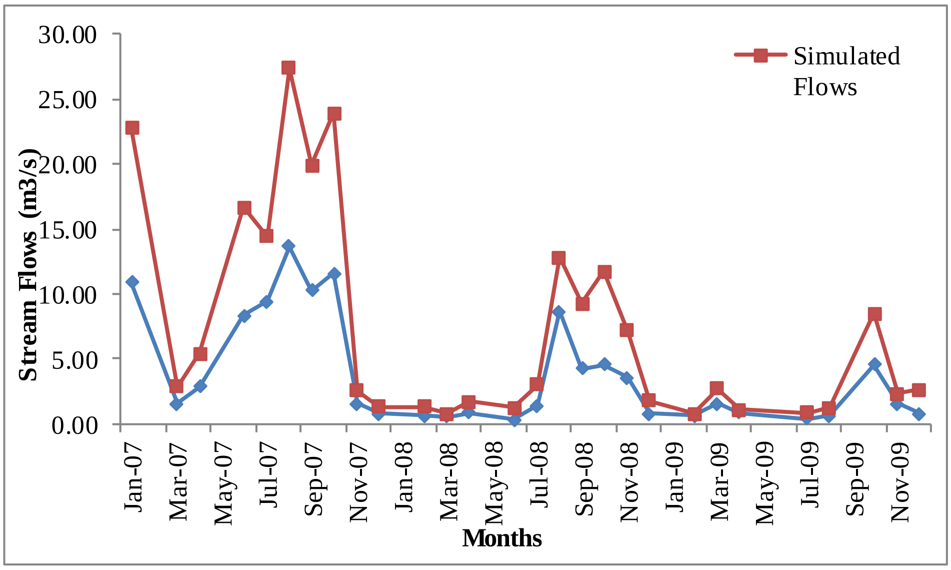


Figure 5.13: Observed and simulated monthly stream flows for Amala River at gauging station ILB02 during validation

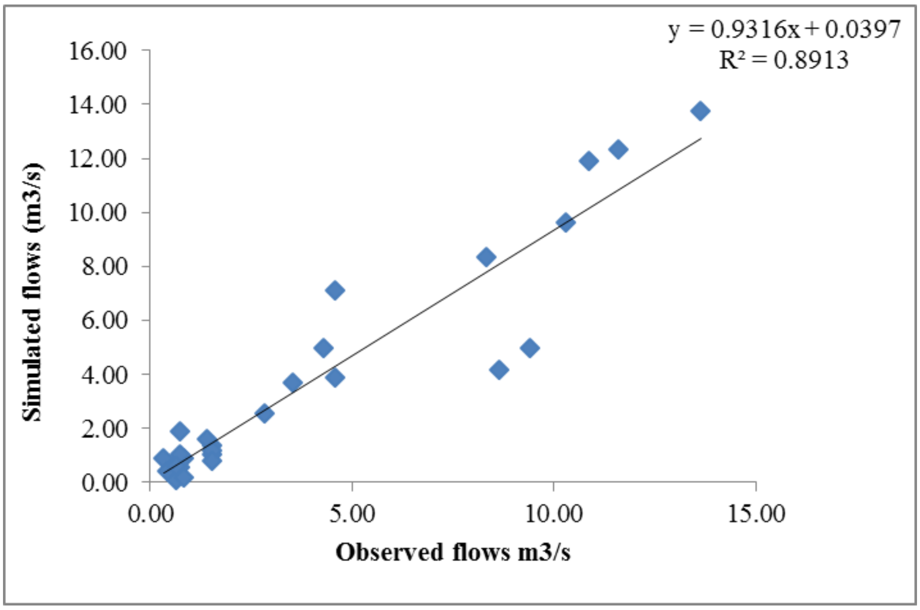


Figure 5.14: A scatter plot showing the R^2 during stream flow validation at gauging station ILB02

These regression coefficients (r^2) statistical results indicated good model performance in reproducing the stream flow trend. Therefore, WEAP model could reproduce the hydrological dynamics for the upper Mara Basin as shown in the calibration and validation process.

Table 5-9: Comparison of the observed and simulated mean flow during calibration period at the 2 gauging stations

Period	River Gauging Station	River	Mean Flow($m^{3/}s$)		Regression Coefficient (R^2)
			Observed	Simulated	
2004-2006	1LB02	Amala	5.0	4.48	0.86
2004-2006	1LA03	Nyangores	9.56	9.22	0.78

Table 5-10: Comparison of the observed and simulated mean flow during validation period at the 2 gauging stations

Period	River Gauging Station	River	Mean Flow($m^{3/}s$)		Regression Coefficient (R^2)
			Observed	Simulated	
2007-2009	1LB02	Amala	3.83	3.61	0.89
2007-2008	1LA03	Nyangores	11.75	11.15	0.83

5.3.1.2 Water Quality Calibration and Validation

Water quality calibration and validation was done by comparing the simulated and measured DO, TDS and TSS levels for 1LB02 and 1LA03 gauges station on Amala and Nyangores Rivers respectively. The parameters that were available for calibration were geometric characteristics of the two rivers including head flow distance marker, tail flow distance marker, (Table 5-11). The distance markers indicate how long each river reach is where head flow distance marker is the start of the river and the tail flow distance marker is the bottom of the last river reach as measured using Arc-GIS 10. WEAP uses the relative lengths from the schematic to estimate the reach the other lengths.

Other geometric characteristic needed for calibration were corresponding river flow, stage (gauge height) and river width for the 2 gauging stations as obtained for the Lake Victoria south WARMA office in Kericho (Table 5-12and 5-13). Climatic data used for model calibration were average monthly air temperature, average humidity and wind speed for the year 2006 at Bomet weather station (Table 5-14). River geometric characteristics were mainly used to compute velocity and residence time of the water along a given river reach while climatic data were needed to compute river water temperature in the model.

Table 5-11: Geometric characteristics of the two rivers used for model calibration

River Gauging Station	River	Head flow distance marker	Tail flow distance marker
1LB02	Amala	0 Km	79.73 Km
1LA03	Nyangores	0 Km	8 m

Table 5-12: Flow, stage and width parameters for station 1LB02 on Amala for calibration

Flow (m^3/s)	Stage (m)	River Width (m)
0.96	0.28	9.50
1.09	0.30	10.05
1.84	0.40	12.90
2.56	0.48	13.30
2.78	0.50	14.50

Table 5-13: Flow, stage and width parameters for station 1LA03 on Nyangores used for calibration

Flow (m^3/s)	Stage (m)	River Width (m)
1.74	0.29	14.40
2.98	0.37	19.40
10.15	0.55	20.80
10.99	0.58	20.95
13.54	0.67	22.40
15.14	0.71	23.60

Table 5-14: Climatic data for 2006 at Bomet weather station used for model calibration

Climate parameter	value
Average humidity	63%
Average wind speed	2 m/s
Cloud cover	1
Monthly average temperature	°c
January	18.2
February	18.35
March	18.5
April	17.55
May	17.15
June	17.2
July	17
August	16.9
September	18
October	18.4
November	18.05
December	18.1

The regression coefficient (R^2) between the simulated and observed DO, TDS and TSS were assessed at the two gauging stations. For station 1LB02, R^2 of 0.72, 0.89 and 0.81 were obtained for DO, TDS and TSS during calibration. Figure 5.23 shows the observed and simulated DO levels at 1LB02 while figure 5.15 shows the regression analysis and the R^2 value during calibration. During the validation process, station 1LB02 had R^2 of o.82, 0.80and 0.87 for DO, TDS and TSS. Figure 5.25 shows the observed and simulated DO levels at 1LB02 while figure 5.16 shows the regression analysis and the R^2 value during validation. The mean observed and simulated water quality parameters for the gauging stations and corresponding R^2 attained during calibration and validation for the two stations are as in table 5.15 and 5.16 respectively.

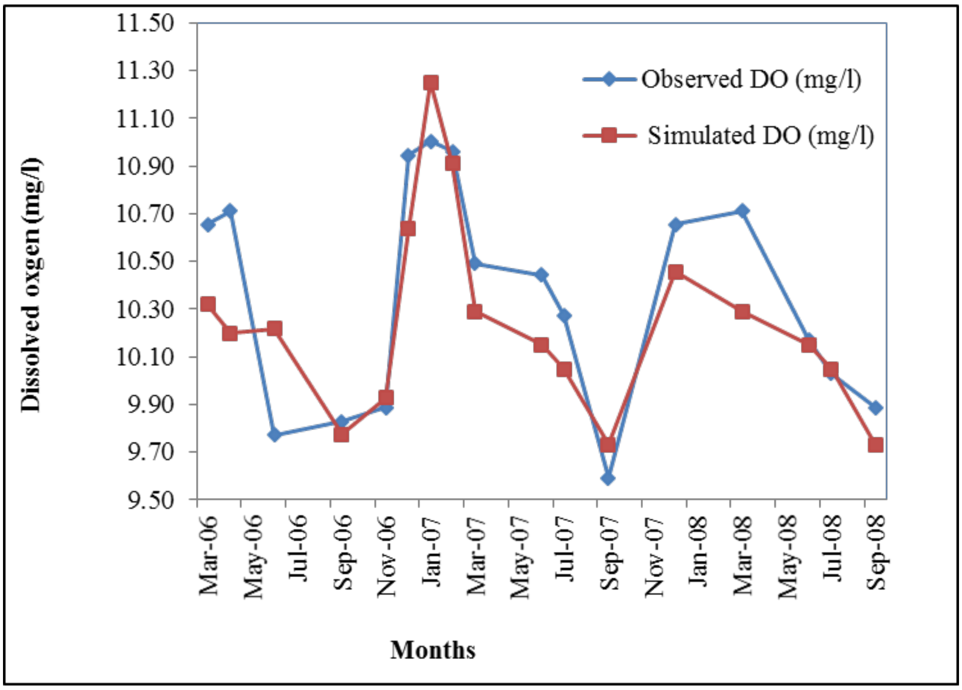


Figure 5.15: Observed and simulated dissolved oxygen levels for Amala River at gauging station ILB02 during calibration

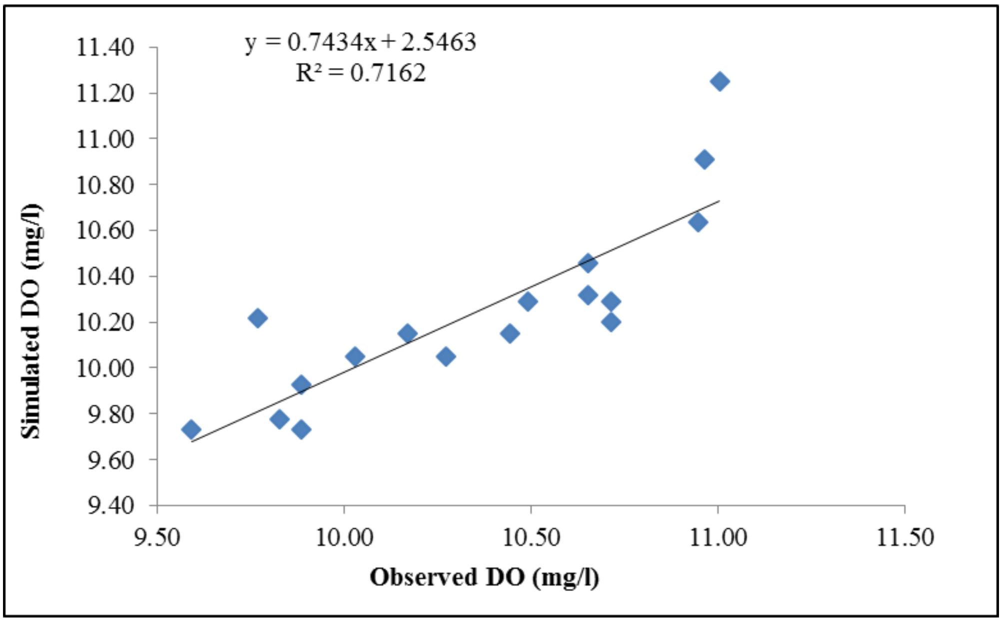


Figure 5.16: A scatter plot showing the R^2 during DO calibration at gauging station ILB02

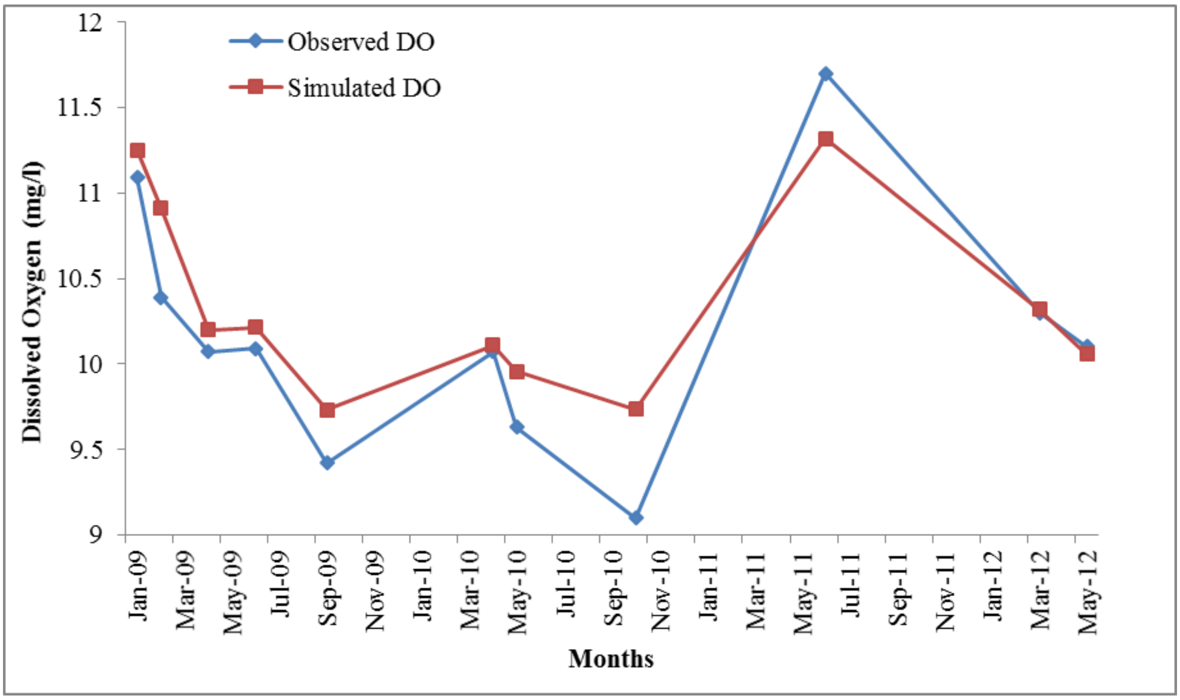


Figure 5.17: Observed and simulated Dissolved oxygen levels for Amala River at gauging station ILB02 during validation

