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Influence of Anthropogenic Activities on Microbial Quality of Surface Water in Subukia Town, Kenya

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ABSTRACT

Water quality and quantity is increasingly under threat by human population increase and anthropogenic activities. Momoi and Subukia rivers in Subukia division, Nakuru County are sources of drinking water for the community but receive point and non-point source pollutants mainly from adjacent livestock grazing fields and pit latrines. To understand the impact of anthropogenic activities on river water quality, a study was conducted to assess the microbial water quality from middle to lower reaches of the two rivers between March and May 2012. Water samples were collected twice a month and analysed for microbiological parameters. The Membrane Filtration Method was used to determine total coliforms, *E. coli* and *Salmonella* spp as indicators of microbial water quality. *In situ* measurements of pH and temperature using Wagtech International portable meter and turbidity using Hach 2100P ISO Turbidimeter were done. Results showed that in River Subukia total coliforms (in cfu per 100 ml water) ranged from 2817±528 (mean±se), recorded in March to 8408±1665 in May while for River Momoi they ranged from 4983±1032 in March to 12117±1494 in April. *E. coli* counts (cfu per 100 ml water) for River Momoi ranged from 1633±280 (mean±se) in March to 3250±723.8 in April and that of River Subukia ranged from 1267±385.3 in March to 2167±544.5 in April. In conclusion, the mean total coliform, *E. coli* and *Salmonella* bacteria counts exceeded WHO and NEMA drinking water guidelines. Since the local residents rely on this water for domestic use, there is therefore need for treatment at the point of use and community education on use of appropriate sanitation techniques to minimize pollution from faecal matter.

Key words: Water quality, Membrane Filtration Method, total coliforms, *E. coli* and *Salmonella*.

INTRODUCTION

Potable water is essential for economic productivity and social well being of humans (GoK, 2005). With the increasing growth in human population and the subsequent socio-economic pursuits, including urbanization, industrial production, tourism and agricultural activities, demand for water has increased rapidly. Water quality is described as the chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose (Liang et al., 2006). Further water quality is determined by comparing the biological, physical and chemical characteristics of a water sample with water quality guidelines or standards. Water quality management according to Geneviève and James (2008)

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contributes both directly and indirectly to achieving the targets set out in the MDGs, although it is most closely tied to specific target 7.C of goal 7, to ensure environmental sustainability.

Water pollution exacerbates water scarcity because it limits the use by, or imposes a higher cost for treatment on downstream users. Deteriorating water quality has become one of the most critical issues affecting both the developed and developing countries (WHO, 2007), hence the need to know water quality status. About 1.1 billion people lack access to a safe drinking water supply, while many more drink water that is grossly contaminated as reported by WHO (2007). In addition, 4 billion cases of diarrhoea occur annually globally. Diarrhoea causes poor growth in children and reduced resistance to infection and it consists of many diseases, especially typhoid fever, amoebic dysentery and cholera. Thus testing of the quality of water is a precautionary measure that can prevent people from getting ill.

The Ministry of Water and Irrigation's Strategic Plan 2009 to 2012 states that Kenya is a water scarce country with 647 cubic meters water per capita providing a serious challenge to water resources management(MWI, 2008). Despite efforts made by the government through policy instruments to ensure sustainable access to safe water and basic sanitation to all Kenyans, 50 per cent of Kenya's population still lacks access to safe drinking water and sanitation (Onyango and Angienda, 2010).

In Subukia Division the community depends on River Subukia and Momoi as sources of domestic water. Increase in population and land use changes have resulted in change in water quality. Documents at the local health centres showed that the average incidence of diarrhoeal diseases in Subukia was 14.4 per cent against a national average of 16.7 per cent (KNBS and ICF Macro, 2010). The two rivers traverse Subukia town and are influenced mainly by non- point sources of pollution. Non-point sources include runoff from grazing fields, feed lots, storm water from urban areas, seepage from pit latrines and near-by farms. Point sources include waste water from homes and over-flowing pit latrines. In a similar study along River Njoro, Yillia et al., (2008) found that in-stream activities by people and livestock, for example, bathing, washing clothes and watering livestock, at the middle reaches of the river significantly influenced microbial water quality downstream of the activities. The aim of the present study was to determine microbiological water quality of River Subukia and Momoi from their middle to lower reaches. The study established physical and microbiological parameters for both rivers and compared them against World Health Organisation (WHO) and local, National Environment Management Authority (NEMA), drinking water guidelines.

MATERIALS AND METHODS

Description of study site

The research was conducted within Subukia Division along Subukia and Momoi rivers which traverse Subukia town and converge about one kilometre downstream of the town to form Waseges river (Figure 1). Subukia town is located at an altitude of 1850 meters above sea level within Subukia Valley. The town is located between longitude $36^{o}13'30"$E to $36^{o}14'08"$E and latitude $0^{o}0'5"$N to $0^{o}0'30"$N within the Nakuru county, Subukia District and Subukia Division. The town is the largest urban area in the division and is about forty kilometres north-east of Nakuru town along the Nakuru-Nyahururu road. The division is bordered by Laikipia and Nyandarua counties to the east, Kabazi division to the south-west and Mbogoini division to the north. The geology of the area falls within the Gregory Rift Valley and comprises mainly of volcanic soils and rocks of tertiary and quaternary age which have been affected by a series of faulting (RoK, 1967). The area drained by River Waseges and its tributaries is covered predominantly by two formations, that is, superficial alluvial deposits and Rumuruti phonolites. The land gently slopes towards the north where it joins the Solai- Baringo basin.

According to MoA (2010) there is considerable variation with the south receiving more rain than the north. The temperature varies from 24 – 29 ^{o}C with a mean of 26.5 ^{o}C and average rainfall is 1270 millimeters per year. The wettest months are between April and July.

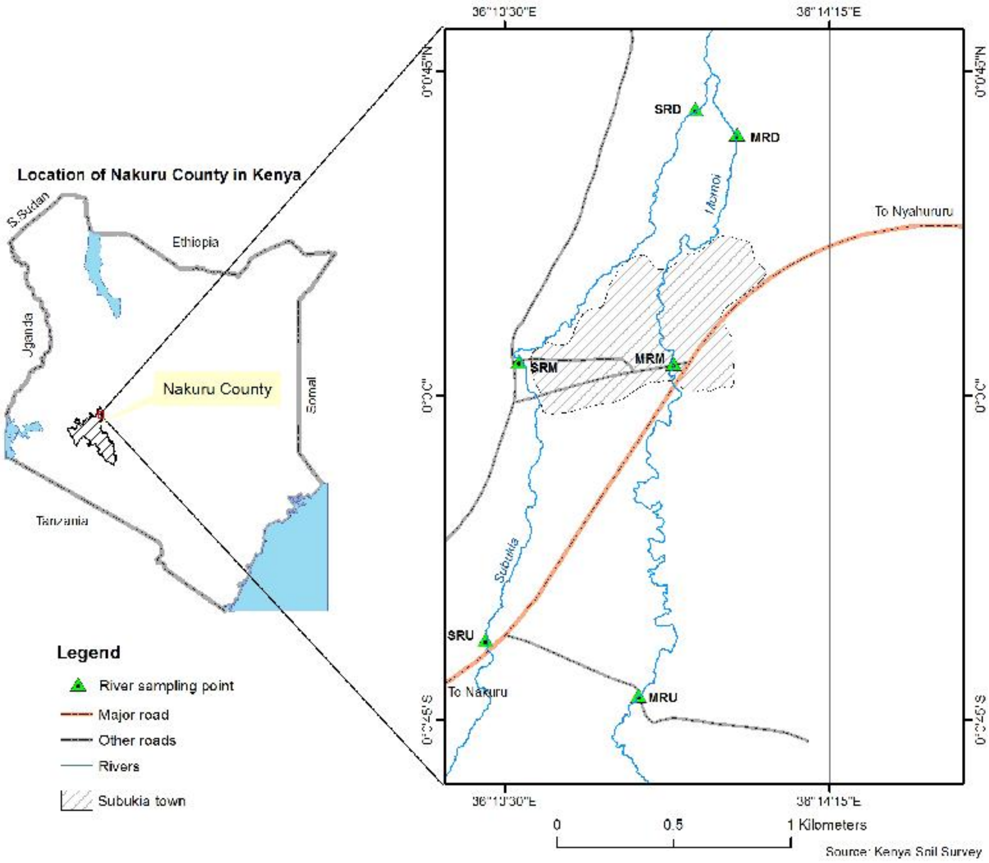

Figure 1: Map of study area (with a map of Kenya inset) showing sampling sites
SRU=Subukia River Up-stream, MRU=Momoi River Up-stream
SRM= Subukia River Mid-stream, MRM=Momoi River Mid-stream
SRD=Subukia River Down-stream, MRD=Momoi River Down-stream

According to the KNBS (2010) the human population of Subukia division is 30,268 (consisting of 14,894 males and 15,374 females) having increased from 19,030 people in 1999. Subukia East location, in which the town is located, has a population of 9,230 people. The population density within the urban area is 1,315 persons per square kilometer while the surrounding areas have an average density of 300 persons per square kilometer. Urbanisation, agricultural activities, soil erosion and water abstraction from rivers have been increasing over the years. Riparian vegetation cover is low or has been cleared in most areas and water level fluctuates greatly depending on the season (MoA, 2010). The two rivers (Subukia and Momoi) receive pollutants mainly in middle and lower reaches due to increased population and anthropogenic activities which include river bank grazing, washing of clothes and construction of pit latrines and feedlots near river banks.

Sample Collection

Three sampling points were identified along each river. The points were purposively selected being areas where the community members fetch water for domestic use. Samples at the sites were taken twice a month for three months (March to May 2012). Three replicate samples were taken at each site. Sample collection was carried out using 200 ml sterilised plastic bottles. The bottles were first washed in dilute hydrochloric acid then thoroughly rinsed with distilled water and finally autoclaved. At sampling sites each bottle was rinsed three times with river water before it was finally filled, capped, labelled and placed in a cool-box. The samples were stored at 4°C and transported to the WRMA Water Pollution Laboratory in Nakuru town and analysis started immediately.