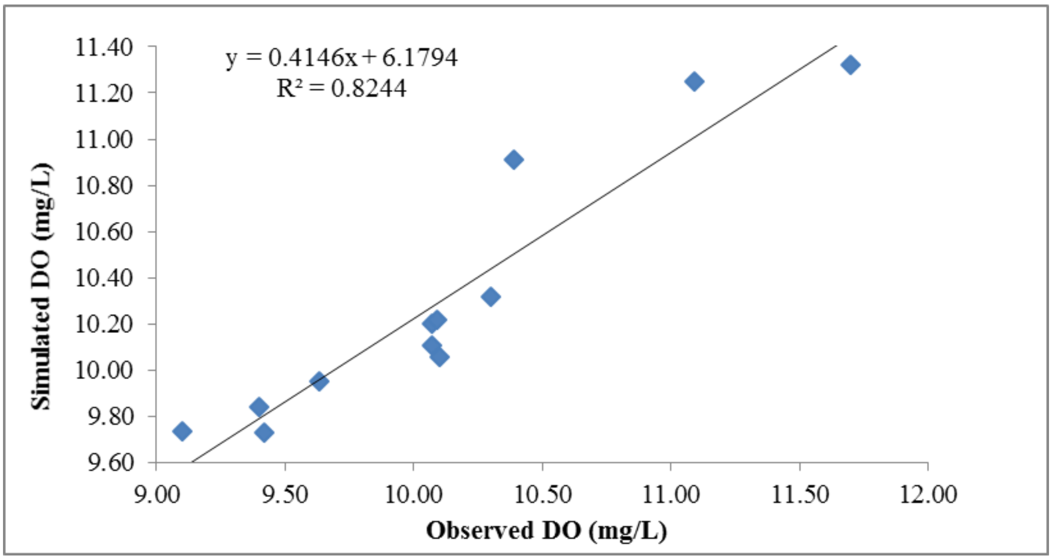


Figure 5.18: A scatter plot showing the R^2 during DO validation at gauging station ILB02

Table 5-15: Comparison of the observed and simulated water quality parameters during calibration period at the 2 gauging stations

Period	River Gauging Station	River		Mean Water quality parameters (mg/l)		Regression Coefficient (R^2)
				Observed	Simulated	
2006-2008	1LB02	Amala	DO	10.30	10.22	0.72
			TSS	49.90	50.95	0.89
			TDS	38.69	36.81	0.81
2006-2008	1LA03	Nyangores	DO	8.75	8.83	0.82
			TSS	49.41	49.20	0.96
			TDS	26.6	27.0	0.71

These statistical results indicated good model performance in reproducing the water quality trend. Therefore, WEAP model could reproduce the water quality dynamics for the upper Mara Basin as shown in the calibration and validation process

Table 5-16: Comparison of the observed and simulated water quality parameters during calibration period at the 2 gauging stations

Period	River Gauging Station	River		Mean Water quality parameters (mg/l)		Regression Coefficient (R^2)
				Observed	Simulated	
2008-2012	1LB02	Amala	DO	10.18	10.35	0.82
			TSS	53.70	49.70	0.80
			TDS	45.68	44.10	0.87
2008-2012	1LA03	Nyangores	DO	8.20	8.42	0.89
			TSS	48.73	50.71	0.96
			TDS	27.7	27.9	0.85

5.3.2 Simulating effects of WASH activities using WEAP

5.3.2.1 Scenario 1: Reference Scenario or business as usual scenario

This scenario represented the changes that were likely to occur in the future, in the absence of any new policy or technological measure in the catchment. It represented the water system in the catchment as defined in the current accounts. The Current Accounts in this study represented the basic definition of the water system as it existed in the year 2012. They included the specification of supply and demand data for the first year of the study: Monthly river flows, current demand, current river and links water quality.

5.3.2.1.1 Reference Scenario River flows

Monthly River flows at gauging stations 1LB02, 1LA03 and 1LA04 on Amala, Nyangores and Mara Rivers respectively for the year 2012 were as in figure 5.19. The highest flows in all the rivers were observed in the month of October and the lowest flows occurring in the month of February. Of the three rivers, Amala had lowest flows. The average flows were 24.11m^3/s for Mara River, 9.43 m^3/s for Nyangores and 2.61m^3/s for Amala River. These flows formed the baseline for water quantity modelling in WEAP.

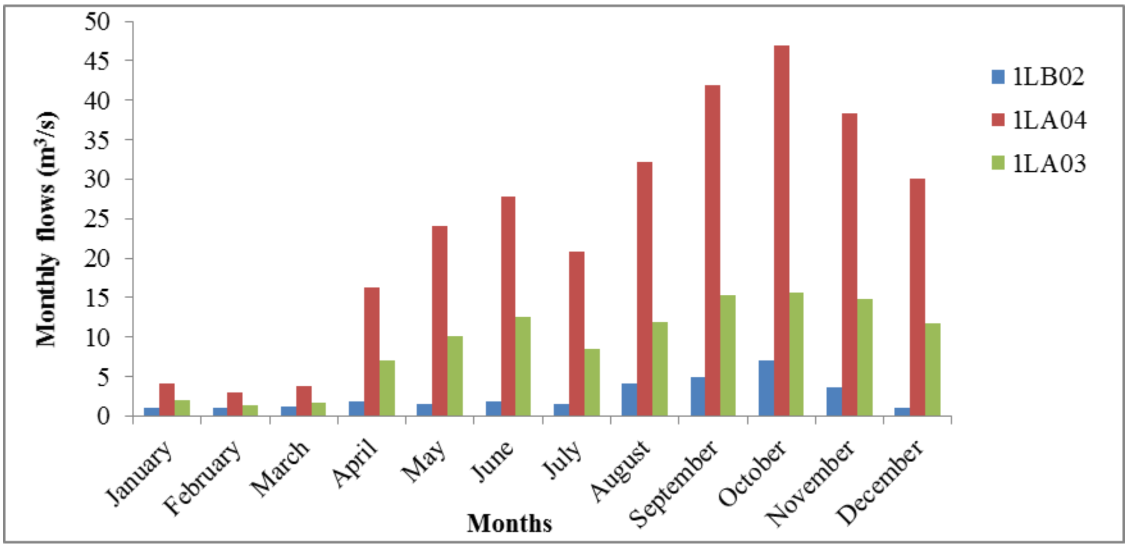


Figure 5.19: Monthly River flows for 2012 at gauging stations 1LB02, 1LA03 and 1LA04 on Amala, Nyangores and Mara Rivers

5.3.2.1.2 Reference Scenario Water demands

During this scenario, the total annual water demand in the upper Mara was 6.24 million cubic metres (MCM) in 2012. Considering the Kenyan annual population growth rate of 2.44% (KNBS, 2010) in the reference scenario, the total annual demand was expected to increase to 9.64 MCM by 2030 (Figure 5.20).

For instance, the annual demand in Bomet town was expected to rise from 0.131 MCM to 0.203 MCM between 2012 and 2030 during this scenario, at Mulot town the demand would increase from 0.066 MCM to 0.102 MCM and at Tenwek Hospital the demand would increase from 0.043 MCM to 0.06 MCM in the same period (Figure 5.21).

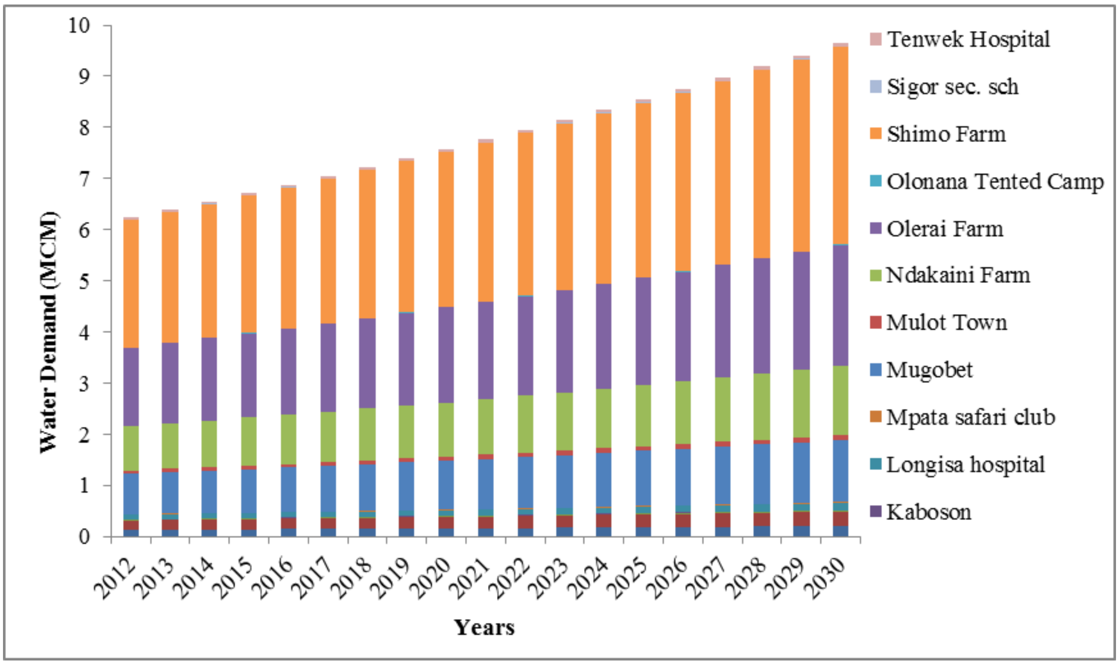


Figure 5.20: Annual water demand (MCM) per demand site in the Upper Mara during the reference scene

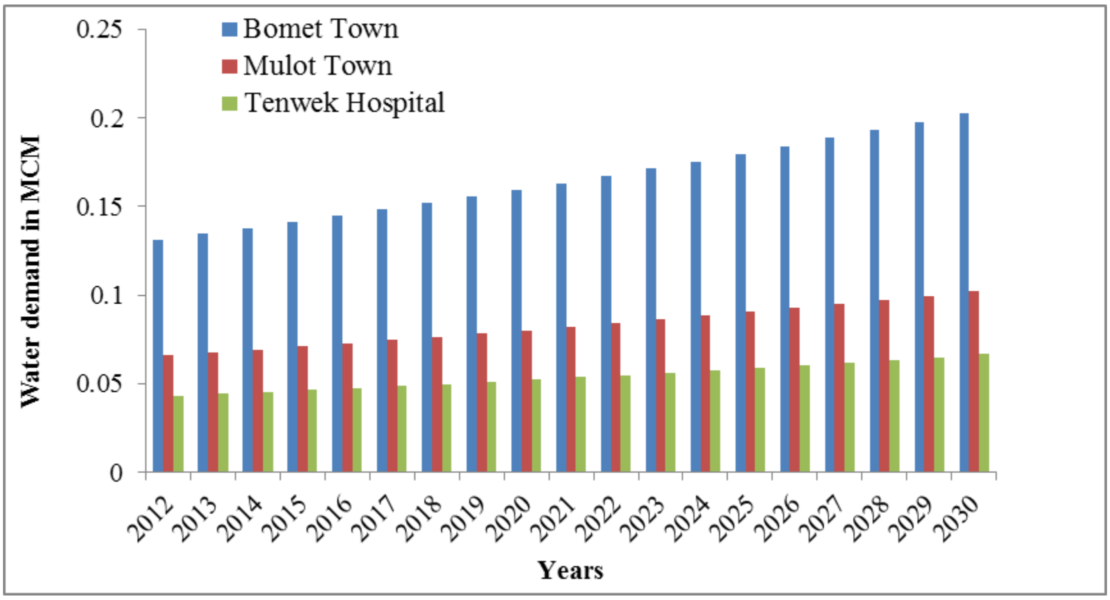


Figure 5.21: Annual water demand at Bomet town, Mulot town and Tenwek hospital demand sites in the reference scenario

Considering the reference supply and demand, the model showed that all demand in all the demand sites in the catchment would be met for the modeling period except for February of 2030. In February of year 2030 the demand for Longisa hospital, Mulot town and Ndakaini farm would be unmet by 95.34m^3(0.88%), 47. 13m^3 (0.6%) and 924.17m^3 (0.89%) respectively (Figure 5.22). These 3 demand sites were supplied by Amala River which was observed to have the lowest flows in the reference scenario. In addition, February was observed to experience the lowest monthly flows in the reference scenario. Therefore, the unmet demand indicated that the available flow in Amala River would be lower than the demand expected during this month; the flows in the other two rivers were adequate to meet demand from all the demand sites they supplied. In addition, it was expected that if the system remained in the business as usual status, water supply constrains would start to be experienced by February 2030 in the upper Mara catchment.

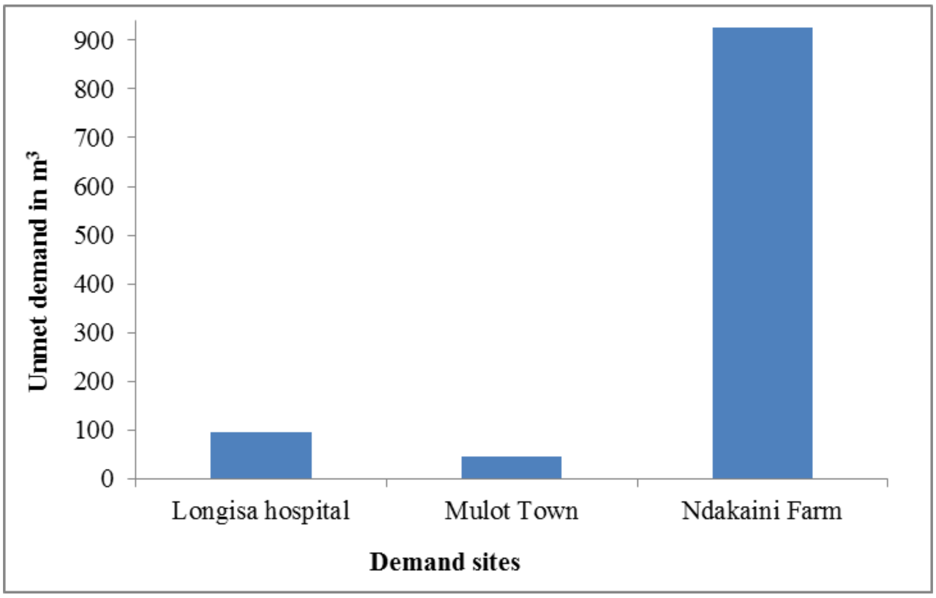


Figure 5.22: Unmet demand in February of 2030 in the Reference Scenario

5.3.2.1.3 Reference Scenario River Water Quality

In the reference scenario, Amala was observed to have the highest level of average dissolved oxygen at 10.27mg/l followed by Nyangores at 8.90 mg/l and Mara River at 7.72 mg/l. Figure 5.23 shows the monthly average DO levels at three gauging stations of the 3 rivers of the upper Mara. Average TSS levels were 45.65 mg/l for Amala, 59.90 mg/l for Nyangores and 62.65 mg/l for Mara. Figure 5.24 shows the monthly average TSS levels for the three rivers while figure 5.25 shows monthly average TDS levels at the 3 gauging stations. These water quality parameters formed the basis for water quality modelling in WEAP.