Sample Analysis

In the laboratory, the following microbiological parameters were determined; total coliforms (cfu per 100 ml water), *E. coli* (cfu per 100 ml water) and *Salmonella* spp (cfu per 100 ml water). Three dilutions were prepared using 1% peptone water for each sample. The Membrane Filter Technique was used to filter 100 ml of water sample through a sterile 0.45µm, 47mm, grid and sterile Pall GN-6 membrane disc filter using an electrical vacuum pump (APHA, 1998). After passage of all water sample through the membrane filter sterilised forceps were used to remove the filter from the filter membrane apparatus and placed onto an absorbent pad saturated with m-ColiBlue24 broth in a sterilised petri dish. The petri dishes were inverted and placed in an incubator at 35°C for 24 hours. M-ColiBlue24 broth is a selective chromogenic medium for the simultaneous determination of total coliforms and *E. coli.* After the set time the petri dishes were removed from the incubator and examined for bacteria colony growth. A magnifier was used to count the colonies where red colonies indicated total coliforms and blue colonies indicated *E. coli*. Only the dilution that gave colony counts of between 20 and 80 was considered (USGS, n.d). Both total coliforms and *E. coli* counts were reported as colony forming units (cfu) per 100 ml of water. The procedure for enumerating total coliforms and *E. coli* was used to obtain for *Salmonella* counts for the same samples. However, the media used was HiChrome *Salmonella* agar which was specific for these bacteria. *Salmonella* species gave pink-red colonies after 24-48 hour incubation period at 35-37 ^{o}C.

With respect to the physical parameters *in-situ* measurements for pH, temperature (^{o}C) and turbidity (NTU) were done during each sampling occasion. The temperature and pH were measured using one Wagtech International portable meter while turbidity was measured using Hach 2100P ISO Turbidimeter.

RESULTS AND DISCUSSION

Physical Parameters

Water quality results for physical parameters are given in Table 1. The mean pH range for River Subukia was from 7.58±0.080 (mean±se) recorded in March to 8.00 ±0.141 s.e. mean recorded in May while that of River Momoi ranged from 7.74±0.054 recorded in March to 7.95±0.125 recorded in May. The pH values for the two rivers did not vary significantly, ($F_{[2,17]}$ =2.93, p=0.081) and were below pH 8 as required by WHO and NEMA guidelines.

Table 1: Physical parameters (mean ±se) for Subukia and Momoi Rivers, Nakuru County, Kenya

Parameter	Month		
	March	April	May
	River Momoi:		
pH	7.74±0.054	7.88 ±0.142	7.95 ±0.125
Temperature (^{o}C)	21.27± 0.395	20.08 ±0.715	20.02 ±1.056
Turbidity (NTU)	19.0 ±3.05	69.2 ±14.47	200.3 ± 84.85
	River Subukia:		
pH	7.58± 0.080	7.78 ±0.103	8.00 ± 0.141
Temperature (^{o}C)	22.88± 0.480	20.70 ± 0.747	19.38 ± 0.796
Turbidity (NTU)	32.9 ± 3.48	139.4 ± 8.98	201.7 ± 50.06

The mean temperature for sampling points during the study period along River Momoi ranged from 20.02±1.056 ^{o}C (mean±se) in May to 21.27±0.395 ^{o}C in March. In River Subukia the mean temperature ranged from 19.38 ± 0.796 ^{o}C in May to 22.88± 0.480 ^{o}C recorded in March (Table 1). There was significant temperature variation during the sampling period ($F_{[2,17]}$ =4.79, p=0.022). The reduction in temperature from March to May was attributed to change in season as rains began in mid- April to May after a hot and dry period in March. The study results are consistent with those of GLOWS (2007) in a study along Mara River basin found that water temperature was affected by season and time of day.

The mean turbidity range for River Subukia was from 32.9±3.48 s.e. mean NTU recorded in March to 201.7±50.06 NTU (mean±se) recorded in May while that of River Momoi ranges from 19.0±3.05 NTU recorded in March to 2003 NTU recorded in May (Table 1). There was significant variation in turbidity levels ($F_{[2,17]}$ =7.8, p=0.004). The hot and dry season in March meant that water and turbidity levels were relatively low however start of the wet season in mid April contributed to the increase in turbidity in the rivers from April to May. GLOWS (2007) reported similar results and states that increase in turbidity in rivers can further be attributed to anthropogenic activities that lead to loose and unprotected soils. In the case of the River Subukia and Momoi there is increased clearing of vegetation for human settlement, cultivating of crops very close to the river banks and destruction of riparian vegetation. In a study along River Njoro Yillia et al., (2008) found that rains in the catchment area led to notable increase in surface run-off and corresponding rise in suspended solids in river water.

Microbiological parameters

Results of microbiological parameters are shown in Table 2. Total coliform counts along the two rivers varied significantly ($F_{[2, 17]}$ =7.90, p = 0.004). Along River Subukia there was a rise in total coliform counts from up-stream (4900±1428 mean±se, cfu per 100 ml water at sampling point SRU) to down- stream (7567±1765 cfu per 100 ml water at SRD). Correspondingly, in River Momoi the range was from 5125±1643 cfu per 100 ml water, up-stream to 11808±2168 cfu per 100 ml water, down-stream. The monthly mean total coliform count results showed that in May, River Subukia, had the highest mean total coliform counts of 8408±1665, cfu per 100 ml water while March had the lowest of 2817±528 s.e. mean, cfu per 100 ml water (Figure 2). In River Momoi, the range was from 12117±1494, cfu per 100ml water recorded in April to 4983±1032, cfu per 100 ml water in March. There was significant temporal variation ($F_{[2,17]}$ = 13.98, p = 0.001) when the two rivers were compared over the study period.

Table 2: Microbiological parameters (mean± s.e.) for Subukia and Momoi rivers, Nakuru County, Kenya

Sampling site	Mean total coliform (cfu per 100 ml water)	Mean *E. coli* (cfu per 100 ml water)	Mean *Salmonella* spp (cfu per 100 ml water)
River Subukia: SRU	4900 ±1428	1450 ±528.4	128±81.1
SRM	5883 ±1093	1450 ±324.3	157±93.3
SRD	7567 ±1765	2067 ±390.4	356±153.7
Mean	6117 ±1429	1656± 414.4	213±109.4
River Momoi: MRU	5125 ±1643	862 ±295.3	11±4.0
MRM	9642 ±1621	2733 ±727.9	33±9.2
MRD	11808 ±2168	3900 ±719.7	104±28.6
Mean	8858 ±1811	2498 ±581.0	49±13.9

E. coli counts along River Subukia showed an increase from up-stream (1450±528.4, cfu per 100ml water) to down-stream (2067±390.4, cfu per 100ml water (Table 2). River Momoi showed a similar trend. The range was from 862± 295.3 s.e. mean, cfu per 100ml water up-stream to 3900± 581.0, cfu per 100ml water down-stream. *E. coli* counts along the two rivers varied significantly ($F_{[2,17]}$ = 7.03, p= 0.006). Results for the mean monthly density of *E. coli* for River Subukia shows that April had the highest *E. coli* density of 2167±544.5 s.e. mean, cfu per 100 ml water while March had the lowest count of 1267±385.3 s.e. mean, cfu per 100 ml water (Figure 3). In River Momoi April had *E. coli* density of 3250±723.8 s.e. mean, cfu per 100 ml water while in March a density of 1633±280.1 s.e. mean, cfu per 100 ml was recorded. The was no significant temporal variation in *E. coli* density ($F_{[2,17]}$ = 3.33, p = 0.060. This means the contaminant sources of *E. coli* (human and animal waste) remained relatively constant over the study period.

Salmonella spp counts along the two rivers varied significantly ($F_{[2,17]}$ = 4.76, p = 0.023). For River Subukia the range was between 128±81.1 (mean±se) cfu per 100 ml water recorded up-stream to 356±153.7 cfu per 100 ml water recorded down-stream (Table 2). A similar trend for River Momoi showed an increase from 11±4.0 cfu per 100 ml water, up-stream to104±28.6 cfu per 100 ml water down-stream.Temporal *Salmonella* spp density for River Subukia showed that the highest record was in May (480±126.6 s.e. mean, cfu per 100 ml water) while the lowest was in March (5.5±1.2 cfu per 100 ml water (Figure 4). For River Momoi the month of April had the highest *Salmonella* spp mean density of 66.7±23.8 cfu per 100 ml water while March had the lowest mean density of 16.7±8.1 s.e. mean, cfu per 100 ml water. There was significant temporal variation in *Salmonella* density for the two rivers ($F_{[2,17]} = 11.10$, $p = 0.001$).

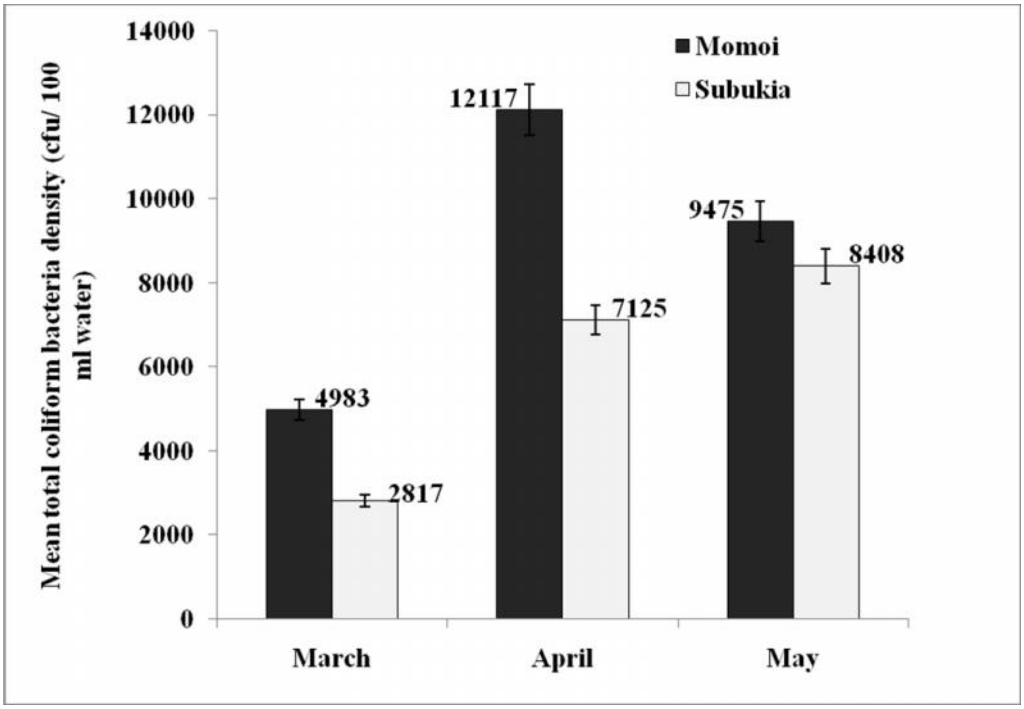

Figure 2: Temporal variation of mean total coliform bacteria densities along River Momoi and Subukia (Vertical lines indicate ± standard error of the mean)

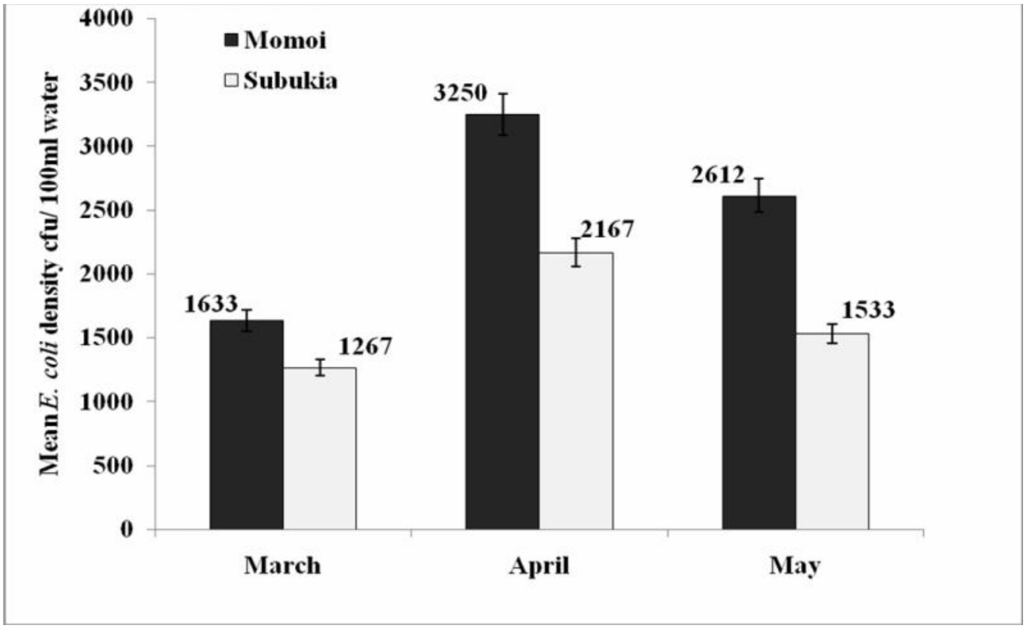

Figure 3: Temporal variation of mean *E. coli* bacteria densities along River Momoi and River Subukia (Vertical lines indicate mean± standard error)

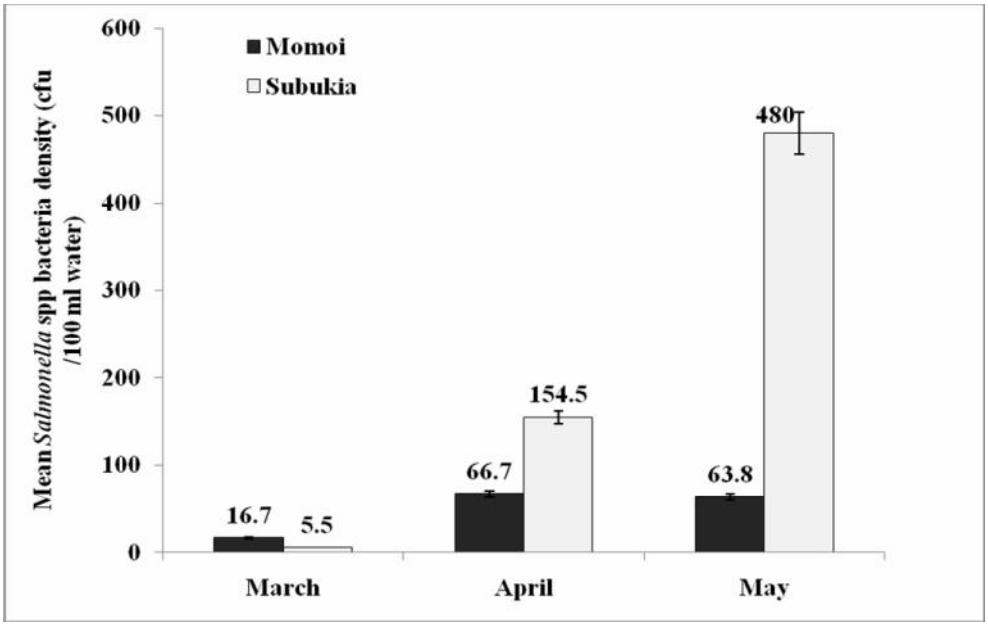

Figure 4: Temporal variation of mean *Salmonella* spp bacteria densities along River Momoi and River Subukia (Vertical lines indicate mean ± standard error)

Microbiological data showed that bacteria densities exceeded WHO and NEMA guidelines of nil per 100 ml water intended for drinking. Bacteria densities showed a marked increase in the month of April which coincided with beginning of the wet season and contributed to a significant temporal variation for total coliforms, *E. Coli,* and *Salmonella* spp. Mobilisation of bacteria and sediments in the environment by surface runoff from agricultural land and feedlots led to the increase. Additionally, increasing human population, river bank grazing, urbanisation and lack of a functional solid and liquid waste management system contributed to the increase in bacteria down-stream.. Turbidity is an important indicator of the possible presence of contaminants like bacteria which are of concern to human health. Suspended solids offer shelter to bacteria which are attached to the particles. High turbidity in water for domestic use can reduce the efficiency of water disinfection (WHO, 2011). Detection of *Salmonella* spp provided proof of the presence of disease causing bacterial species.

CONCLUSIONS AND RECOMMENDATIONS

The microbiological quality of water in the two rivers was unacceptable since bacteria densities were above WHO and NEMA guidelines. It indicates that there was contamination with human and animal waste. Further bacterial densities increased as the two rivers entered Subukia town indicating that more pollutants were injected into the rivers within the town. Detection of *Salmonella* spp indicates that consumers were exposed to pathogenic bacteria. It is recommended that water filtration, boiling or disinfection at point of use is done to reduce risk to consumers.

Both rivers recorded tubidity levels that are higher than WHO and NEMA guideline value for drinking water of a maximum of 5 NTU in the dry and wet seasons. Provision of piped safe drinking water and liquid and solid waste management services by the County government should be improved while also carrying out community education to promote good hygiene practices. The community should also be educated on the importance of conserving river catchments.

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Spatio-temporal Variations in Physicochemical Parameters and Coliform Levels of Domestic Water Sources in Njoro District, Kenya

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ABSTRACT

A previous study on waterborne diseases conducted on in- and out-patients visiting Health Centres in Njoro District, Kenya revealed that amoebiasis and giardiasis are very common whenever a stool test is done. The study recommended for an investigation on the quality of domestic water sources in the District. The aim of the current study was therefore to determine the quality of water obtained from wells and springs in the study area and to establish compliance of measured parameters with Kenya Water Quality Regulation guidelines for domestic water. Water samples were collected and analyzed for biochemical oxygen demand (BOD), nutrients and coliforms. The results revealed that the water sources were highly impaired with pathogens at elevated levels particularly during the wet season. The wells in seasonally flooded sites recorded significantly higher BOD, nutrients and coliforms (t-test, $P<0.05$) during wet season than those in well drained sites. Further, most of the measured water quality parameters were non-compliant with Kenya's Water Quality Regulations guidelines. The elevated levels of contaminants in drinking in the study area can adversely affect human health. To prevent further ingress of pollutants into drinking water sources, the springs and wells should be protected through engineering works and by relocating sources of pollution, such as pit latrines and livestock feedlots away from drinking water sources.

Keywords: Faecal contamination, Water coverage, Improved source and Domestic water guidelines

INTRODUCTION

About one sixth of the world population do not have access to clean drinking water, nearly 80% of this population is concentrated in Sub-Saharan Africa, Eastern Asia and Southern Asia (WHO/UNICEF, 2006). In Sub-Saharan Africa 37% of the people do not have access to improved water sources (WHO/UNICEF, 2010). According to Marshall, 2011, about 17 million people (43%) do not have access to clean water in Kenya. Use of unimproved water sources exposes citizens to risk of cholera epidemics and multiple other water-borne diseases, which contribute to between 70-80% of human health problems in the country (Chabalala & Mamo, 2001). The

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objective of Kenya Government is to provide its citizens with clean and potable water. That water should be available for key socioeconomic activities such as domestic, recreation, agriculture and industry in all places at all time. However, this is not the case because most surface and groundwater sources in Kenya are increasingly becoming polluted by point and non-point sources of pollution, mostly of faecal origin. Water pollution exacerbates the problem of water scarcity and quality by limiting the use of available water resources and this has made the country a water scarce with only 647 cubic meters of fresh water per capita (UN-WATER/WWAP, 2006). Due to continued population growth, it has been projected that by the year 2025, Kenya's per capita water availability will be 235 cubic meters per year, about two-thirds less than the current (Marshall, 2011). The coverage of improved water sources in the country stood at 61% nationally with 83% and 54% in urban and rural areas respectively, while the coverage of piped water provided by the Ministry of Water and Irrigation by the year 2011 stood at 20% nationally with 45% in the urban areas and as low as 12% in rural areas (WHO/UNICEF, 2013).

A study on waterborne diseases in Njoro District by Kinuthia, et al., (2012) revealed that amoebiasis and giardiasis are common occurrence whenever a stool test is carried out on in-and-out-patients visiting the local Health Centres. In addition, a study on Njoro River Watershed by Tiwari and Jenkins (2008) showed that Nakuru, Molo and Njoro Districts are endemic for diarrheal diseases due to poor water supply conditions. Kinuthia, et al., (2012) recommended for further investigation on quality of domestic water sources in Njoro District to establish the sources of pollution. The aforementioned recommendation formed the basis upon which the present study was conceived. The objective of the current study was therefore carried out to determine the physicochemical parameters such as temperature, pH, electrical conductivity, biochemical oxygen demand, nitrate, and nitrite including total and faecal coliforms in domestic water sources from wells and springs in seasonally flooded and non-flooded sites. The results were compared with guidelines for domestic water (Kenya Water Quality Regulation, 2006) to establish the compliance of measured parameters with the stipulated standards.