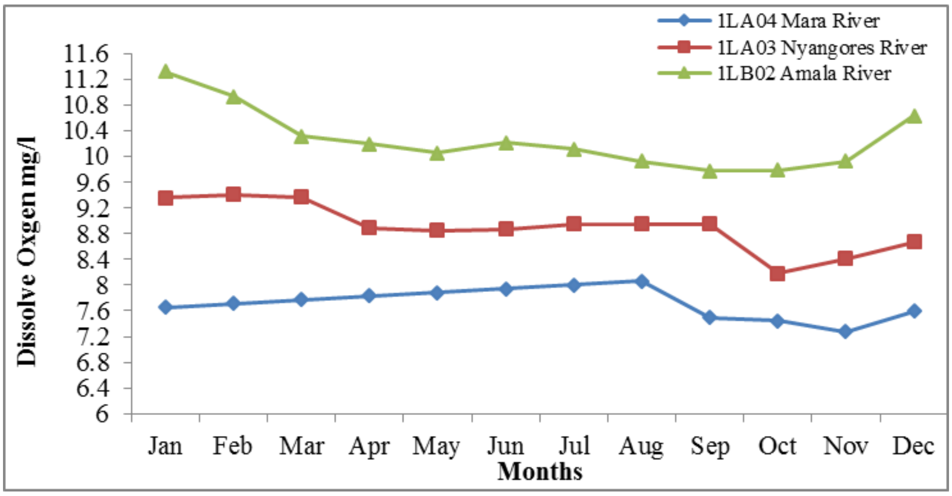


Figure 5.23: Monthly average DO levels at three gauging stations of the 3 rivers for 2012, in the Reference Scenario

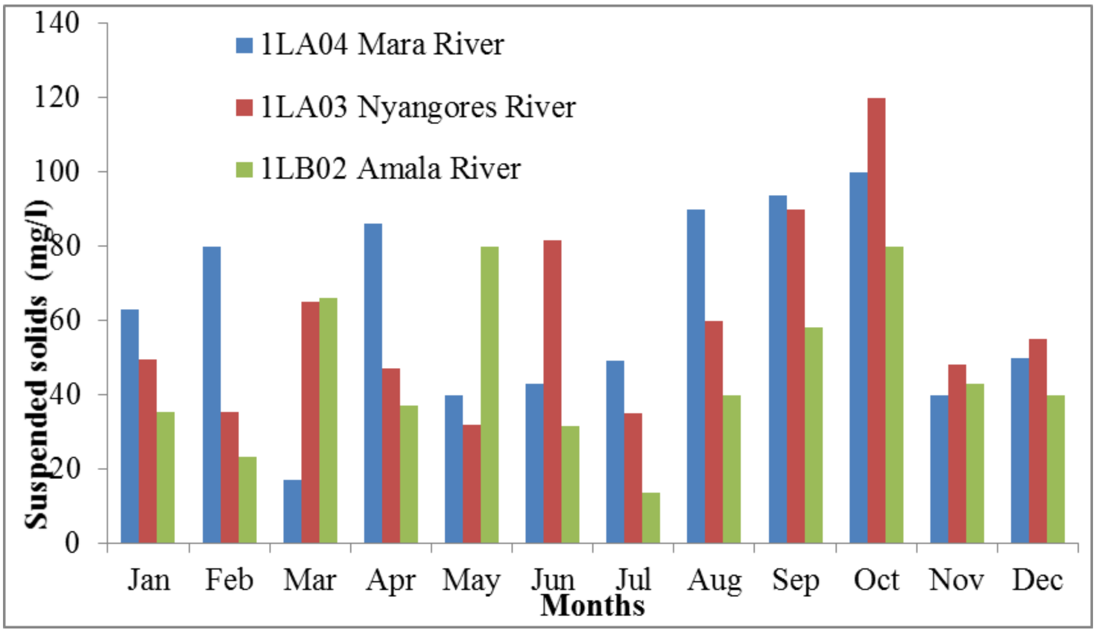


Figure 5.24: Monthly average TSS levels at three gauging stations of the 3 rivers for 2012, in the Reference Scenario

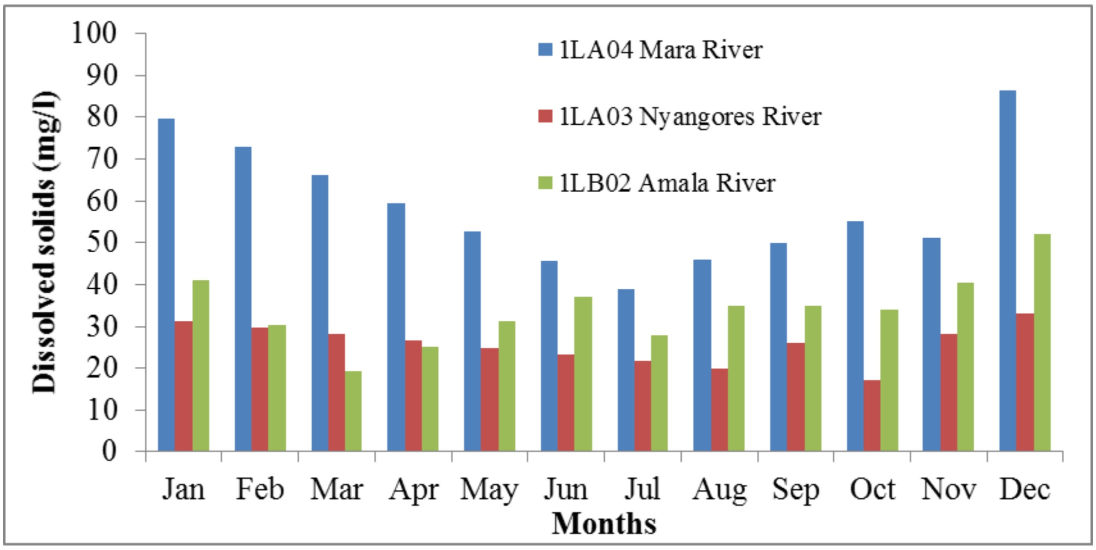


Figure 5.25: Monthly average TDS levels at three gauging stations of the 3 rivers for 2012, in the Reference Scenario

5.3.2.1.4 Reference Scenario Point Source Pollution

Average return flow quality for June 2012 indicated that return flow from Bomet town was causing the highest pollution load into upper Mara river system compared to all the other waste water generating sources such as Tenwek hospital and OLonana Hotel, (Figure 5.26). The BOD_5, TDS and TSS levels for Bomet town return flows were 644mg/l, 1310 mg/l and 1067 mg/l respectively. The return flow quality data formed the basis for waste water treatment and water quality modeling in WEAP.

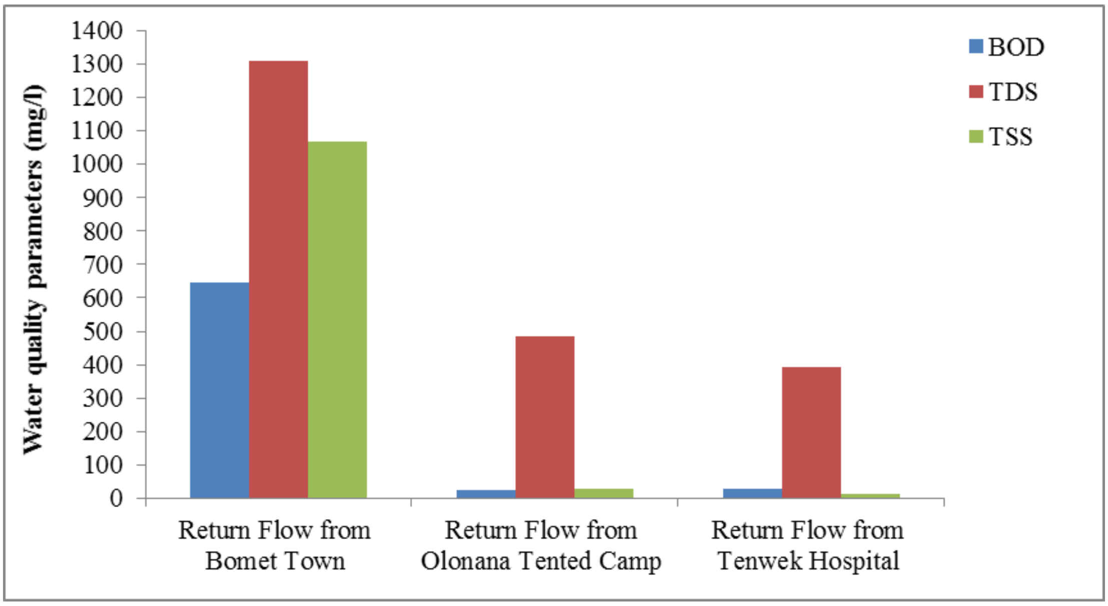


Figure 5.26: Average return flow water quality from various demand sites in June of 2012 in the reference scenario

5.3.2.2 Scenario 2: Demand increases by 10% each year

This scenario assumed that the reference climate and hydrological regime remained unchanged so that the water supply in the upper Mara remained constant but water demand would increase by 10% each year. The growth function of WEAP was used to model the scenario: if demand increased progressively by 10% from the reference year (2012) to the last year of scenario analysis (2030). The demand would probably increase due to higher population growth rate, change of lifestyle by the catchment residents, increase in tourist facilities etc.

In this scenario, the total annual water demand in the upper Mara would increase from 6.24 million cubic metres (MCM) in 2012 to 34.72 MCM by 2030 (Figure 5.27).

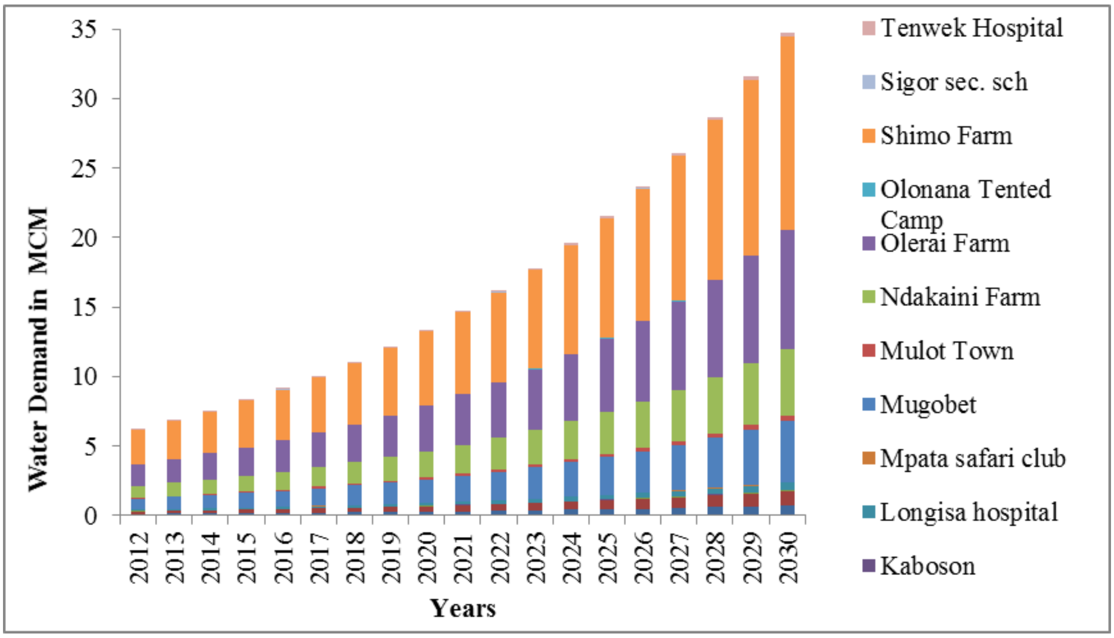


Figure 5.27: Annual water demand (MCM) per demand site in the Upper Mara during the water demand increases by 10% per year scenario

For instance, the annual demand in Bomet town was expected to rise from 0.131 MCM to 0.731 MCM between 2012 and 2030 during in this scenario, at Mulot town the demand would increase from 0.066 MCM to 0.378 MCM and at Tenwek

Hospital the demand would increase from 0.043 MCM to 0.24 MCM in the same period (Figure 5.28).

The model showed that all demand in all the demand sites in the catchment would be met for the modeling period until the year 2017 to the 2030 where Longisa hospital, Mulot town and Ndakaini farm will experience unmet demand. The total annual unmet demand in 2017 for Longisa hospital, Mulot town and Ndakaini farm would be 565.77m^3(0.38% of the required supply), 388m^3 (0.36%) and 5427m^3(0.38%) respectively. This unmet demand would increase to 40474 m^3 (27.54%), 29277m^3 (27.49%) and 387427.41m^3 (27.54%) respectively in the year 2030 (Figure 5.29 and 5.30).

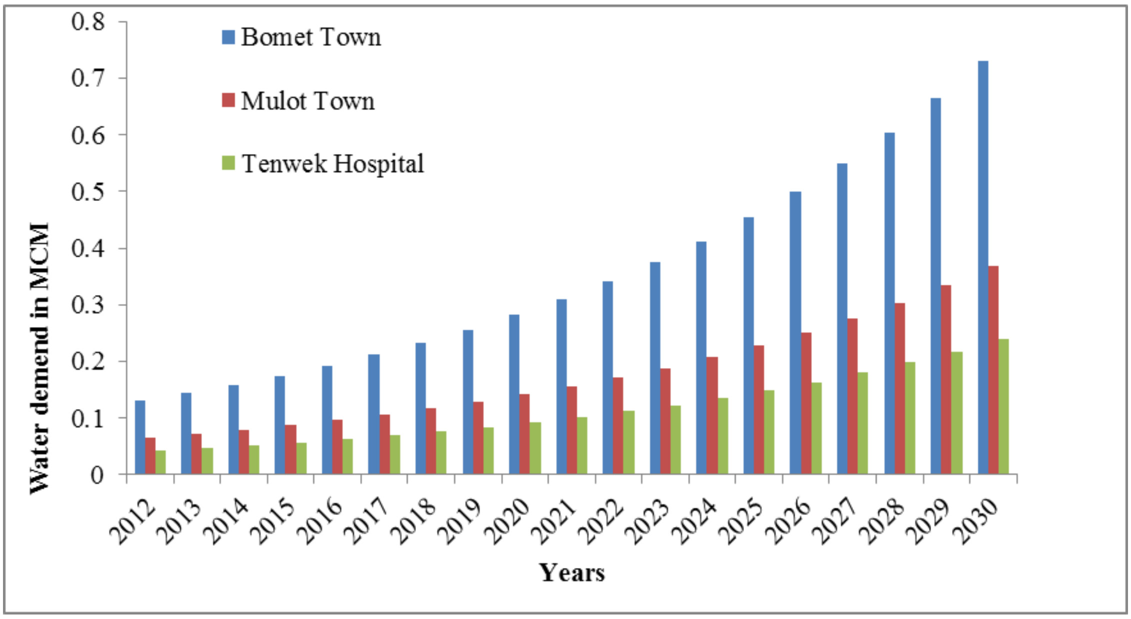


Figure 5.28: Annual water demand at Bomet town, Mulot town and Tenwek hospital demand sites in the water demand increases by 10% per year scenario

Amala river was again observed to be unable to meet the water demand on the three demand sites starting from the year 2017 to 2030 in the scenario demand in the catchment increased by 10% per. Therefore, it was expected that if the total demand in the catchment increased by 10% annually, water supply constrains would start to be experienced by 2017. Careful considerations should be made before further issuance of water abstractions permits especially along Amala River to avoid depleting the river flows to unsustainable levels in the future.

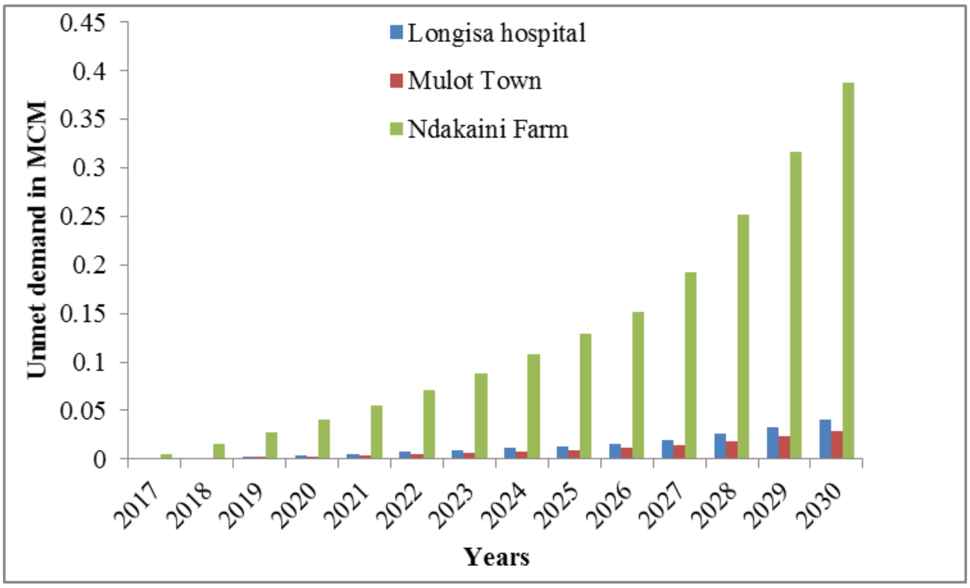


Figure 5.29: Unmet demand between 2017 and 2030 in the water demand increases by 10% per year scenario

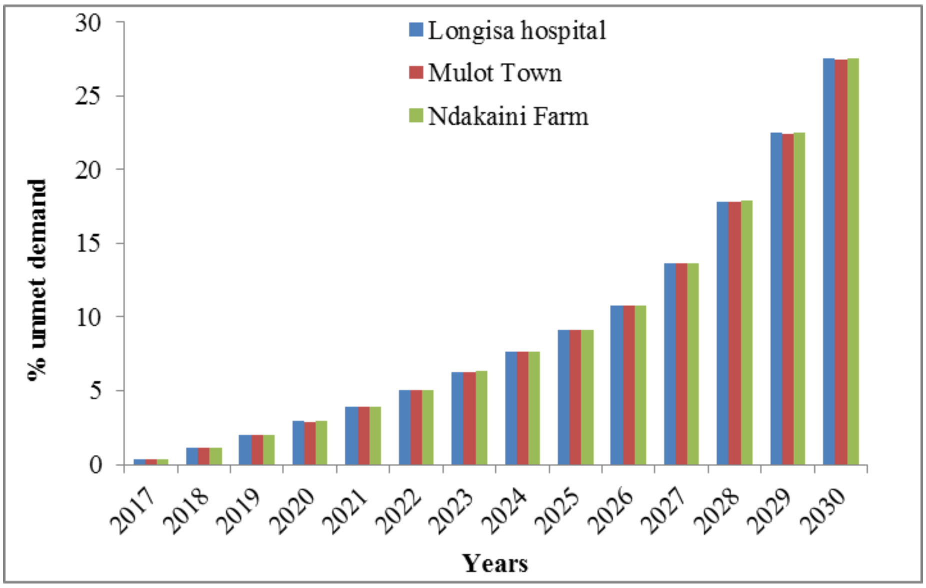


Figure 5.30: % Unmet demand between 2017 and 2030 in the water demand increases by 10% per year scenario

5.3.2.3 Scenario 3: River water flows reduced by 10% per year

This scenario assumed that the reference water demand remained the same but changes in the climate and hydrological regime would reduce river flows by 10% each year. The growth function of WEAP was used to model the scenario: if supply decreased progressively by 10% from the reference year (2012) to the last year of scenario analysis (2030). The river flows would reduce due to climate change or due to destruction of the catchment by deforestation.

In this scenario, the average flow for Amala would reduce from 2.22m^3/s in 2012 to 0.33m^3/s by the year 2030, flows for Nyangores would reduce from 9.46m^3/s to 1.42m^3/s while average flow in Mara river would reduce from 24m^3/s to 3.65m^3/s in the same period (Figure 5.31).

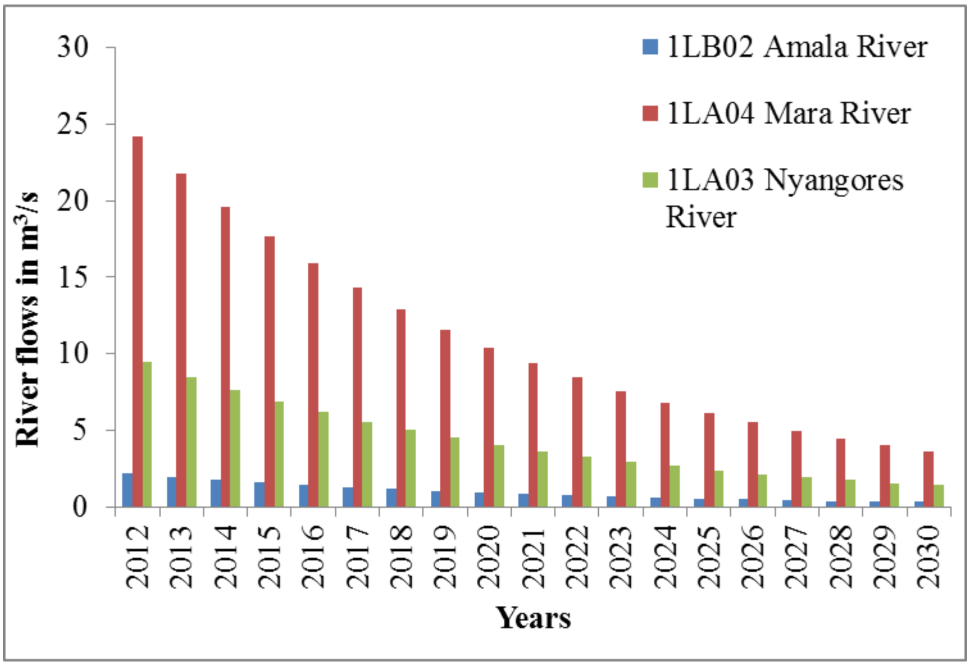


Figure 5.31: Average Annual River flows for Amala, Nyangores and Mara River between 2012 and 2030 in the scenario river flows reduce by 10% annually

The model showed that in this scenario total demand in all the demand sites in the catchment would be met until unmet demand start to be experienced by the year 2016 to 2030. In these years, Longisa hospital, Mulot town and Ndakaini farm would experience unmet demand. The total annual unmet demand in 2016 for Longisa hospital, Mulot town and Ndakaini farm would be 683.51m^3 (0.68%), 486.59m^3 (0.68%) and 6540.95m^3 (0.0.68%) respectively. This unmet demand would increase to 18881.60 m^3 (18.79%), 13664m^3 (18.76%) and 180724.3m^3 (18.79%) respectively by the year 2030 (Figure 5.32 and 5.33).

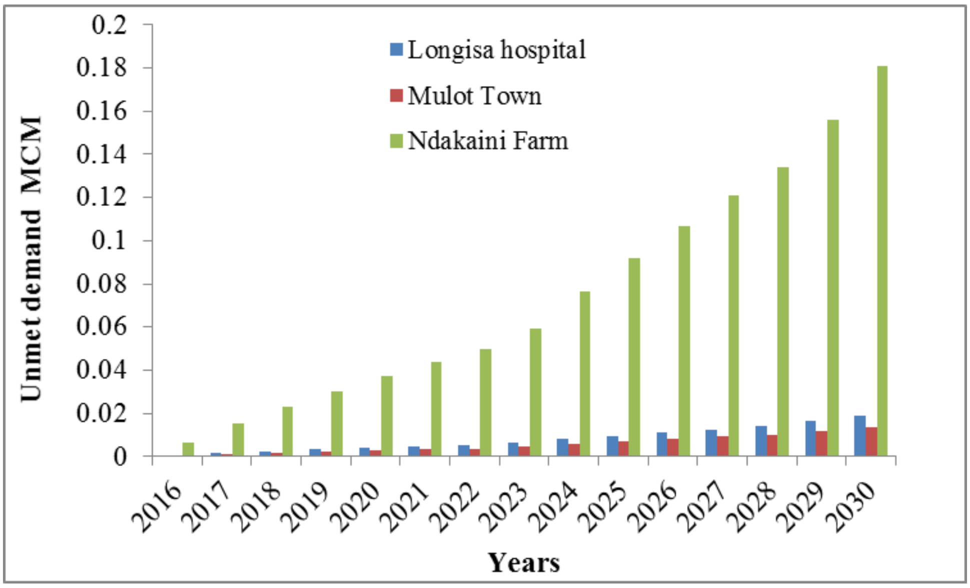


Figure 5.32: Unmet demand between 2016 and 2030 in the River flows reduces by 10% per year scenario

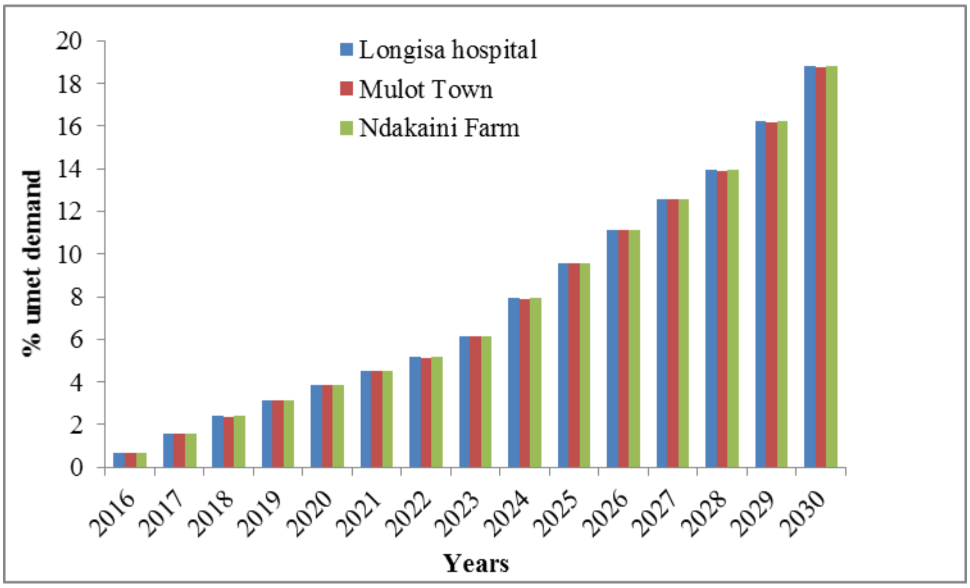


Figure 5.33: % Unmet demand between 2016 and 2030 in the River flows reduces by 10% per year scenario

5.3.2.4 Scenario 4: Bomet Town Wastewater Treatment Plant Added

This scenario represented the effects of wastewater treatment to the water quality of upper Mara Rivers if a three stage; primary, secondary and tertiary stage waste water treatment plant (WWTP) was to be established in Bomet town by the year 2015. The scenario assumed that the plant would be operated to treat the wastewater generated from the town to the Kenya water regulations standards of 2006 (Republic of Kenya, 2006) by removing BOD_5 of the waste water upto 99%. It also assumed that the plant's efficiency would reduce by 10% annually from the year 2016 to the last year of scenario analysis (2030). Waste water treatment plant efficiency would decreases due to pollution load increase from the town, wear and tear of plant equipment or due to poor maintenance of the plant facilities and equipment.

If a waste water treatment plant (WWTP) would be established at Bomet town to treat waste water from Bomet town, the model predicts that it would reduce the BOD_5 of the effluent to Nyangores River from 644mg/l measured in June 2012 to 4.67 mg/l in 2015 (Table 5-17) which is way below the Kenya water quality standards for effluent discharged to the environment of 30mg/l, (Republic of Kenya, 2006). Effluent TDS level would reduce from 1310mg/l to 170.3mg/l, while TSS level would reduce from 1067mg/l to 4.57 mg/l by 2015 and the town would be NEMA compliant in terms of waste water treatment since these levels are below the standard set at 1200mg/l and 30mg/l respectively.

However, if the plant's efficiency would progressively reduce by 10% annually from the year 2016 to the last year of scenario analysis (2030), the quality of the effluent from the plant would progressively reduce up to the year 2030. The model predicts that, the effluent BOD_5 would increase from 4.67mg/l in 2015 to 37.47mg/l by 2030 which is above the set standards. Effluent TDS level would increase from 170.3mg/l to 1387mg/l while TSS level would increase from 4.57 mg/l to 37.35mg/l in the same period (Table 5-17). Therefore if the WWTP would not be operated efficiently, it would release polluting waste water to the river by the year 2030 since these levels are above the standard set at 1200mg/l and 30mg/l for TDS and TSS respectively.

Table 5-17: Effluent quality from Bomet town in various years in the scenario Bomet WWTP is added and its efficiency reduces by 10% from 2016 – 2030

Waste water quality parameter	2012	2015	2030	Standard for effluent discharge
BOD_5 (mg/l)	644	4.67	37.47	30
TDS (mg/l)	1310	170.3	1387	1200
TSS (mg/l)	1067	4.57	37.35	30

Since domestic wastewater (sewage) is the major contributor of organic matter; which lead to a significant reduction in dissolved oxygen in the water during microbial breakdown (APHA, 1992), establishment of an efficient waste water treatment plant would have a positive impact on the water quality of Nyangores River by the year 2015. The average BOD_5 level of Nyangores River below Bomet town would be expected to reduce from 0.31 mg/l in year 2014 to 0.0057mg/l in 2015 (Figure 5.34) but it would be expected to rise 0.02mg/l by 2030 as the efficiency of the treatment work reduces.

As oxygen demand reduces, there would be more oxygen available in the aquatic system thus a better environment for the aquatic organism as indicated by expected dissolved oxygen levels. The average dissolved oxygen level in Nyangores River below Bomet town would increase from 9.766 mg/l in 2014 to 9.803 mg/l by 2015 but progressively reduce to 9.796mg/l by 2030 (Figure 5.35) as the efficiency of the plant decreases

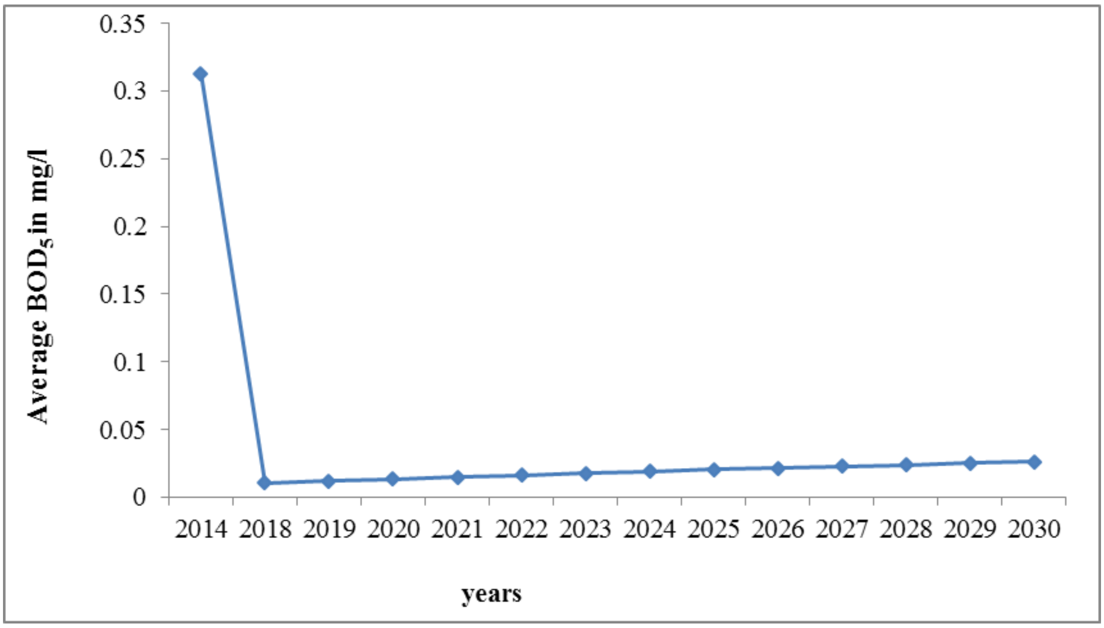


Figure 5.34: Annual Average BOD_5 levels in Nyongores River below Bomet town in the scenario Bomet WWTP is established by 2015