MATERIALS AND METHODS

Study site

The study was carried out in two sites, located at coordinates (S 0° 21' 37", E 35° 55' 2" and S 0° 25' 46", E 35° 59' 0") of Njoro sub-location in Njoro District, Nakuru County. The sites are adjacent to one another and they lie between 3-8km south of Egerton University and the Njoro-Mau-Narok road passes through the sites. The non-flooded site (Belbur) has well drained soils, whereas, the seasonally flooded site (Subuku) has poorly drained soils (Figure, 1). The two sites receives almost the same amount rainfall, though, the rainfall pattern displays temporal variability. Long wet season is usually between the months of April and September while short wet season occurs between November and December. On average the total annual rainfall is usually between 600 and 1200mm with variable peaks in May, August and November; dry weather is experienced in January to April (Mathooko and Kariuki, 2000). The atmospheric temperature lies between 9ºC and 24ºC (Baldyga, 2005).

The lithology of the study area is volcanic rocks, ranging in age from tertiary, quaternary to recent, and consisting of pyroclastic rocks of recent volcanoes. The rocks are predominantly agglomerates, sediments, welded tuffs, and phonolites on mountains, ciders, pumice, sanidine minerals, basaltic tuffs and black ashes on hills and valleys (Sombroeck, 1982).The soils are shallow and extremely prone to erosion during wet weather, which are characterized by increased surface runoff and massive transfer of loose materials from farmlands and residential areas (Yillia, et al., 2008). The drainage classes range from poorly drained, moderately well drained, well drained to excessively drained, with textures ranging from loam, clay loam to cay and structures in the range of moderately strong to strong.

The wells in seasonally flooded and non-flooded sites were dug to depth of between 10 to 30m manually by use a mattock and a shovel. Deeper wells of up to 30m deep are found in non-flooded site and shallow wells in seasonally flooded site. Water from the wells is drawn using buckets of up to 20 litres with a rope tied to it and lifted manually by a hand pulley or just by a hand. Most of the wells are owned privately by individual households and access is restricted to only household members, although, sometimes are shared with neighbours who don’t have their own for domestic purposes. Water springs are located on communal land and are owned by the community. Access to the spring is open to any members of the community and strangers who use for domestic purposes as well as for livestock. The water from the springs is normally drawn by submerging the buckets/ containers into the spring and lifting it by hand. The springs are the main source of domestic water for the majority of residents in the two sites.The residents who are mainly subsistence farmers, small traders and civil servants use water for domestic purposes such as drinking, bathing, cooking, washing, watering of livestock, and sometimes small scale vegetable farming.

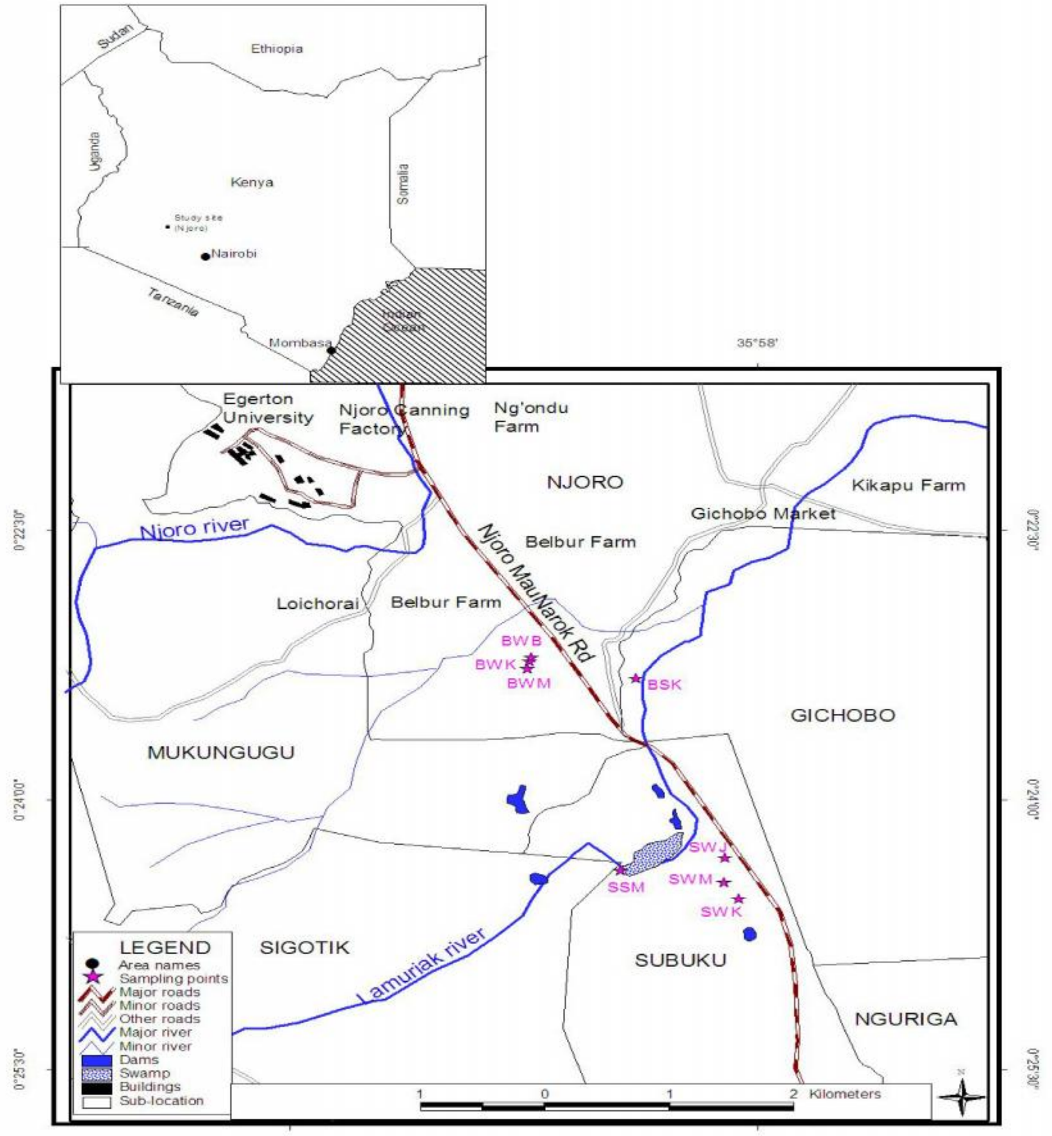

Figure 1: Map of study area showing wells and springs, where, BWB-Belbur Benda Well, BWK-Belbur Kilo Well, BWM-Belbur Mwalimu Well, BSK-Belbur Kasiminde Spring (Non-flooded Site) and SWJ-Subuku Jane Well, SWK-Subuku Kinyanjui Well , SWM- Subuku Mutonyi Well, and SSM-Subuku Maji-moto Spring (Flooded site)

Sample Collection

Water samples were collected in triplicates from eight (8) water points which were Belbur Benda Well (BWB: 36M0828471 and UTM997258), Belbur Kilo Well (BWK: 36M0828451 and UTM9957214) and Belbur Mwalimu Well (BWM: 36M0828436 and UTM9957144) and Belbur Kasiminde Spring (BSK: 36M0829189 and UTM9957071), which represented the wells and the spring from Non-flooded site. From seasonally flooded site, samples were collected from Subuku Jane Well (SWJ: 36M0830024 and UTM9955174), Subuku Kinyanjui (SWK: 36M0830130 and UTM9954753) and Subuku Mutonyi Well (SWM: 36M0830013 and UTM9954921) and Subuku Majimoto Spring (SSM: 36M08291885 and UTM9955047). The wells are known by the names of the site and household-head, while, the springs by their local names, the wells and springs exact positions on the ground were also given by use of GPS. The samples were collected from wells and springs using the 500ml sample containers.

Samples were collected on a monthly interval from January, February and March, 2011 representing dry season and from April, May and June, 2011 representing wet season. In total 288 samples were collected and analyzed for physicochemical and microbial parameters during the study period. Sampling was carried out between 0900 and 1200 hours. Prior to water sample collection *in-situ* measurements were made for the following physical parameters: Temperature, pH, Dissolved Oxygen (DO) and Electrical Conductivity (EC) using Hydrolab™ (Environmental Data System) Quanta Model No. QD02233. The samples for Biochemical Oxygen Demand (BOD), and nutrients were collected in acid washed 500ml polyethylene containers, rinsed with de-ionized water and sample water before sampling, whereas, that for microbial analyses were collected in Pyrex sterile 500ml glass containers. All the samples were stored in ice in a cooler box before they were transported to Nakuru Water and Sewerage Service Laboratory for analyses. The samples which were not analyzed in the same day of sampling were kept in the refrigerator set at 4^{o}C.

Sample preparation and analysis

Water quality analysis was done in accordance with the standard analytical procedures as outlined in APHA (1995). Samples were filtered through rinsed glass fibre (pore size 0.45µm). Filtered samples were analyzed for Nitrite-Nitrogen (NO_2-N) and Nitrate-Nitrogen (NO_3-N). The 2, 6-dimethylphenol method was used for NO_3-N, while amodification of the Sulfanil acid method with Naphthylaminsulphonic acid salt NO_2-AN was used to determine NO_2-N. After digestion for 45–60 minutes the samples were analyzed for NO_3-N. The BOD was determined by use of standard 5 day incubation procedure at 20ºC in darkness using an oxygen electrode.

Three appropriate dilutions were made for total coliforms (TC) and faecal coliforms (FC). Dilutions were duplicated and filtered using sterile membrane filters (0.45µm; 47 mm) with a vacuum pump. Filters for TC and FC were incubated on Chromocult Coliform Agar at 37ºC for 24 hours. Pink to red colonies and blue colonies were counted for TC and FC, respectively. Plates with countable colonies between 20 and 300 were selected for counting. Median values of colony forming units (cfu) were reported per cfu per 100 ml for TC and FC (APHA, 1995).