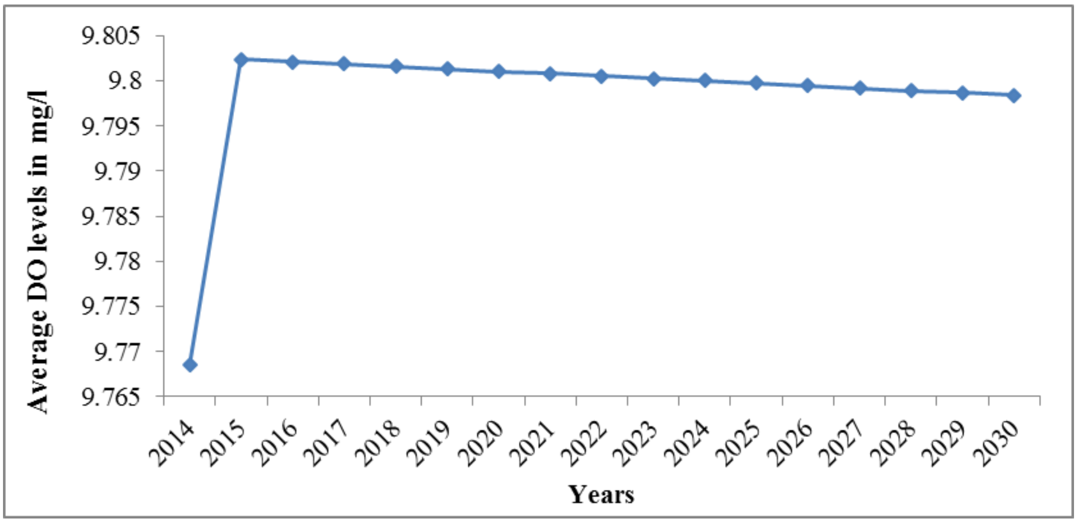


Figure 5.35: Annual average DO levels in Nyongores River below Bomet town in the scenario Bomet WWTP is established by 2015

The effect of treatment plant to the river TDS levels would be as shown in figure 5.36, it would reduce from 26.70mg/l in 2014 to 25.96mg/l in 2015 but progressively increase to 26.87 mg/l by 2030 as the plant efficiency reduces. The river TSS levels below Bomet town would be expected to change as shown in figure 5.37, it would reduce from 60.54mg/l in 2014 to 59.87mg/l in 2015 then progressively increase to 59.88 mg/l by 2030 as the plant efficiency reduces. Therefore, to reduce pollution from Bomet town to Nyangores River an efficient waste water treatment plant should be established in the town soonest possible. Also, efforts to ensure that it operates at high efficiency constantly in years should be made to ensure that all effluent from Bomet town is fully treated before release to the river. This would ensure a sustainable and a favourable aquatic environment in the river below this town.

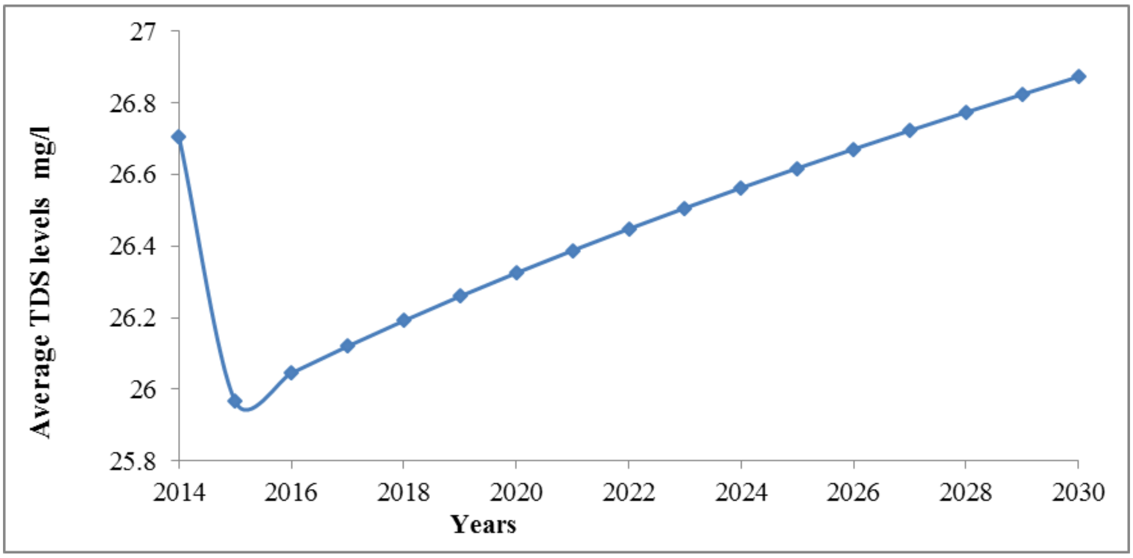


Figure 5.36: Annual average TDS levels in Nyongores River below Bomet town in the scenario Bomet WWTP is established by 2015

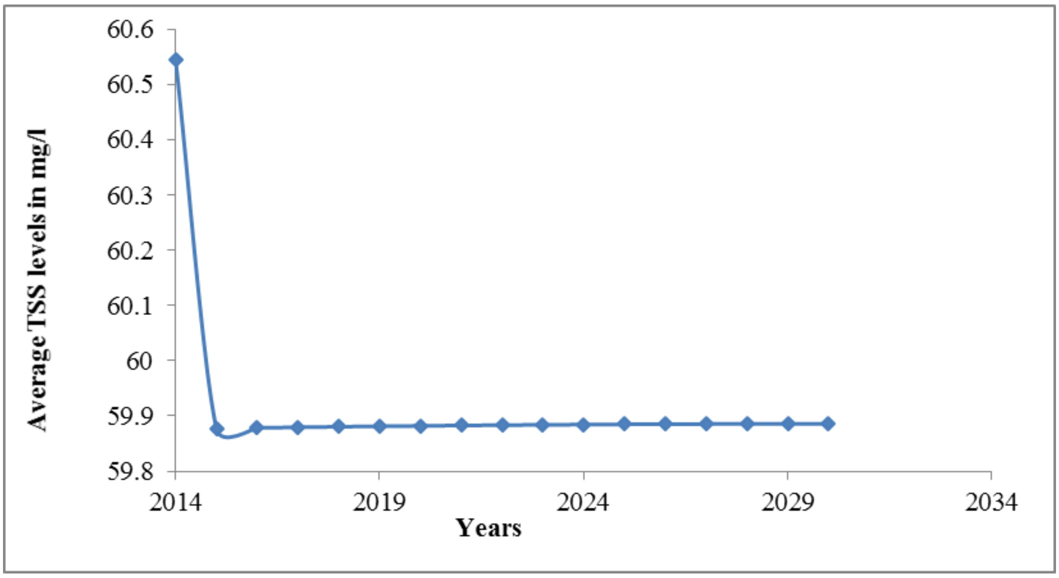


Figure 5.37: Annual average TSS levels in Nyongores river below Bomet town in the scenario Bomet WWTP is established by 2015

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

6.1.1 Water and Sanitation accessibility in the Upper Mara Basin

Majority of the population the upper Mara had poor access to adequate portable water and are therefore vulnerable to using contaminated water from unimproved sources which is detrimental to health. Kirindon division had the poorest access to water, followed by Siongiroi while Elbergon recorded the highest percentage of household with piped water.

Most residents of the basin disposed human waste into pit latrines however, none were connected to a main sewer for human waste disposal and open defecation (OD) was practiced by on average 38% of the households. Mara division recorded the highest percentage of household open defecating followed by Kirindon and Olkurto while Olenguruone recorded the lowest % open defecation.

6.1.2 Impacts of WASH activities to the environment in the Upper Mara

Most of sampled water sources were found unsuitable sources for domestic water sources. While poor access to sanitation services lead to open defecation which caused faecal contamination of open water sources. Waste water from Bomet Municipal stabilization pond, Bomet slaughter house and Kapsimotwa slaughter house was poorly treated thus caused pollution to the environment in the Upper Mara basin.

Most of the solid waste in the upper Mara was disposed by open burning and dumping especially in urban and market centers thus emitting unpleasant odor, blocking drainages, defacing urban habitations and polluting adjacent aquatic systems. Some water supply projects sites were eroded due to overstocked livestock sharing water points with the humans causing degradation of the environment around the water points.

6.1.3 Long term effects of Water Supply and Sanitation Activities

High regression coefficients (r^2) during calibration and validation of WEAP model indicated acceptable model performance in reproducing the stream flow and water quality trends in the upper Mara basin. Therefore, WEAP model could simulate stream flow and water quality dynamics of the study area.

All water demand in the catchment would be met fully until February of 2030 in the reference scenario. In the scenario demand increases by 10% the water supply constrain will start by 2017 and if river flows reduce by 10%, the constraint will start in 2016. In all these scenarios Amala River flows will be inadequate to supply Mulot town, Longisa Hospital and Ndakaini farm.

If a waste water treatment plant (WWTP) would be established at Bomet and to 99% of the BOD_5 in 2015, it would reduce the effluent pollution load from the town to set standards by 2015, and the town would be NEMA compliant in terms of waste water treatment. However, if the plant’s efficiency would progressively reduce by 10% annually from the year 2016 to 2030, it would release polluting waste water to the river by the year 2030. Therefore establishment of an efficient waste water treatment plant would have a positive impact on the water quality of Nyangores River by the year 2015.

6.2 RECOMMENDATIONS

1. Provision of improved water and improved sanitation services should be expanded in the catchment to cover 100% households to reduce their vulnerability to contaminated water and reduce pollution of the environment with feacal matter and *E. Coli*

2. All water points should be protected to avoid contamination and all water supplied should be treated effectively before supply to improve the quality of water supplied from various water points.

3. All effluents in the catchment should be treated effectively before discharging it to the environment. In particular, an efficient waste water treatment should be established at Bomet town immediately to treat waste water from the town and its surrounding. Slaughter house waste water should be treated to standards before discharge to the environment

4. All solid waste generated in the basin should be collected and disposed efficiently to avoid environmental pollution and to destroy breeding grounds for disease vectors and rodents.

5. Overcrowding of livestock at water points should be minimized by providing water to individual farmers or widely distributed water troughs for the pastoral communities to avoid degradation of the sites. Soil conservation should be practiced around water points used by livestock.

6. Alternative sources of water other than abstractions from the rivers such as rainwater harvesting should be explored to avoid over dependence on river water supply by the residents as demand increases with time.

7. Long term effects of the scenarios based on scientifically projected changes in water demand in the Upper Mara, river flows and a designed waste water treatment plant should be modeled sing WEAP

7.0 REFERENCES

ABN. (1999). The Niger Basin Authority Three-Year Action Plan 2000-2002, *ABN, Niger*. Application of Water Evaluation and Planning (WEAP): A Model to Assess Future Water Demands Using WEAP in the Niger River, Niger Republic.

Aboud, A. A., Obweyere, G. O., Mutinda, M. M. and Raini, J. A. (2002). A Rapid Participatory Socioeconomic Assessment of the River Mara Basin. Mara River Catchment Basin Initiative WWW-Eastern Africa. Regional *Programme Office (EARPO).WWF, Nairobi.*

Almasri, M.N. and Hindi, I. (2008). Modeling Wastewater Management Options With a Water Evaluation and Planning Tool (WEAP) for Wadi Nar Watershed, West Bank, Palestine, Twelfth International Water Technology Conference, IWTC12 2008 Alexandria, Egypt

American Public Health Association (APHA). (1992). Standard methods for the examination of water and waste water. 18th Edition American Public Health Association, *American Water Works Association and American Pollution Control Federation, Washington, DC.*

American Public Health Association (APHA). (1998). Standard Methods for the Examination of Water and Wastewater (20th Edition). American Public Health Association, *American Water Works Association, and the Water Environment Federation, Washington, D.C.*

APHA. (1975). Standard Methods for the Examination of Water and Wastewater 14th edition, AWWA & WPCF ISBN 0-87553-078-8 pp.89-98

Arranz, R. and McCartney, M. (2007). Application of the Water Evaluation and Planning (WEAP) model to assess future water demands and resources in the Olifants catchment, South Africa. Colombo, Sri Lanka: International Water Management Institute; pp.103 (IWMI Working Paper 116)

Bashir, H. and Kawo, A. H. (2004). Environmental Pollution: A Case Study of Waste Water Effluent Parameters of Some Industries in Kano, Nigeria. *Biological and Environmental Sciences Journal for the Tropics,* ***1***(1).

Benneh, G., Songsore, J., Nabila, J. S., Amuzu, A. T., Tutu, K. A., Yangyuoru, Y. and McGranahan, G. (1993). Environmental problems and the urban household in the Greater Accra Metropolitan Area (GAMA) – Ghana. *Stockholm Environment Institute.*

Beukerung, P.V., Sehker, M., Gerlagh, R. and Kumar V. (1999). Analysing Urban Waste in Developing Countries: a perspective on Bangalore, India. Working Paper No.24 http://www.wri.org, accessed in April, 2013

Bonnardeaux, D. (2012). Linking Biodiversity Conservation and Water, Sanitation, and Hygiene: Experiences from sub-Saharan Africa

Bosch, C., K. Hommann, G., Rubio, C. S., and Travers L. (2000). Water and Sanitation. Chapter 23 in *A Sourcebook for Poverty Reduction Strategies* (2), pp.371-404, Washington, D.C.: World Bank.

Brillaud, L. Fischer, A., Manning L., Nishikawa J., Escobar M. and Yamaguchi U. E. (2008) Valuating Economic and Social Impacts of Improved Water and Sanitation Services, SIPA WaterAid Madagascar.

Bruijnzeel, L.A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems and Environment*, 104 (1), pp.185-228.

Cheremisinoff, P. N. (2002). "Handbook of Water and Wastewater Treatment Technologies", Butterworth-Heinemann Publications, Woburn, USA

Clarkson, M.B.E. (1995). A stakeholder framework for analyzing and evaluating corporate social performance, *Academy of management review*, 20, pp.92-117.

Davis, R. (1990). EC 90-2502, Perspectives on Nitrates, Chapter 4 - Nitrates, Nitrites and Methemoglobinemia; Lincoln, NE; *University of Nebraska Cooperative Extension*.

Derk K. (2011). A list of global environmental indicators,

Dregne, H. E. (1986). Desertification of arid lands, In *Physics of desertification,* ed. F. El-Baz and M. H. A. Hassan. Dordrecht, The Netherlands: Martinus, Nijhoff.

Dumanski J. (1997). Criteria and indicators for land quality and sustainable land management, *ITC Journal* 1997-3/4.

Dumanski, J., Pettapiece,W.W. and Macgregor, R.J. (1997). Relevance of Scale Dependent Approaches for Integrating Biophysical and Socioeconomic Information and Development of Agroecological Indicators, *Kluwer Acad Publ* (in press).

Economic Commission for Africa. (1996). Urban Environment and Health in ECA Member States, Addis Ababa, *Economic Commission for Africa*.

Edmond, J., Sorto, C., Davidson, S., Sauer, J., Warner, D., Dettman, M. and Platt, J. (2013). Freshwater Conservation and WASH Integration Guidelines: A Framework for Implementation in sub-Saharan Africa. Washington, D.C., USA: Africa Biodiversity Collaborative Group, Conservation International, and the Nature Conservancy

Eisakhani, M., Abdullah M. P., Karim O.A. and Malakahmad A. (2012). Validation of MIKE 11 Model Simulated Data for Biochemical and Chemical Oxygen Demands Transport, *American Journal of Applied Sciences 9* (3): p 382-387, 2012, ISSN 1546-9239

Environment Protection and Heritage Council (EPHC). (2002). Plastic Shopping Bags in Australia. National Plastic Bags Working Group Report to the National Packing Covenant Council, 6 December.

Environmental Protection Agency (EPA). (1998). "National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule," 63 Fed. Reg. 69477–69521.

Fawell, J. (2006). Fluoride in Drinking-water, WHO Drinking-water Quality Series. Geneva: WHO. Available at: www.who.int/water_sanitation_health/publications/fluoride_drinking_water/en/ (Accessed March, 2014)

FDEP. (2013). Health Effects & Standards for Microbiological Contaminants, FDEP

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

Gabrielsen P., and Bosch P. (2003). Environmental Indicators*:* Typology and Use in Reporting. *Prepared by: European Environment Agency, EEA internal* *working paper, Nature and Environment* No. **71**. *Council of Europe Press, Strasbourg*. 99 p.

Gakubia R., Pokorski U. and Onyango P. (2010). Upscaling Access to Sustainable Sanitation – Kenya, International Year of Sanitation (IYS) conference, 26 January 2010, Tokyo, Japan

Gathanju, D. (April 2009). *"Special Report: Human pressures destroying Maasai Mara Wildlife"*. Available at www.peopleand planet.net/…/special-report-human-pressures-destroying masai-mara-wildlife.html (Accessed April, 2014)

Gathenya, M. (2011). Hydrology study to guide development of an Equitable Payment for Watershed Services Scheme in Mara River Basin, final report, submitted to *WWF-Eastern and Southern Africa Regional Programme Office* (WWF-ESARPO).

Gelinas, Y., Randall, H., Robidoux, L. and Schmit, J. P. (1996). Well water survey in two districts of Conakry (Republic of Guinea) and comparison with the piped city water. *Water Resource, 30*(9): 2017-2026.

Gereta, E. J., Chiombola, E. A. T. and Wolanski, E. (2001). Assessment of the Environmental Social and Economic impacts on the Serengeti ecosystem of the development in the Mara River Catchments.

GLOWS. (2007). Water Quality Baseline Assessment Report: Mara River Basin, Kenya-

GLOWS. (2010). *Mara River Flows, Integrated Water Resource Management,* for people and for nature, Tanzania. Global Water for Sustainability Program, Florida International

GLOWS. (2011). *Grassroots Solutions to Transboundary Water Problems*, GLOWS http://glows.fiu.edu/glows/Projects/MaraRiverBasinKenyaTanzania/tabid/77/Default.aspx Accessed, 6th September, 2011

Goldman, C. R. and Horne, A. (1983). Water quality indicators J. *Limnology* (1983) McGraw-Hill ISBN 0-07-023651-8, pp.111

Grillas, P. (1996). Identification of indicators. In *Montitoring Mediterranean wetlands: A methodological guide,* ed P Tomàs Vives, MedWet publication, Wetlands International, Slimbridge, UK and Instituto da Conservacao da Naturez, Lisboa, Portugal.

Halden, R. U. (2010). Plastics and Health Risks. *Annual Review of Public Health, (31)*: 179– 194

Halvorson, H. O and Ziegler N. R. (1933). Application of Statistics to Problems in Bacteriology: I. A Means of Determining Bacterial Population by the Dilution Method, *J. Bacteriol. February 1933 (25):* pp.101-121

Harvey, M. (2010). Managing the Mara River in Kenya and Tanzania, WWF.http://www.equatorinitiative.org/: Accessed on 15th October, 2011.

Helland, J. (1980). Five Essays on the Study of Pastoralists and the Development of Pastoralism, *Occasional Paper No. 20,* Bergen: University of Bergen

Hoffman, C. M. (2007). Geospatial mapping and analysis of water availability-demand-use within the Mara River Basin. Thesis. Florida International University, Miami, FL, USA.

Howard, G. and Bartram, J. (2003). Domestic Water Quantity, Service Level and Health. *World Health Organization*

Howard, G., Ince, M. and Smith M. (2003). Rapid Assessment of Drinking Water Quality: A handbook for implementation (draft). Geneva: UNICEF/WHO/WEDC.

Hudson N. W. (1993). Field measurement of soil erosion and runoff, *Food and Agriculture Organization of the United Nations***,** Rome,

Inanc, B., Kinaci, C., Ozturk, I., Sevimli, M.F., Arikan, O. and Ozturk, M. (1998). Pollution Prevention and Restoration in the Golden Horn of Istanbul. *Water Science and Technology, 37*(8): pp.129-136.

Institute of Economic Affairs (IEA). (2007). A Rapid assessment of Kenya's Water, Sanitation and Sewerage Framework. Institute of Economic Affairs. ISBN: 9966-7183-1-1

Janssen, P.J.C.M., and Knaap, A.G.A.C.. (1989). Integrated Criteria Document Fluorides: Effects. Appendix to report 75847010. Bilthoven, The Netherlands: National Institute of Public Health and Environmental Protection

Jenkins, M., Marques, G., Lelo, F., and Miller, S. (2005). WEAP as a Participatory Tool for Shared Vision Planning in the River Njoro Watershed in Kenya. *Impacts of Global Climate Change*: pp. 1-13. doi: 10.1061/40792(173)510

JMP. (2008). Rapid Assessment of Drinking-Water Quality (RADWQ) Summary Report, Geneva and New York: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP).

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

Kendie, S. (1999). Do attitudes matter? Waste disposal and wetland degradation in the Cape coast municipality of Ghana. Development and project planning center, University of Bradford discussion paper no. 21. Bradford.

Kenya National Bureau of Statistics (KNBS) and ICF Macro. (2006). Kenya Demographic and Health Survey 2004-05. Calverton, Maryland: KNBS and ICF Macro.

Kenya National Bureau of Statistics (KNBS) and ICF Macro. (2010). Kenya Demographic and Health Survey *2008-09*. Calverton, Maryland: KNBS and ICF **Macro.**

Ketibuah, E., Asase M., Yusif S., Mensah, M.Y. and Fischer, K. (2004). "Comparative Analysis of Household Waste in the Cities of Stuttgart and Kumasi-Option for Waste Recycling and Treatment in Kumasi", *Proceedings of the 19th international CODATA Conference*, 1-8.

Kiragu, G. M. (2009). Assessment of suspended sediment loadings and their impact on the environmental flows of Upper transboundary Mara River, Kenya. MSc Thesis, JKUAT.

Klawitter, S., Mutlack, N., and Meran, G. (2007). Waste water treatment management options for the Wadi Nar/Kidron and their characteristics, Discussion paper prepared for the project "From Conflict to Collective Action: Institutional Change & Management Options to Govern Transboundary Watercourses", Technical University, Berlin, Germany.

KNBS, Ministry of Health (MOH) [Kenya] and ORC Macro. (2004). Kenya Demographic and Health Survey 2003: Key Findings. Calverton, Maryland, USA: CBS, MOH and ORC Macro.

La Valle, P. D. (1975). Domestic sources of stream phosphates in urban streams. *Water Resource, 9*: pp.913-15.

Lu D, Li, G., Valladares, GS. and Batistella, M. (2004). Mapping soil erosion risk in Rondonia, Brazillian Amazonia: Using RUSLE, remote sensing and GIS. *Land* ***Degradation and Development*** **15:499-512.**

LVBC & WWF-ESARPO. (2010). Assessing Reserve Flows for the Mara River. Nairobi and Kisumu, Kenya, Lake Victoria Basin Commission of the East African Community and WWF Eastern & Southern Africa Regional Programme Office (WWF-ESARPO).

LVBC. (2008). Assessing Reserve Flows for the Mara River, Kenya and Tanzania, Lake Victoria Basin Commission.

LVBC. (2012). The Trans-Boundary Mara River Basin Strategic Environmental Assessment (Mrb Sea), LVBC, WWF, USAID and the Governments of Tanzania and Kenya

LVBC. (2013). Mara river basin-wide water allocation plan, LVBC.

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

Majule, A. E. (2010). Towards sustainable management of natural resources, in the Mara River basin in Northeast Tanzania. *Journal of Ecology and the Natural Environment*, ***2***(10): pp. 213-224.

Majule, A.E. and Mwalyosi R.B.B. (2005). Enhancing Agricultural Productivity Through Sustainable Irrigation. A case of Vinyungu Farming System in selected Zones of Southern Highland, Tanzania”. In H. Sosovele,J. Boesen and F. Maganga (Ed). Social and Environmental Impacts of Irrigation Farming in Tanzania: Selected Cases;pp. 108-133. *Dares Salaam University Press*. ISBN 9976 60 431 9.

Mango, L. M. (2010). Modeling the Effect of Land Use and Climate Change Scenarios on the Water Flux of the Upper Mara River Flow, Kenya. FIU Electronic Theses and Dissertations. Paper 159. http://digitalcommons.fiu.edu/etd/159 (accessed on 11th October, 2011)

Martin, J. C., Hoggart, C. and Matissa, A. (1998). Improvement Priorities for Sewage Treatment in Latvian Small and Medium Sized Towns. *Water Science and Technology*, *37*(8): pp. 137-144.

Mati, B. M.; Muchiri, J. M.; Njenga, K.; Penning de Vries, F. and Merrey, D. J. (2005). Assessing water availability under pastoral livestock systems in drought-prone Isiolo District, Kenya. *Working Paper 106. Colombo, Sri Lanka: International Water Management Institute (IWMI).*

Mbuya, L.W. (2004). Baseline Study on the Hydrology of the Mara River Basin – The Tanzania Section, WWF-Tz

Meybeck, M. (1998). Man and River interface: Multiple impacts on water and particulates chemistry in Seine River Basin. *Hydrobiologia 37(*4): pp. 1-20.

Michael, N.N., Terry W.S., and Graig L.B. (1988). Anaerobic Contact Pretreatment of Slaughterhouse Wastewater, Proc. Ind Waste 42nd, Conf.,

Miller, C. (2008). Biological Oceanography. 350 Main Street, Malden, MA 02148 USA: *Blackwell Publishing Ltd*. pp. 60–62.

Ministry of public health and sanitation (MOPHS). (2010). Rapid environmental health assessment Bomet district, Ministry of public health and sanitation

Ministry of Water and Irrigation (MOWI). (2010). Water Services, Sanitation, *Annual Water Sector Review 2009*, pp.35–40.

Mitchell, R..K., Agle, B.R. and Wood, D.J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of management review*, 22 (4), pp.853-886.

Mohapatra, P.K. (2009). Environmental Impact of Water and Sanitation Issues, *Journal of Water Supply- Research and Technology – Aqua*, 53 (6), 117-219.

Mohapatra, P.K., Siebel M.A., Gijzen H.J., Van der Hoek J.P., and Groot, C. (2002). Improving ecoefficiency of Amsterdam water supply - a LCA approach. *Journal of Water Supply: Research and Technology – Aqua*, 51 (4), 217-227.

Mounir, Z. M., Ma C. M., Amadou, I. (2011). Assess Future Water Demands in the Niger River (In Niger Republic), *Modern Applied Science 5*, (1), 38-49

Multilevel consultants Kenya limited. (2011). Knowledge, attitude, practice and behaviour (KAPB) baseline survey report, prepared for World Vision – Kenya

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., Mati B., Home P., Gadain H. and Gathenya J. (2006). Evaluating land use change effects on river flow using USGS geospatial stream flow model in Mara river basin, Kenya, proceedings of the 2nd workshop of the

EArsel SIG on land use and land cover, center for remote sensing of land surfaces, Bonn, pp. 28-30

Nataro, J.P. and Kaper J.B. (1998). Diarrhoeagenic Escherichia coli, *Clinical Microbiology Reviews* 11(1): pp.142-201

Navaratne, A., Tomasek T., R and E. (2010). Water and Sanitation Green Recovery and Reconstruction: Training Toolkit for Humanitarian Aid, World Wildlife Fund, Inc. and American National Red Cross.

Nevada Division of Environmental Protection (NDEP). (1994). Truckee river final total maximum daily loads (TMDLs) and waste load allocations (WLAs), Nevada Division of Environmental Protection Bureau of Water Quality Planning

Ngwuluka, N., Ochekpe, N., Odumosu, P. and John, S. A. (2009). Waste management in healthcare establishments within Jos metropolis, Nigeria. *African Journal of Environtal Science and Technology*, ***3***(12): pp. 459–465.

NRC. (1999). Health Effects of Ingested Fluoride, Washington, D.C.: Subcommittee on Health Effects of Ingested Fluoride, National Research Council.

O'Keeffe, J., Piet L., Erik de R., van Steveninck W D., Anne van D., and Peter van der S. (2007). The Environmental Integrity of Water Resources, UNESCO-IHE, Institute for Water Education, Delft, the Netherlands (Includes case study on the Mara Basin).

Ødegaard, H. (1992). Norwegian experiences with chemical treatment of raw wastewater. Water Sci. Technol., 1992, 25(12): pp. 255–264

OECD. (2012). Environmental Insight, Rural Water and Sanitation, OECD

OECD. (1997). OECD Environmental Performance Reviews - A Practical Introduction" OCDE/GD (97)35 Paris 1997.

Onibokun, A. and Kumuyi, A. J. (1999). Ibadan, Nigeria (Chapter 3). In: A.G. Onibokun (Ed.) Managing the Monster: urban waste and governance in Africa. IDRC, pp. 49-100.

Organisation for Economic Development and Co-Operation. (2008). Key Environmental Indicators. OECD Environment Directorate Paris, France.

Pailler, S. and Thompson, P. (2010). Project Design, Monitoring and Evaluation, World Wildlife Fund, Inc. and 2010 American National Red Cross

Pieri, C., Dumanski, J., Hamblin, A.S., and Young, A. (1995). Land Quality Indicators. World Bank discussion paper 315, World Bank, Washington DC.

Poeson, J. (1993). Gully typology and gully control measures in the European belt, Farm Land Erosion: in temperate plains environment and Hills. *Journal of Elsevier Science*.16:pp. 221-239.

Porter, R., Boakye-Yiadom, L., Mafusire, A. and Tsheko, B. O. (1997). The economics of Water and Waste in Three African Capitals. Ashgate Publishing Limited, England.

Prennushi, G., Rubio G., and Subbarao K. (2000). Monitoring and Evaluation. Chapter 3 in *A Sourcebook for Poverty reduction Strategies* (1), pp.105-130, Washington, D.C.: World Bank.

Prüss, A., Kay, D., Fewtrell, L. and Bartram, J. (2002). Estimating the burden of disease from water, sanitation and hygiene at the global level. *Env. Health Perspectives* 110: pp. 537-42

Prüss-Üstün A, Bos R, Gore F, and Bartram J. (2008). Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. World Health Organization, Geneva,

Prüss-Üstün, A. and Corvalán, C. (2006). Preventing disease through healthy environments: toward an estimate of the environmental burden of disease. Geneva: The World Health Organization.

Republic of Kenya. (2006). Kenya gazette supplement no 6829th september, 2006 (legislative supplement no. 36) legal notice no. 120 environmental management and coordination (water quality) regulations, 2006 arrangement of regulations.

Republic of Kenya. (2010). 2009 Kenya population and Housing Census.

Ronald, E.W and Raymond, H.M. (1989). Probability and Statistics for Engineers and Scientists, Fourth Edition.

Rottier, E. and Ince M. (2003). Controlling and Preventing Disease: The role of water and environmental sanitation interventions. Loughborough: WEDC. Available at: www.lboro.ac.uk/wedc/publications/cpd.htm; Accessed, April, 2014.