Data Analysis

Data was entered into excel data sheet for initial processing. All analyses were done with SPSS for Windows 10.0 (SPSS Inc., Chicago, Illinois 60606, USA).Prior to statistical analysis by t-test, the data was tested for normality using Kolmogorov-Smirnov test ($\alpha = 0.05$), and homogeneity of variance using Levenes's test ($\alpha = 0.05$) and where there were violations of these assumptions appropriate transformations were done. The difference in means between wet and dry seasons for the following water quality variables: DO, EC, BOD, NO_2-N, NO_3-N, TC and FC were determined using independent sample t-test. The differences were declared significant or not at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Physicochemical Water Quality Parameters

Temperature is an important property of water, since, it determines water suitability for human use, industrial applications and aquatic ecosystem functioning. On average, the temperatures of wells, in flooded and non-flooded sites and spring in non-flooded site ranged from 18.1 to 21.3^oC. Although, there is no set guidelines for temperature by Kenya Water Quality Regulations (2006) the temperature of the spring in flooded site was observed to be abnormally high ranging from 31 to 32^oC throughout the study period. The area residents who normally use the spring water confirmed that the water temperature is relatively warmer than that of other water sources in the area. Due to the warmer temperature the residents refer to the spring as *'Majimoto'* (Kiswahili word for hot water). Majimoto spring is located at the bottom of the fault scarp in pyroclastic rock which overlies a trachyte flow and is believed to be associated with a concealed fault (Thompson 1964). The relatively warmer temperature could be attributed to absorption of heat from localized spots of remnant volcanic heat which might be heating groundwater (Mink 1964). Higher water temperatures are known to promote algal blooms, increase the bacteria and fungi content in water (Environment Canada 2001). These microbial activities may in turn lead to a bad odour and taste in chlorinated drinking water and the occurrence of toxins. Additionally, higher water temperatures are known to enhance transfer of volatile and semi-volatile compounds such as ammonia, mercury, dioxins, and pesticides from water bodies to the atmosphere (Schindler 2001) thus increasing the health risk to those consuming the water. The study also revealed that the residents of the surrounding villages prefer water from the hot spring to other water sources in the area. They claim that hot spring water is softer to drink, has good taste and consumes less soap while washing clothes or bathing compared to other water sources in the area.

All water sources examined during the study showed pH values within the acceptable limits of between 6.5 to 8.5 (Kenya's Water Quality Regulation 2006), except wells in seasonally flooded site which had pH as low as 6.3 during wet season. Although, water pH has no direct impact on consumers, low water pH allows toxic chemicals to become mobile and available for uptake by aquatic plants, animals and humans producing conditions that could be toxic to consumers. For effective disinfection of water with chlorine, the pH should preferably be less than 8, as pH less than 6.5 or greater than 9.2 would markedly impair the portability of the water (WHO 2008). The acidity in wells in seasonally flooded site during wet season could have been attributed to ingress of storm-water containing complex humic material and organic acids (Wetzel, 2001).

The mean dissolved oxygen (DO) concentration observed in all water sources was above 3.0 mgl^{-1} except the spring in seasonally flooded site spring (Majimoto spring) which recorded as low as 1.87mgl^{-1}. The low DO in the Majimoto spring could be attributed to high water temperature which remained markedly high throughout the study period. All water sources examined also showed statistically significance difference in DO between wet and dry season, except the Majimoto spring which did not show any difference ($t = 1.233$; $p = 0.249$; Table 2). The low level of DO in Majimoto spring could be attributed to high water temperature of the spring. Since, the solubility of oxygen is affected nonlinearly by temperature and increases considerably in cold water (Wetzel, 2001). All water sources showed relatively, lower DO in dry season. This could be due to several factors such as short residence time of water in wells and springs owing to high abstraction rates in dry season, since these are the only reliable sources of portable water and also due to elevated ambient air temperature during the dry season. High rate of abstraction does not allow time for oxygen to diffuse from the atmosphere into wells and springs. Although, no health-based guideline value is recommended for DO by Kenya's Water Quality Regulation (2006), depletion of dissolved oxygen is known to encourage the microbial activity capable of converting nitrate to nitrite and sulfate to sulfide thus, imparting bad odours and taste in water in drinking water (WHO, 2008).

The mean electrical conductivity (EC) measured in all water sources showed an increase in value during dry season, except in the wells in flooded site which on contrast showed an increase during the wet season (Table 2). The springs in both flooded and non-flooded sides showed significantly greater difference in mean EC value between wet and dry seasons ($p<0.05$) Table 2 and 4, whereas the wells did not Table 1 and 3. The elevated EC values in dry season could have been caused by increased ionic concentration as water evaporates leaving behind salts and other dissolved compounds, while, the elevated EC value of the wells in seasonally flooded site in wet season could have been attributed to mineralization of the organic material seeping into the wells.

With respect to BOD on average it ranged between 4.45 and 35.19 mgl^{-1} (Table 1) with highest observed in wells in flooded site. All water sources examined showed elevated BOD concentration during wet season; with most of them measuring almost double that of dry season (Table 2, 3 and 4). BOD measurements in all water sources were above the stipulated in the Kenya's Water Quality Regulation (2006) recommended value of 0.5 mgl^{-1}. Additionally, all water sources showed statistically significance difference in means of BOD between wet and dry seasons ($p<0.001$) Table, 1, 2, 3 and 4. The high level of BOD in wells during wet season could have been caused by seepage of storm-water contaminated with human and livestock waste from the nearby pit latrines and livestock feedlots. The high level of BOD in Majimoto spring (Table, 2) during wet season could be due ingress of runoff carrying high content of organic materials from the catchment area where open defecation is common practice and also from foot paths which are usually littered with livestock waste. However, the high level in dry season could be attributed to the mode of drawing water from the spring, which is normally submerging of the 20 litre container into the spring. Submerging and lifting up of the container could causes re-suspension of organic rich sediments from the bottom of spring or the container may also introduce organic material attached on it (Plate, 1).

Plate 1: A woman drawing water from Majimoto Spring

Nitrate (NO_3-N) value in all water sources ranged between 0.10 and 9.05 mgl^{-1} with higher levels recorded during the wet season (Table, 1, 2, 3, & 4). All water sources showed statistically significance variation in means between wet and dry season ($p<0.001$), except Majimoto spring which did not (Table, 2). Further, all water sources measured nitrate levels that were within the allowable limit of 10 mgl^{-1} by the Kenya's Water Quality Regulation (2006). The higher levels recorded in the spring in non-flooded site during wet season could be attributed to the excessive growth of algae and blue-green-algae which covered the surface of the spring water in the open-to-sky accumulation tank. Algae and blue-green-algae are known to release extracellular complex organic carbon and nitrogenous compounds (Wetzel 2001). Slightly higher nitrate levels in wells in seasonally flooded and non-flooded sites could have been caused by pollution from leachates or seepage of organic materials from livestock feedlots and pit latrines which are located a few meters from the wells. Nitrates at concentrations of 10 mgl^{-1} or higher in water used for human consumption can cause adverse effects on human health especially on young children. Consumption of water with elevated levels of nitrates by infants is known to cause blue-baby syndrome, a condition that affects the ability of blood to carry oxygen (WHO 1996 and WHO 2008). This syndrome causes increased susceptibility to illness in children and may even result in death. Additionally, consuming water with high nitrate can also result in formation of nitroso-amines which are known carcinogenic (WHO 2008).

The mean concentration of nitrite (NO_2-N) in water sources ranged between 0.1 and 0.6 mgl^{-1} (Table, 1, 2, 3 and 4). Although, most of water sources showed elevated levels of nitrite in dry season, except the wells seasonally flooded site, which on contrast had the highest levels in wet (Table, 1). Fortunately, all water sources were within the Kenya's Water Quality Regulation (2006) guideline for maximum allowable level of 3 mgl^{-1} nitrite. In addition, all water sources did not show any significance difference in levels of NO_2-N between wet and dry season, except the wells in seasonally flooded site ($t = 6.055$; $p = 0.000$), (Table, 1). Consumption of water with high levels of nitrites can cause blue-baby syndrome (WHO 2008).

Table 1: Seasonal variation of physicochemical parameters of wells in flooded site (Subuku Wells)

	Wet season		Dry season				
Parameter	Mean	SE	Mean	SE	df	t-test	p-value
DO mgl^{-1}	3.94	0.20	3.06	0.42	34	2.077	0.045*
EC (µS/cm)	737.00	64.00	677.00	59.00	41	0.622	0.538
BOD_5 mgl^{-1}	35.19	8.13	4.48	0.28	52	3.776	0.000**
NO_3-N mgl^{-1}	4.99	1.12	0.12	0.02	52	4.352	0.000**
NO_2-N mgl^{-1}	0.62	0.07	0.16	0.03	52	6.055	0.000**

Table 2: Seasonal variation of physicochemical parameters of spring in flooded site (Subuku spring: Maji-moto spring)

	Wet season		Dry season				
Parameter	Mean	SE	Mean	SE	df	t-test	p-value
DO mgl^{-1}	2.54	0.24	1.87	0.25	9	1.233	0.249
EC (µS/cm)	517.00	16.00	740.00	82.00	12	-3.545	0.004*
BOD_5 mgl^{-1}	9.15	0.47	5.00	0.90	16	4.099	0.001**
NO_3-N mgl^{-1}	0.53	0.19	0.10	0.01	16	2.268	0.038
NO_2-N mgl^{-1}	0.10	0.04	0.21	0.05	16	-1.679	0.113

Table 3: Seasonal variation of physicochemical parameters of wells in non-flooded site (Belbur wells)

	Wet season		Dry season				
Parameter	Mean	SE	Mean	SE	df	t-test	p-value
DO mgl^{-1}	3.93	0.13	3.38	0.27	37	2.051	0.047*
EC (µS/cm)	911.00	35.00	981.00	67.00	37	-1.004	0.322
BOD_5 mgl^{-1}	9.58	0.59	5.81	0.32	52	5.601	0.000**
NO_3-N mgl^{-1}	8.95	1.29	0.17	0.02	52	6.967	0.000**
NO_2-N mgl^{-1}	0.18	0.03	0.19	0.02	52	-0.461	0.647

Table 4: Seasonal variation of physicochemical parameters in spring in non-flooded site (Belbur spring)

	Wet season		Dry season				
Parameter	Mean	SE	Mean	SE	df	t-test	p-value
DO mgl^{-1}	4.99	0.25	3.74	0.38	12	2.865	0.014*
EC (µS/cm)	689.00	18.00	1019.00	15.00	12	-11.887	0.000**
BOD_5 mgl^{-1}	13.33	1.62	4.33	0.67	16	5.140	0.000**
NO_3-N mgl^{-1}	9.05	2.17	0.21	0.06	16	4.064	0.001**
NO_2-N mgl^{-1}	0.19	0.04	0.25	0.05	16	-0.913	0.375

* The difference in means between wet and dry season is statistically significant ($p<0.05$)

** The difference in means between wet and dry season is statistically highly significant ($p<0.001$).

Microbial status of water sources

Microbiological examination revealed that all water sources were faecally contaminated with most of them measuring higher levels of faecal and total coliforms in wet season, except the Majimoto which had high levels of faecal coliform during dry season. Majimoto spring measured 76 and 713 cfu 100 ml^{-1} in wet and dry seasons respectively (Table 5). All water sources did not show any significance difference between seasons, except the wells in seasonally flooded site which shown highly significant difference ($t = 2.890$; $p = 0.006$) between the seasons. In terms of faecal and total coliforms none of the water sources met the guideline requirement value of nil coliform forming unit (cfu) 100 ml^{-1} which is a requirement by Kenya Water Quality Regulation (2006). The elevated level of faecal contamination in the Majimoto spring during wet season could be attributed to ingress of storm-water into the spring water. The storm-water is usually rich in organics and other pollutants after collecting livestock and human waste from catchment area where open defecation is a common practice. However the high levels of fecal coliforms pollution during dry season could have been caused by the mode of drawing water from the spring; contamination of spring water can result from using contaminated containers which is usually done by submerging into the water and lifting it once it is filled (Plate 1). This poses high risk of contamination of spring water with faecal and organic material, given the unhygienic manner in which the containers are handled both at home and around the Majimoto spring. Water containers are usually placed carelessly, anyhow and anywhere at home and around the spring area. Both places are highly littered with children waste from clothe washing, cow dung and donkey droppings which can easily cross contaminate the spring (Plate 2). Additionally, Maji-moto spring being the only major water source in the area during dry season could also be polluted by humans washing directly from the spring, livestock, wildlife and birds drinking directly from the spring.