Rykiel, E.J., Jr. (1996). Testing ecological models: the meaning of validation. *Ecological Modeling*, *90*:pp. 229-244.

Sandford, S. (1983). Organisation and management of water supplies in tropical Africa, The International Livestock Centre for Africa (ILCA), Addis Ababa Ethiopia

Sansalone, J.J. Koran J., Buchberger S.G., and Smithson J. (1998). “Physical Characteristics of Highway Solids Transported During Rainfall”, *J. of Environmental Engineering, 124* (5), pp. 427-440

Sarairah, A. and Jamrah, A. (2008). Characterization and Assessment of Treatability of Wastewater Generated in Amman Slaughterhouse, *Dirasat Engineering Sciences, 35 (*2), p. 71

Semerjian, L and Ayoub G M. (2003). High-pH-magnesium coagulation-flocculation in wastewater treatment. *Advances in Environmental Research*, 2003, *7*(2): pp. 389–403

Sidneit, M. T., Fakio, A. L. T., Maria, C. R., Francises, A. E. and Adaunto, F. (1992). Seasonal variation of some limnological factors of Lagoa do Guarana, a varzea lake of the Rio Parana State of Mato Groso do Sul, Brazil. *Review of Hydrobiology, 25*: pp. 269-276.

Sieber, J. and Purkey, D. (2011). Water Evaluation and Planning System user guide, developed at Stockholm Environment Institute, USA.

Singh, B. (2005). Harmful effect of plastic in animals. *The Indian Cow* Oct-Dec: 10–17.

Smyth, A. J. and Dumanski, J. (1993). International Framework for Evaluating Sustainable Land Management. *World Soil Resources Rep* 73, FAO, Rome.

Speece, R.E. (1999) Anaerobic Biotechnology for Industrial Wastewater Treatment, Water Science Tech., *23*, pp. 1259-1264.

Tchobanoglous, G. & Kreith, F. (2002). "Handbook of Solid Waste Management", The McGraw-Hill Companies, USA.

Tchobanoglous, M., Mannarino, F. L., and Stensel, H. D. (2003). Wastewater Engineering (Treatment Disposal Reuse) / Metcalf & Eddy, Inc, 4th Edition, McGraw-Hill Book Company, ISBN 0-07-041878-0

Tharannum, S., Sunitha S., Nithya, J., Chandini, M., Vanitha, J., Manjula, T.S., Shyam and S. C. (2009). Molecular confirmation of the presence of coliforms in drinking water using polymerase chain reaction, Kathmandu university journal of science, engineering and technology; *5* (ii), September, 2009, pp 130-136

The World Bank. (2006). A Guide to Water and Sanitation Sector Impact Evaluations, World Bank

Thubu, J. (2010). Use of WEAP for Developing a Sustainable Water Use Plan: Case Study of Ruiru-Ndarugu Basin, Kenya. Thesis for Master of Science in civil Engineering, Jomo Kenyatta University of Agriculture and technology

UN Water. (2010). Climate Change Adaptation: The Pivotal Role of Water. http://www.unwater.org/downloads/unw_ccpol_web.pdf: Accessed March, 2014

UN. (2013). International Year of fresh water, UN

UNICEF. (2013). UNICEF Water, Sanitation and Hygiene Annual Report 2012, UNICEF

United Nations Environment Programme. (1999). Global Environment Outlook - 2000. United Nations Environment Programme. Earthscan Publications, London. Available at: http://www.unep.org/geo2000: Acessed, April 2014

United Nations of human settlement (UN Habitat). (1987). Water supply and waste management impact evaluation guidelines, UN-Habitat

United States Environmental Protection Agency (USEPA). (2002). Method 1604: Total coliforms and *Escherichia coli* in water by membrane filtration using a simultaneous detection technique (MI medium). Publication EPA-821-R-02-024. USEPA Office of Water (4303T), Washington, D.C..

USAID. (2013). Sector environmental guidelines, water supply and sanitation, USIAD

Vince, F., Aoustin, E., Bréant, P., and Marechal, F. (2008). LCA tool for the environmental evaluation of potable water production. *Desalination*, 220, 37–56.

Wagener, S. M. and LaPerriere, J. D. (1985). Effects of placer mining on the invertebrate communities of interior Alaska streams. *Freshwater Invertebrate Biology*. ***4***: 208-214.

Walter, R.H., Shermah R.M. and Downing D.L. (1974). Reduction in Oxygen demand of abattoir effluent by Precipitation with metal. J. Agric. Fd Chem. *22*, pp. 1097-1099

Walter, E. (2013). Water, Sanitation and Hygiene: A Global Crisis with Real Solutions. Washington, DC: WASH Advocates

Wamalwa, I.W. (2009). Prospects and limitations of integrated watershed management in kenya: a case study of Mara watershed. Master of Science thesis, Lund university international Masters programme in environmental studies and sustainability science, SWEDEN

Warner, D. B. (2000). Water and Food-Aid in Environmentally Sustainable Development, an Environmental Study of Potable Water and Sanitation

Activities within the Title II Program in Ethiopia, U.S. Agency for International Development

Warner, D. B., and Abate C. G. (2005). Guidelines for the development of small-scale rural water supply and sanitation projects in East Africa, Catholic Relief Service.

WASH Advocates. (2010). the post 2015 water thematic consultation- water, sanitation and hygiene. WASH Advocates 1506 21st Street NW, Suite 200 Washington DC 20036 | 202-293-4002 |Available at: info@WASHadvocates.org : Accessed April 2014

Water Resource Management Authority- Regional Office (WRMA-RO). (2011). Nyangores water resource users association sub-catchment management plan (SCMP), Lake Victoria basin WARMA Regional office.

Water Resources and Energy Management (WREM) International Inc. (2008). Mara River Basin Monograph, Mara River Basin Transboundary Integrated Water Resources Management and Development Project, Final Technical Report, Atlanta, p. 446"

Waterloo inc. (2011). Visual MODFLOW Premium Demo Tutorial Includes New Features of Visual MODFLOW and a Step-by-Step Tutorial

Wetherell, I. (2003). "Rubbish piling up". *Zimbabwe Independent* (Harare), March 28th, 2003.

Wetlands International. (2010), Wetlands & Water, Sanitation and Hygiene (WASH)- understanding the linkages. *Wetlands International*, Ede, The Netherlands.

WHO (World Health Organization). (2000). Global Water Supply and Sanitation Assessment 2000 Report. New York: World Health Organization and United Nations Children's Fund.

WHO and UNICEF. (2004). Meeting the MDG Drinking Water and Sanitation Target: A mid-term assessment of progress. World Health Organization, Geneva, and UNICEF, New York

WHO. (2013). Top 10 Causes of Death. Available at: www.WHO.org/top, accessed, April 2014

World Wildlife Fund, Kenya. (2009). Report on proceedings of Meeting with Camp and lodge managers within and around Mara Triangle on waste water management. Held at Olonana Tented Camp Maasai Mara Game Reserve On 11th June 2009.

WWF-KENYA. (2010). Fairer access to water through the Mara River Water Users Association. http://weekly.farmradio.org/2010/10/25/kenya-fairer-access-to-water-through-the-mara-river-water-users-association-wwf-kenya/ (accessed, 15 July, 2011).

Xiaochang, W., Pengkang, J., Hongmei, Z. MENG Lingba, M. (2007). Classification of contaminants and treatability evaluation of domestic wastewater, *Environ. Sci. Engin*. China 2007, 1(1): 57–62 DOI 10.1007/s11783-007-0011-7

Yates, D., Sieber, H. H., Purkey, D. and Huber-Lee, A. (2005). WEAP21 a demand-, priority-, and preference-driven water planning model: Part 1, Model characteristics. *Water International* 30; pp. 487-500.

Young, A. (1989). Agroforestry for soil conservation, CAB International, Wallingford, UK

8.0 APPENDICES

APPENDIX 1: WASH STAKEHOLDERS IN THE UPPER MARA AND THEIR ROLES

WASH Stakeholder	Role
Mara River Water Users Association (MRWUA)	Representative of the community's interests, and acts as agent of change and awareness creation, also implements WASH activities in the catchment using donated funds
Global water for sustainability (GLOWS)	Funds WASH activities in the catchment through MRWUA, World Vision Kenya, Kirindon office and Care Tanzania at Musoma
Ministry of Public health and Sanitation (MOPHS)	Monitoring WASH accessibility and coverage, Implementing priority interventions in public health, Sensitization public training in disease prevention and detection, public health, investigation, research and control
Ministry of Water and Irrigation (MOWI) District offices	Management and implementation of water supply projects and policies
National Environmental Management Authority (NEMA)	Responsible for overall coordination of matters with regard to environment in Kenya, in terms of pollution control, assessment, audit and conservation

Non-Governmental Organizations eg. WWF, World vision Kenya, Free the children and Water line.	Funding and implementing WASH activities, community capacity building and awareness creation, environmental conservation and management
County councils Bomet, Narok and Transmara	Responsible with provision public water and sanitation in their respective counties
Municipal councils of Bomet, and Transmara	Responsible with provision public water and sanitation in their respective municipalities
Water Resources Management Authority (WARMA)	Water resources development Coordination, catchment management, Allocation of water supply, water quality and quantity monitoring in the basin
Hoteliers: Olonana hotel, Mpata Safari lodge, Fairmont Mara safari Club	Water supply, waste water and solid waste management in their respective hotels
KTDA tea factories: Kaptagich, Kapkoros and Tirgaga	Water supply, waste water and solid waste management in the tea factories

APPENDIX 2: AN INVENTORY OF WATER SUPPLY PROJECTS IN THE UPPER MARA, THEIR DEVELOPERS, LOCATIONS AND CONDITIONS

Developer	Water project	Lat.	Long.	Type	Source covered	Stagnant water around	Overgrown with aquatic plants
Bomet teachers sacco	Bomet t sacco	-0.7843	35.3389	Borehole	Yes	No	No
Fairmont Mara safari	Fairmont Mara safari	-1.0924	35.20633	Piped water supply	Yes	No	No
KTDA	Kapkoros	-0.6686	35.3167	Piped water supply	Yes	No	No
	Kiptagich ktda factory	-0.60661	35.58722	Piped water supply	Yes	No	No
	Tirgaga tea factory ws	-0.71477	35.36632	Piped water supply	Yes	No	No

World Gospel Mission	Kaboson gospel mission	-1	35.2608	Piped water supply	Yes	No	No
	Tenwek hospital	-0.7455	35.3646	Piped water supply	Yes	No	No
Moneal	Emarti wp	-1.0484	35.1966	Water pan	No	Yes	No
	Kirindon wp	-1.1476	35.0639	Water pan	No	No	Yes
MOWI	Bomet ws	-0.7896	35.3451	Piped water supply	Yes	Yes	No
	Chepalungu ws	-0.8540	35.2780	Piped water supply	Yes	Yes	No
	Kiploky ss	-0.7455	35.3243	Borehole	Yes	No	No
	Longisa cwp intake	-0.9063	35.4253	Piped water supply	No	No	No
	Longisa	-0.8610	35.3902	Piped water	Yes	No	No

	hospital			supply			
	Mugobet ws	-0.7306	35.3471	Piped water supply	Yes	No	No
	Mulot secondary school	-0.90239	35.4232	Piped water supply	Yes	No	No
	Sergutiet	-0.6629	35.3248	Piped water supply	Yes	No	No
	Sigor mk	-0.9193	35.2995	Piped water supply	Yes	No	No
	Sigor sec school	-0.91333	35.26865	Piped water supply	Yes	No	No
	Ildugisho	-1.5506	35.5907	Water pan	No	No	Yes
	Embole naibor	-1.2921	35.4895	Water pan	No	No	Yes

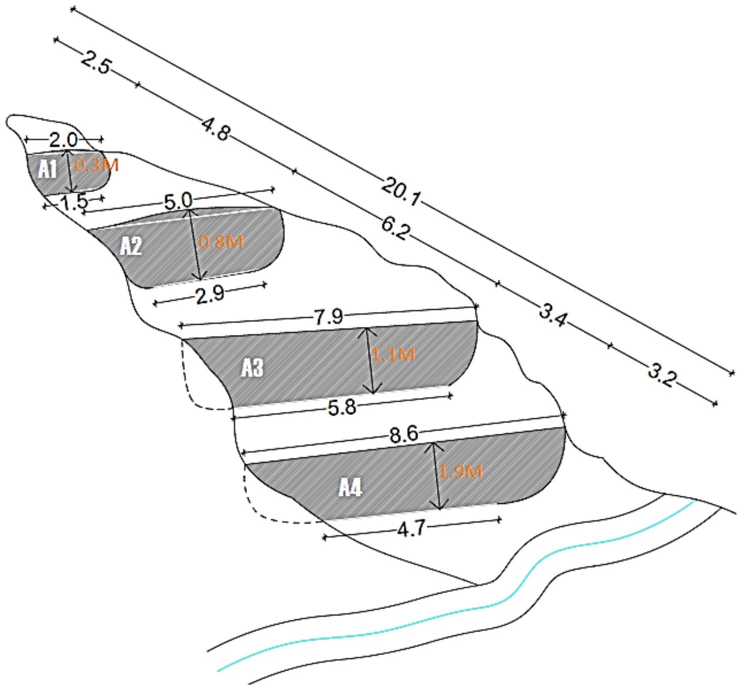
	Oldonyo narasha	-1.2599	34.4995	Water pan	No	No	Yes
	Lemek sp	-1.09738	35.38535	Protected spring	Yes	No	No
	Olmusereji	-1.07131	35.45771	Protected spring	No	Yes	No
	Lemek	-1.0465	35.1872	Borehole	Yes	No	No
	Ngosuan	-1.1362	35.3248	Borehole	Yes	No	No
	Oloomirani sec. School			Piped water supply	Yes	No	No
	Ndaraweta sec. Schoo			Piped water supply	Yes	No	No
	Siongiroi water projec			Piped water supply	Yes	No	No

	Kaboson sec sch.			Piped water supply	Yes	No	No
Mpata safari	Mpata safari club	-1.09104	35.20393	Piped water supply	Yes	No	No
MRWUA	Dikirr wp	-1.0144	35.1015	Water pan	No	Yes	Yes
	Kapcheluch community ws	-0.70176	35.38726	Piped water supply	Yes	No	No
	Mara wrua	-0.94327	35.42424	Piped water supply	Yes	No	No
	Olbobo rwh	-0.9348	35.3999	Roof catchment	Yes	No	No
	Tumoi community ws	-0.89265	35.2698	Piped water supply	Yes	No	No
	Longisa sp	-0.8600	35.3952	Protected	No	Yes	Yes

				spring			
	Oljoro sp	-0.9044	35.4641	Protected spring	No	No	Yes
	Simotwet ps	-0.9390	35.4165	Roof catchment	Yes	Yes	No
	Tilimiet sp	-0.7361	35.3347	Protected spring	No	No	No
	Tilomwet sp	-0.8831	35.3701	Protected spring	No	Yes	Yes
	Aoonet community ws			Piped water supply	Yes	No	No
Olonana hotel	Olonana tented camp	-1.2227	35.0371	Piped water supply	Yes	No	No
Waterline ngo	Aisaik ps	-0.7213	35.3450	Roof	Yes	Yes	No

				catchment			
WVK, kirindon	Kabolecho rwh	-0.9824	35.1483	Roof catchment	Yes	Yes	No
	Kingsir wp	-1.2025	35.0228	Water pan	No	Yes	No
	Kipsilat b/h	-1.0541	35.1658	Borehole	Yes	No	No
	Kirok b/h	-1.0465	35.1872	Borehole	Yes	No	No
	Kurito wp	-1.1588	35.9769	Water pan	No	No	No
	Pusanki rwh	-1.1691	34.9686	Roof catchment	Yes	Yes	No