Plate 2: Water containers placed anywhere and anyhow around the Maji-moto Spring

Table 5: Seasonal variation in coliform levels of wells and spring in flooded and non-flooded sites

Site	Parameter	Water source	Season				df	t-test	p-value
			Wet		Dry				
			Mean	SE	Mean	SE			
Subuku	Faecal coliforms	Wells	399.96	120.96	48.52	12.32	52	2.890	0.006*
		Spring	713.78	342.68	76.67	12.02	16	1.858	0.082
	Total coliforms	Wells	3799.78	1160.31	64.44	14.91	52	3.219	0.002
		Spring	939.78	229.19	84.44	13.35	16	3.726	0.002**
Belbur	Faecal coliforms	Wells	126.19	67.96	38.52	6.44	52	1.284	0.205
		Spring	25.56	10.69	41.11	20.51	16	-0.673	0.511
	Total coliforms	Wells	2880.59	57.04	1084.75	9.90	52	2.603	0.012
		Spring	3960.89	2306.57	41.11	20.51	16	1.699	0.109

* The difference in means between wet and dry season is statistically significant ($p<0.05$).
** The difference in means between wet and dry season is statistically highly significant ($p<0.001$).

CONCLUSIONS

The study revealed that most of the water sources measured elevated values of physicochemical and coliform in wet season. It also showed that the wells in seasonally flooded site measured higher values of physicochemical and coliform levels than those in non-flooded site. Additionally, for all sampled water sources the levels of BOD, NO_3-N, faecal coliforms and total coliforms were above the maximum allowable limits for domestic water by Kenya's Water Quality Regulation (2006), thus, the water sources are not fit for human consumption, unless the water is treated. To prevent further contamination of wells in the study area, the feedlots and pit latrines should be relocated to about 20 meters away from the water points. This will not only reduce the amount of organics and other pollutants drifting into the wells but also those seeping from feedlots and pit latrines. To protect Maji-moto spring from ingress of pollutants from catchment area and livestock drinking directly from the spring, some engineering works is required. The engineering works should collect the spring water into reservoirs, from where water can be directed through pipes to different sections such as through taps domestic purposes, to troughs for watering livestock, washing clothes and other points for bathing. Meanwhile, the study recommends that the residents should start treating drinking water by boiling, adding water-guard or by filtering. The study also recommends for further investigation to establish the exact distance the pit latrines and feedlots should be located in order to prevent further pollution of wells and to establish the exact origin of the high level of faecal pollution in these groundwater sources.

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Characterization of Rainfall Variability in Kwale County, Kenya

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ABSTRACT

The study sought to determine the magnitude of seasonal rainfall variability in Kwale County. Rainfall data for the period 1992-2011 was obtained from Kwale and Voi meteorological stations. Data was analyzed using INSTAT version 3.36 software. Coefficients of variation, cumulative departure index (CDI) and percentage cumulative mean rainfall (PCMR) were used to analyze rainfall data to determine rainfall variability. With coefficients of variation greater than 0.30 for MAM (March, April, May) and OND (October, November, December), the study findings indicate that Kwale County receives highly variable seasonal rainfall in terms of amount and number of rainy days. On the basis of the study, the following recommendations were made: (i) Rainfall received in the study area is highly variable and it is therefore important that this information is made available to the farmers and other stakeholders in a manner that is clear and understandable; (ii) The government of Kenya should empower farmers by providing simple to read, interpret and use packaged agro-meteorological products through awareness creation and training on aspects of rainfall variability and ways of reducing its effects on agricultural production; (iii) Organizations should develop and provide farmers with high yielding and drought tolerant seeds and crops to reduce effects of rainfall variability.

Key words: Seasonal Rainfall Variability · MAM rainfall · OND Rainfall · Onset · Cessation

INTRODUCTION

Food insecurity in Kenya can be attributed partly to stagnating agricultural development and rainfall variability which involves changes in rainfall totals as well as changes in rainy days (Jacob, 2010). Inter-annual rainfall variability in Africa is determined by several factors: El Nino Southern Oscillation (ENSO), Inter-Tropical Convergence Zone (ITCZ), topography, urbanization and global warming.

ENSO is the most dominant perturbation responsible for inter-annual rainfall variability over Eastern and Southern Africa (Matondo, 2010). It is associated with a bimodal rainfall pattern characterized with two rainy seasons: July, August and September (JAS) and January, February and March (JFM). ENSO occurs as a result of instabilities in air-ocean interaction in the Equatorial Pacific Ocean, characterized by variation in the temperature of the surface of the tropical eastern Pacific Ocean and air surface pressure in the tropical western Pacific. The warm oceanic phase in the eastern Pacific accompanies high air surface pressure in the western Pacific, while the cold phase accompanies the low air surface pressure in western Pacific. This results in rise in surface pressure over the Indian Ocean, Indonesia and Australia and fall in air pressure over Tahiti and rest of the central and eastern Pacific Ocean, influencing the pattern of rainfall in both regions. *La Nina* results in wetter than normal conditions in Southern Africa from December to February and drier than normal conditions over Equatorial East Africa over the same period.

On the other hand, El Nino results in wetter than normal conditions in East Africa including Kenya, Tanzania and White Nile basin.

Inter-Tropical Convergence Zone (ITCZ) also plays a very important role in determining rainfall variability in most parts of Africa, particularly along the equator. The forward and retreat pace of the African sector of the ITCZ and their ending and beginning times vary annually, causing most of the inter-annual variability in rainfall over most parts of Africa in the regions of convergence (Seleshi and Zanke, 2004). The influence of ITCZ on rainfall variability depends on its amplitude, the greater the amplitude, the more the space for precipitation and the space for precipitation is less when the amplitude is small. The amplitude varies from year to year and therefore influence inter-annual rainfall pattern (Caminade and Terray, 2010).

The presence of topographical features such as mountains, highlands, rift valleys and lowlands play a role in determining rainfall variability. On the mountainous regions of East Africa, for example, the North-South exposure contrasts are the dominant factor of rainfall variations throughout the year. South facing slopes are wetter, especially during the long rains (March to May). This is because the southerly winds are slightly wetter than those with a northerly component. East facing slopes only tend to be wetter in the short rains (October to December) and to some extent April. In the dry seasons, especially between June and September, monsoon flows tend to be strongly divergent along the East African coast and west facing slopes have more rainfall than east facing locations, which are fairly dry (Subyani, *et al.,* 2010).

According to Kovats and Akhtar (2008), urbanization to some extent is responsible in influencing rainfall variability in some parts of Africa. Urban structures affect thermal structure, water balance, wind flow and aerosols and leads to the development of urban “heat island”. Build up areas alter the physical properties of the surface and therefore influences the wind field. The roughness create eddies around the buildings and streets and free spaces channel the wind. Strong currents sometimes flow through some parts of the city. All these bring about polluted air and low humidity and in turn low precipitation.

Rainfall has been regarded as the most significant climate parameter affecting human activities (Vogel, 2000) and its variability has significantly reduced land under crop production affecting the yields, forcing farmers to adopt new agricultural techniques fitting the altered conditions. Kori *et al.,* (2012) and Allamano *et al.,* (2010) indicates that marginal rain-fed agricultural areas with low and erratic precipitation are the most vulnerable and worst affected with droughts or floods resulting in low and unpredictable level of crop production.

Detailed knowledge of rainfall regime is an important prerequisite for agricultural planning. It increases farmers’ adaptive capacity and improves agricultural production and therefore there is need to determine the magnitude of within season rainfall variability. Several studies have provided information on inter-annual rainfall variability but these efforts have neither been comprehensive nor adequate to provide sufficient information on within-season variability in terms of rainfall amount, rainy days, onsets and cessation, which directly impact on agricultural production (Caminade and Terray, 2010; Seleshi and Zanke, 2004; Ziervogel *et al.*, 2006).

MATERIALS AND METHODS

Study Area

Kwale County lies within latitudes $3^{o}30'$S and $4^{o}40'$S and longitudes $38^{o}27'$E and $39^{o}40'$E. The County borders Taita Taveta County to the West, Kilifi County to the North, Mombasa County and Indian Ocean to the East and Republic of Tanzania to the South (Figure 1). It has a total population of 649,931 people, (32% of which is classified as food insecure while 40% are in absolute poverty category) (RoK, 2010c). The County is mainly inhabited by the Duruma and Digo communities respectively but other communities such as Kamba, Kikuyu, Waitharaka, Luo, and even Europeans have significant presence (RoK, 2009; 2010c). Most of the farmers depend on rain-fed agriculture; mainly crop farming and therefore characterization of rainfall variability form a basis for understanding its effect on crop yields and broadly, the extent of vulnerability of small holder farmers. The main crops cultivated in Kwale County are maize and cassava. Other crops grown but not widespread include: beans, cowpeas, green grams, mangoes and coconuts. Some farmers keep poultry, goats, cows and occasionally sheep (Mwalonya *et al.,* 2004; RoK, 2009; 2010a).

The overall study site has monsoon type of climate; hot and dry from January to March and cool between June and August of every year. The study area experiences a bimodal rainfall pattern with the short rains occurring between October and December and the long rains occurring between March and May. The average annual rainfall ranges between 400mm and 1200mm (RoK, 2005; 2010b).

Kwale County has four major physiographic features namely; The Coastal plain, Foot Plateau, Coastal Uplands and Nyika Plateau with altitude ranging from sea level to 462m in the Shimba Hills and 842m on Kibashi Hills.

According to Jaetzol and Schmidt (2007), Kwale County is divided into 5 major AEZ's ranging from medium to extremely low agro-ecological potentials. These include: L2 (sugarcane zone), L3 (Coconut-Cassava Zone), L4 (cashew nut-cassava zone), L5 (livestock-millet zone) and L6 (ranching zone).

Administratively, Kwale County is divided into three constituencies: Matuga, Kinango and Msambweni and five divisions: Kinango, Kubo, Matuga, Msambweni and Samburu.

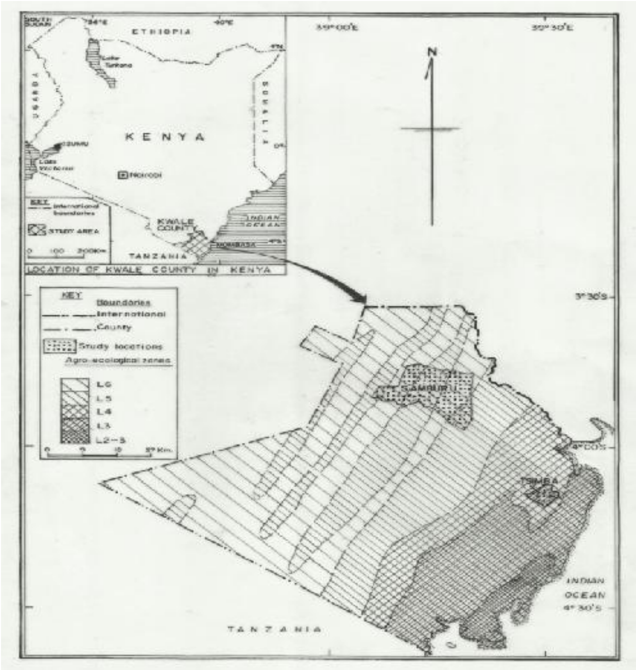

Figure 1: Location of Kwale County in Kenya, study sites and agro-ecological zone

Data Collection

Daily rainfall data for the period 1992 to 2011 was collected from Voi and Kwale Meteorological stations representing AEZ L5-6 (Samburu Location) and AEZ L4 (Tsimba Location), respectively. The choice of the rainfall stations was based on agro-ecological zones, length of data required and percentage of missing data that should be less than 10% for any given year for climatological analysis, a requirement by the World Meteorological Organization. Other rainfall stations such as Samburu, Matuga and Kinango had data that did not meet the defined threshold.

Criteria for Onset and Cessation Dates

This study employed a threshold value of 0.85 mm to define a rainy day, implying that all values less than 0.85 mm was considered to be zero. This threshold concurs with the definition of Odekunle (2006) and Kenya Meteorological Department (Shisanya, 1996). The study used onset criteria as defined by Recha *et al.*, (2012) as the day after 1st March and 1st October for MAM and OND season respectively that received at least 20 mm of rainfall totaling over 2 days with dry spell not exceeding 7 days in 30 days. Cessation date is defined as the last day before 30th June for MAM and 31st December for OND that accumulates 10 mm or more of rainfall.

Data Analysis

Data was analyzed by use of Microsoft Office Excel 2007 and INSTAT version 3.36 software. Coefficient of Variation (CV) was used to test variability in seasonal rainfall amount and rainy days. The mean for MAM and OND rainfall amount by pentad for the period under study was calculated and presented in graphs to show variability in seasonal rainfall. INSTAT version 3.36software and method of Percentage Cumulative Mean Rainfall (PCMR) were used to obtain the onset and cessation dates for MAM and OND rainfall for the period 1992 to 2011 and Cumulative Departure Index (CDI) to characterize trends in MAM and OND rainfall.

RESULTS AND DISCUSSION

Trend Analysis of Seasonal Rainfall

The cumulative departure index curves (Figures 2a and 2b) display the seasonal trends of rainfall in Kwale County. Based on analysis of rainfall data representing the area of study, Voi MAM and OND mean rainfall was 172.0 and 310.0 mm respectively while Kwale MAM and OND mean rainfall was 368.0 and 313.0 mm respectively. For the period 1992 to 2010,with the exception of 2006, Kwale station experienced below average OND rainfall (Figure 2a). The year 2006 was characterized by above average rainfall. For the period on record, cumulative departure index (CDI) results show that MAM rainfall was above average – with the exception of 1992, 1993 and 2009. The pattern is almost similar to that of annual rainfall for the Kwale station. For the same period, OND rainfall was characterized by below average rainfall with the exception of 2006. On average, MAM and annual rainfall in Kwale station depicted above average trend while OND rainfall below average. Kwale MAM rainfall shows an almost constant but decreasing trend while OND shows a slight increasing trend.

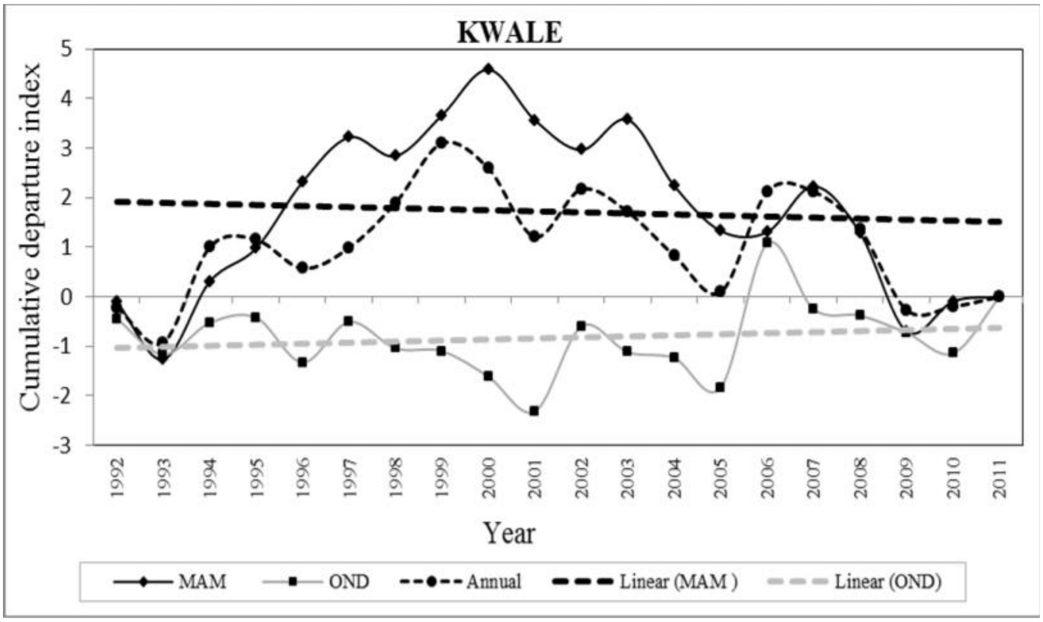

Figure 2a: Kwale cumulative departure index time-series plot
Source: Survey data, 2012

At Voi (Figure 2b), OND rainfall shows above average trend except the period 2007-2011. With annual normal rainfall ranging between 400-1200 mm, the rainfall season for MAM showed a predominantly below normal trend except for the period 1997-2001 and 2008-2011.

The results at Voi compare to those of Recha *et al.,* (2012) who established that annual rainfall had a similar pattern with OND rainfall. It was evident that OND rainfall of 1997 was below normal. This is unlike studies such as Anyamba and Tucker (2001), Amissah-Arthur (2002) and Seleshi and Zanke (2004) showing that 1997 OND season was characterized by above normal rainfall in most parts of East Africa. It is apparent from the results that for the period on record OND rainfall have been consistently below normal at Kwale when compared to MAM. While at Voi, OND had a higher seasonal rainfall contribution than MAM. On the basis of these results, farmers in AEZ L4 may need to invest more in farming during the MAM season while their counterparts in AEZ L5-6 should invest more in farming during the OND season.

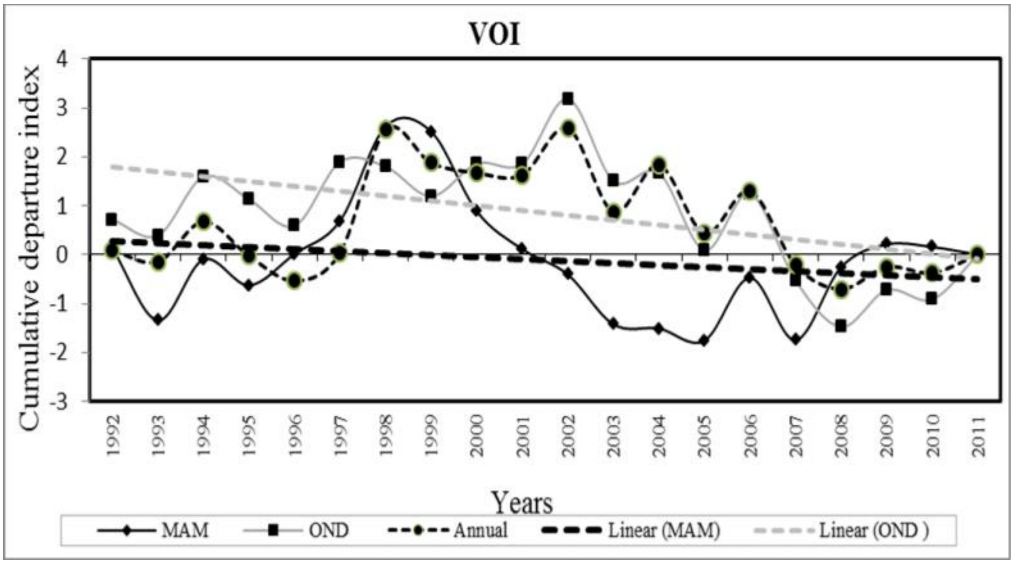

Figure 2b: Voi cumulative departure index time-series plot
Source: Survey data, 2012

The decreasing trend of Voi MAM and OND rainfall is a cause of concern as it is a sign of persistent drought that threatens agricultural production. Below average rainfall depicted in Kwale for OND rainfall suggests that these rains cannot fully support agricultural production and therefore urgent need for intervention. The decreasing trend of MAM rains as reflected at both stations is a strong signal that farmers ought to change or adjust their farming techniques. In particular, below average rains expose smallholder farmers who depend on rain-fed agriculture to hunger due to reduced yields while long period of below average rainfall could lead to loss of pasture and water and ultimately loss of livestock.