APPENDIX 3: GULLY EROSION MEASUREMENTS



A representation of the gully at the Tilimiet protected spring

Soil erosion estimation at Tilimiet protected spring

$$\sum\left(\frac{0+0.53}{2}*2.5\right)+\left(\frac{0.53+3.16}{2}*4.8\right)+\left(\frac{3.16+7.54}{2}*6.2\right)+\left(\frac{7.54+12.64}{2}*3.4\right)+\left(\frac{12.64+0}{2}*3.2\right)=186.5m^3$$

APPENDIX 4: PERMITTED WATER ABSTRACTIONS AND PERMITTED AMOUNTS IN THE UPPER MARA

Station_Name	**lat**	**lon**	**Source**	**Amount (m^3/day)**	**Purpose**
Bomet WS	-0.78988	35.34664	Nyangores	360.00	Public
Chepalungu	-0.98635	35.27785	Nyangores	981.00	Public
Kaboson Gospel Mission	-1	35.2608	Nyangores	445.50	Domestic
Kaboson Irrigation scheme - Bomet CC	-0.98267	35.25544	Nyangores	3300.00	Irrigation
Kapcheluch Community WS	-0.70176	35.38726	Nyangores	70.5	Domestic
Kiptagich KTDA factory	-0.60661	35.58722	Nyangores	200	Industrial
Longisa Community WS	-0.90619	35.42526	Amala	416.7	Domestic
Mara WRUA	-0.94327	35.42424	Amala	524.10	Irrigation
Mogombet WS	-0.73299	35.3602	Nyangores	1300.00	Public
Mpata Safari Club	-1.09104	35.20393	Mara	23.46	Domestic
Mulot Secondary School	-0.90239	35.4232	Amala	22.95	Domestic
Mulot WS	-0.093364	35.42813	Amala	181.74	Public
Ndakaini Farm Ltd	-0.94928	35.41	Amala	2000.00	Irrigation
Ndakini Farm Ltd	-0.94928	35.41	Amala	22272.72	Irrigation
Olerai Ltd	-1.06804	35.23223	Mara	2363.60	Irrigation
Olerai Ltd	-1.06804	35.23223	Mara	4.55	Domestic
Olerai Ltd	-1.06875	35.23256	Mara	1818.18	Irrigation

Olerai Ltd	-1.06875	35.23256	Mara	11.50	Domestic
Olonana Tented Camp	-1.2227	35.03719	Mara	14	Domestic
Shimo Ltd	-1.04678	35.23944	Mara	387.13	Irrigation
Shimo Ltd	-1.04678	35.23944	Amala	1818	Irrigation
Sigor Sec School	-0.91333	35.26865	Nyangores	45.91	Domestic
Tenwek Hospital WS	-0.74445	35.3637	Nyangores	118.18	Domestic
Tirgaga Tea Factory WS	-0.71477	35.36632	Nyangores	88.00	Domestic/Industrial
Tumoi Community WS	-0.89265	35.2698	Nyangores	2228.00	Domestic
Fairmont Mara Safari club	-1.0924	35.20633	Mara	40.25	Domestic
Nyangores forest station			Nyangores	40.09	Domestic/Irrigation
longisa town and hospital			Amala	250	Domestic
oloomirani sec. School			Amala	45.9	Domestic
Joseph Ngetich			Nyangores	45	Aquaculture
stanley sang			Nyangores	6.8	Domestic/Industrial
ndaraweta sec. Schoo			Nyangores	23.04	Domestic
leonard kemei			Nyangores	2.7	Domestic
aoonet community S. H. G			Nyangores	283.5	Domestic
siongiroi water project			Nyangores	76.5	Domestic
Isaac Ruto			Mara	315	Irrigation
Kaboson sec sch.			Nyangores	19.35	Domestic

APPENDIX 5: SAMPLED WATER POINTS, THEIR QUALITY AND REMARKS

Water Source	Nitrates mg/l	Fluoride mg/l	TSS mg/l	Coliforms	Coliform count	*E. Colli* count	Remarks	Livestock-human shared	Eroded	Division	% open defication
Bomet T Sacco	1.9	2.3	5	present	nil/100ml	nil/100ml	unsuitable	NO	NO	Bomet Central	3%
Kiploky	1.6	1.16	4	absent	nil/100ml	nil/100ml	suitable	NO	NO	Bomet Central	3%
Kipsilat	1.3	2.23	4	absent	nil/100ml	nil/100ml	unsuitable	NO	NO	Kirindon	81%
Kirok B/H	0.9	0.31	3	absent	nil/100ml	nil/100ml	suitable	NO	NO	Kirindon	81%
Lemek Bh	1.3	1.87	7	absent	nil/100ml	nil/100ml	unsuitable	NO	NO	Mara	84%
Ngosuan	1.7	1.57	11		nil/100ml	nil/100ml	unsuitable	NO	NO	Mara	84%
Amala At Mulot Mk	8	0.14	88	present	1800+/100ml	170/100ml	unsuitable			Mulot	24%
Amalo	0.9	0.55	16	absent	nil/100ml	nil/100ml	suitable			Olenguru one	2%
Cheptwetch	1.0	0.77	36	absent	nil/100ml	nil/100ml	unsuitable			Olenguru one	2%
Ilmolelian	2.8	1	64	present	35/100ml	11/100ml	unsuitable			Olkurto	50%
Kipsinoi	2.0	0.95	36	absent	nil/100m	nil/100m	unsuitable			Keringet	4%

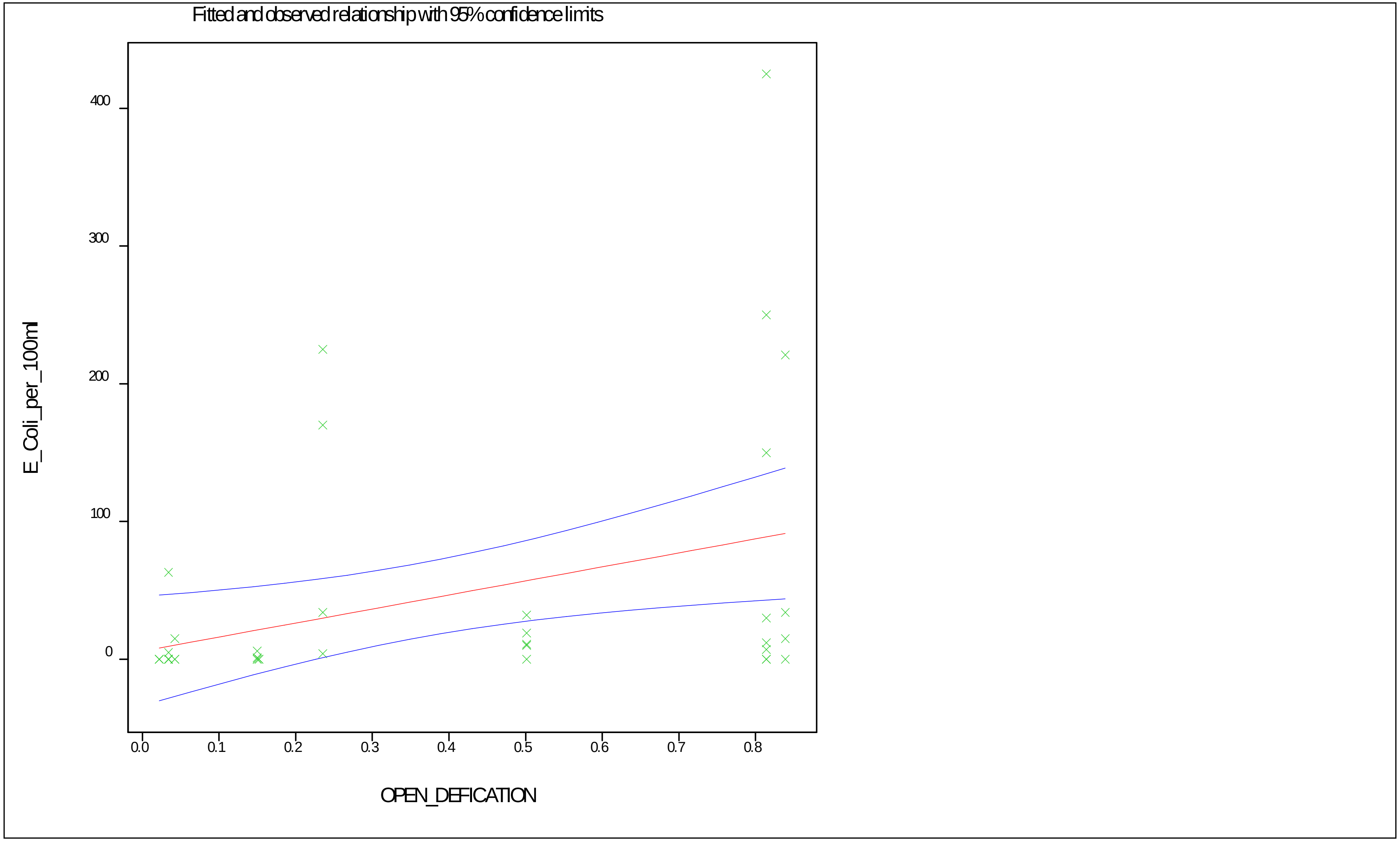
					l	l					
Mara River	6.4	0.76	65	present	1800+/100ml	250/100ml	unsuitable			Kirindon	81%
Mukuki	4.8	0.65	50		56/100ml	nil/100ml	unsuitable			Keringet	4%
Nyangores At Bomet Bridge	10.6	0.95	108	present	1800+/100ml	63/100ml	unsuitable			Bomet Central	3%
Tinet	2.3	0.56	23		13/100ml	15/100ml	unsuitable			Keringet	4%
Bomet	6.1	0.73	13	absent	nil/100ml	nil/100ml	unsuitable	NO	NO	Bomet Central	3%
Chepalungu	6.3	0.24	39	absent	nil/100ml	nil/100ml	unsuitable	NO	NO	Sigor	15%
Kapkoros	2.3	0.68	10	absent	nil/100ml	nil/100ml	suitable	NO	NO	Bomet Central	3%
Longisa Cwp Intake	6.3	0.69	60	present	1800+/100ml	1800+/100ml	unsuitable	YES	NO	Longisa	15%
Longisa Hospital	3.1	1.1	2	present	35/100ml	6/100ml	unsuitable	NO	NO	Longisa	15%
Mugobet	5.7	0.07	78	present	1800+/100ml	nil/100ml	unsuitable	NO	NO	Bomet Central	3%
Sergutiet	1.2	0.92	22		13/100ml	5/100ml	unsuitable	YES	NO	Bomet Central	3%
Sigor	1.2	0.4	1		nil/100ml	nil/100ml	suitable	NO	NO	Sigor	15%
Tenwek Hospital	2.5	0.89	2	absent	nil/100ml	nil/100ml	suitable	NO	NO	Bomet Central	3%
Chebinyinyi	22.8	0.97	94	absent	45/100ml	34/100ml	unsuitable	YES	YES	Mulot	24%

Kiptaragon	3.5	0.45	14	absent	nil/100ml	nil/100ml	suitable	NO	NO	Olenguruone	2%
Lemek Ps	5.2	0.55	7	present	36/100ml	10/100ml	unsuitable	NO	NO	Ololunga	50%
Longisa Ps	12.1	1.92	21	absent	nil/100	nil/100	unsuitable	NO	NO	Longisa	15%
Oljoro	2.5	1.82	25	present	1800+/100ml	225/100ml	unsuitable	YES	YES	Mulot	24%
Olmusereji	6	0.54	88	present	29/100ml	19/100ml	unsuitable	YES	NO	Ololunga	50%
Simotwet	2.4	0.48	2	present	35/100ml	4/100ml	unsuitable	NO	NO	Mulot	24%
Tilimiet	5.2	0.55	7	absent	nil/100	nil/100	suitable	YES	YES	Bomet Central	3%
Tilomwet	10.2	1.06	32	absent	nil/100	nil/100ml	unsuitable	YES	NO	Longisa	15%
Aisaik	1.7	0.38	4	absent	nil/100ml	nil/100ml	suitable	YES	NO	Bomet Central	3%
Kabolecho	2	0	6	present	6/100ml	3/100ml	unsuitable	NO	NO	Kirindon	81%
Olbobo Rwh	0.8	0.37	6	present	180/100ml	1/100ml	unsuitable	NO	NO	Longisa	15%
Pusanki	2.5	0.02	5	absent	nil/100	nil/100ml	suitable	NO	NO	Kirindon	81%
Dikirr	10.2	1.58	66	absent	nil/100	nil/100	unsuitable	YES	NO	Kirindon	81%
Emarti	11.1	0	81	present	1800+/100ml	150/100ml	unsuitable	YES	NO	Kirindon	81%
Embole Naibor	13	1.13	115	present	46/100ml	34/100ml	unsuitable	YES	YES	Mara	84%
Ildugisho	6	1	32	present	24/100ml	15/100ml	unsuitable	NO	NO	Mara	84%

Kingsir	9	1.16	79	present	1800+/100ml	425/100ml	unsuitable	NO	YES	Kirindon	81%
Kirindon	22.8	1.66	90	present	900/100ml	7/100ml	unsuitable	YES	YES	Kirindon	81%
Kurito	7	0.89	26	present	45/100ml	30/100ml	unsuitable	NO	NO	Kirindon	81%
Oldonyo Narasha	8	0.69	93	present	1800+/100ml	221/100ml	unsuitable	YES	NO	Mara	84%
Olmariko	2.3	0.37	29		nil/100ml	nil/100ml	suitable			Olkurto	50%
Standard	**10**	**1.5**	**30**	**absent**	**nil/100ml**	**nil/100ml**					

APPENDIX 6: REGRESSION AND CORRELATION ANALYSIS BETWEEN *E. COLI* AND OPEN DEFECATION

Regression analysis					
Response variate: E_Coli_per_100ml					
Fitted terms: Constant, OPEN_DEFICATION					
Summary of analysis					
Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	46575.	46575.	6.41	0.015
Residual	39	283165.	7261.		
Total	40	329740.	8243.		
Percentage variance accounted for 11.9					
Standard error of observations is estimated to be 85.2.					



Fitted and observed relationship with 95% confidence limits
E_Coli_per_100ml
400
300
200
100
0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
OPEN_DEFICATION

Estimates of parameters (model)

Parameter	estimate	s.e.	t(39)	t pr.
Constant	5.9	19.6	0.30	0.764
OPEN_DEFICATION	101.9	40.2	2.53	0.015

Parameter	lower95%	upper95%
Constant	-33.74	45.60
OPEN_DEFICATION	20.51	183.2

Correlations

E_Coli_per_100ml	1	-	
OPEN_DEFICATION	2	**0.3758**	-
		1	

APPENDIX 7: LIVESTOCK SHARING AND EROSION RELATIONSHIP CHI SQUARE RESULTS

Erosion * Livestock Crosstabulation

Count

		Livestock		
		Not Sharing	Sharing	Total
Erosion	Absent	20	10	30
	Present	2	8	10
Total		22	18	40

Chi-Square Tests

	Value	Df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	6.599[a]	1	.010		
Continuity Correction[b]	4.848	1	.028		
Likelihood Ratio	6.852	1	.009		
Fisher's Exact Test				.025	.013
Linear-by-Linear Association	6.434	1	.011		
N of Valid Cases	40				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.50.

b. Computed only for a 2x2 table