Characterization of Rainfall Variability

Rainfall Amount/Rainy Days and Coefficient of Variation (CV) for Seasonal Rainfall by Stations

Results in Table 1a and Table 1b show monthly distribution and coefficient of variation (CV) for MAM and OND rainfall season respectively. For the MAM rainfall season, March and April are wet months at Voi, while May and April are wet months at Kwale. For OND rainfall season, December and October are wet months at Voi and Kwale respectively. Kwale (368mm) receives more rainfall during MAM than Voi (172mm). However, the two stations receive nearly the same amount of rainfall during OND season. According to Araya and Stroosnijder (2011), a CV greater than 0.30 is an indicator of large rainfall variability. CV results show that at Kwale, MAM (0.42) and OND (0.50) are highly variable. At Voi however, MAM rainfall (CV=0.31) is less variable compared to OND rainfall (CV=0.45).

Table 1a: Rainfall amount (RA) by months and season and coefficient of variation (CV) for MAM Rainfall Amount (RA)

Station	AEZ	March-RA	April-RA	May-RA	MAM-RA	Std Dev	CV
Voi	L5-6	75.95	72.40	23.54	171.89	53.64	0.31
Kwale	L4	42.53	119.97	205.52	368.02	153.82	0.42

Source: Survey data, 2012

Table 1b: Rainfall amount (RA) by months and season and coefficient of variation (CV) for OND rainfall amount (RA)

Station	AEZ	Oct-RA	Nov-RA	Dec-RA	OND-RA	Std Dev	CV
Voi	L5-6	29.52	161.71	119.21	310.44	141.20	0.45
Kwale	L4	126.20	120.19	66.26	312.64	155.06	0.50

Source: Survey data, 2012

Tables 2a and 2b show results of number and co-efficient of variation of rainy days and CV for Voi and Kwale stations. April and May are very wet months during the MAM season at Voi and Kwale respectively. While December and October/November are very wet months at Voi and Kwale respectively. This is the same pattern depicted by rainfall amount.

Table 2a: Rainy days (RD) by months and season and coefficient of variation (CV) for MAM rainy days (RD)

Station	AEZ	March-RD	April-RD	May-RD	MAM-RD	Std Dev	CV
Voi	L5-6	7	9	6	21	6.83	0.32
Kwale	L4	3	7	9	19	7.42	0.39

Source: Survey data, 2012

Table 2b: Rainy days (RD) by months and season and coefficient of variation (CV) for OND rainy days (RD)

Station	AEZ	Oct-RD	Nov-RD	Dec-RD	OND-RD	Std Dev	CV
Voi	L5-6	5	11	12	28	9.36	0.33
Kwale	L4	6	6	5	17	6.38	0.37

Source: Survey data, 2012

Tables 1a and 2a indicate that though Kwale station had fewer rainy days, it received more rain during MAM averaging 368.0 mm compared to Voi which had a MAM mean rainfall of 172.0 mm across the same study period. Table 1b shows that there is no much difference in mean seasonal rainfall for the period. Kwale station exhibited a mean value of 312.6 mm for the period OND and Voi a mean value of 310.4 mm for OND. The relatively higher MAM rainfall at Kwale as compared to Voi station suggests that the AEZ L4 has a better chance to support rain-fed agriculture during the MAM season as compared to AEZ L5-6. The mean OND rainfall suggests that the condition of the two AEZs is relatively similar. Comparatively, the mean rainfall received in the two AEZs is low suggesting that the farmers in the study area should grow early maturing, and drought tolerant crops in order to improve crop yield production, while livestock farmers should shift focus to producing alternative livestock feeds and reduce their reliance on natural pasture that cannot be sustained by the low and highly variable rains.

Mean Rainfall Amount received during MAM and OND Seasons by Pentads

Figure 3a shows that most of the MAM rains at Kwale are received in May with the peak during the 4th pentad of May. Kwale MAM rains depict seasonal variability with an increasing trend. Voi MAM rains show a decreasing trend with the peak during the 5th pentad in March. Figure 3b on the other hand, shows that Voi long rains spans the period March to May while Kwale MAM rains extend into June. The rainfall peaks (4th pentad of May in Kwale and 5th pentad in March in Voi) are important to farmers as it guides them on the cropping season in order to make good use of rain water

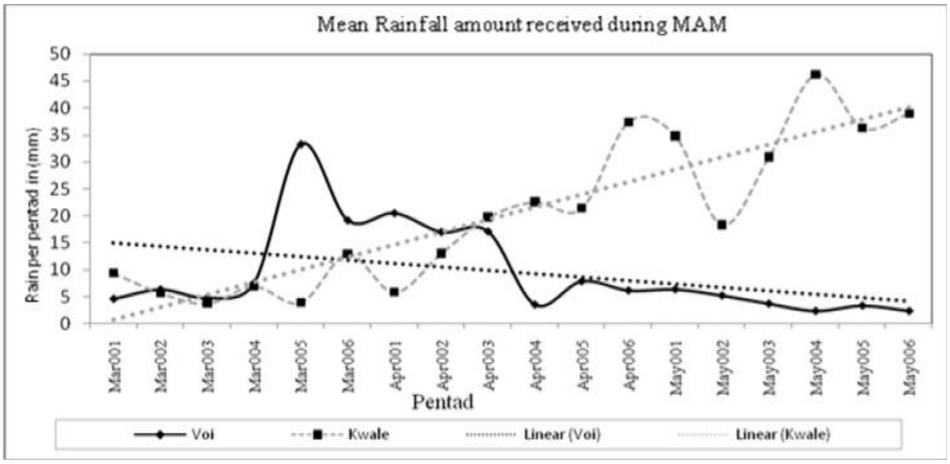

Figure 3a: MAM mean rainfall amount by pentads
Source: Survey data, 2012

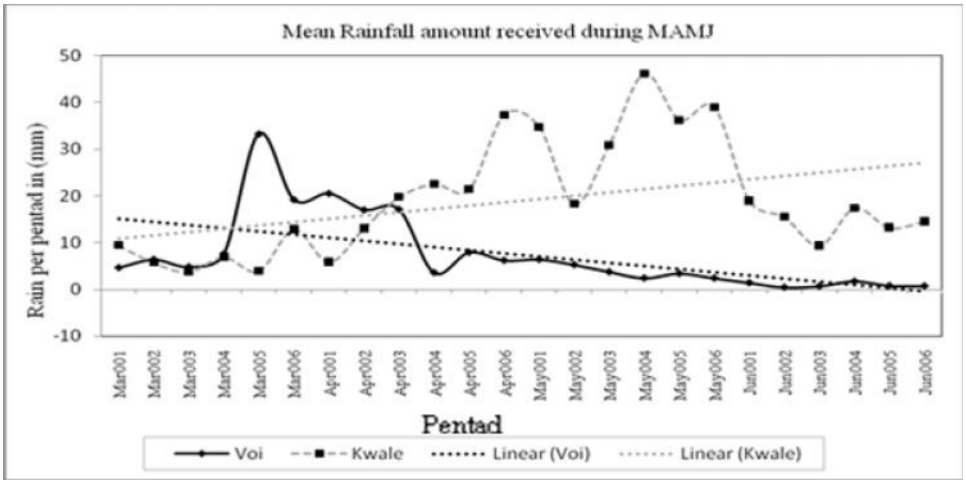

Figure 3b: MAMJ mean rainfall amount by pentads
Source: Survey data, 2012

Onset and Cessation of Seasonal Rainfall

It is noted from Figure 4 that while Kwale OND rainfall is characterized by a decreasing trend, Voi OND rainfall is characterized by an increasing trend in amount received across the rainy season. Kwale OND rains peak during the 6th November pentad while Voi OND depicts a low peak during the 4th pentad of October. It is evident from Figures 3a and 4 that all the rainy season months experienced within-season variability in rainfall received except for the month of May at Voi and December at Kwale which indicated a decreasing trend. Apart from the 1st pentad of April, Voi station received less than 20 mm of rainfall per pentad during MAM. At Kwale station, all March pentads and 1st – 3rd pentads of April received less than 20 mm of rainfall per pentad during MAM. During OND, 50% and 55.6% of the pentads received less than 20 mm of rains per pentad at Voi and Kwale stations, respectively suggesting that the rainfall received is not sufficient to support rain-fed agricultural production.

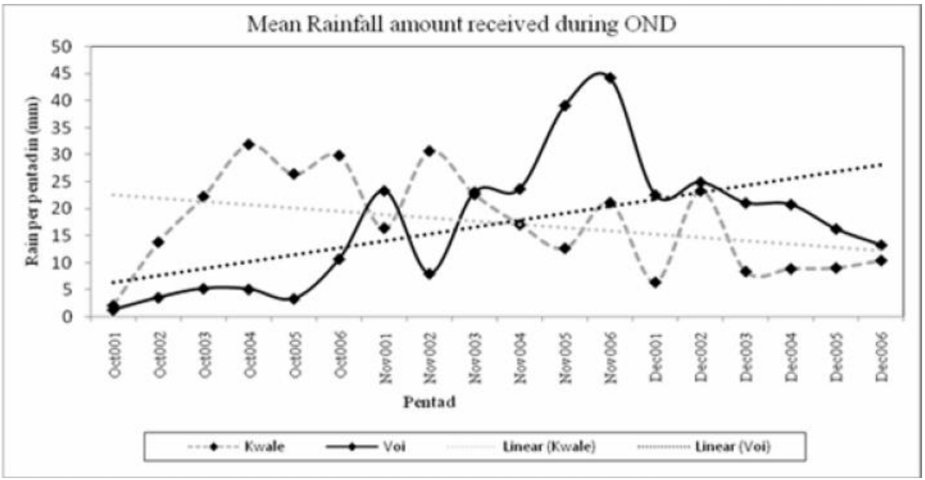

Figure 4: OND mean rainfall amount by pentads
Source: Survey data, 2012

From Figures 5 and 6, it is evident that Voi MAM onset is in 5^{th} pentad of March while Kwale MAM onset is in the 2^{nd} pentad of April. This implies that the start of rains at Voi is between 21^{st} and 25^{th} March, while Kwale experiences late MAM onset at around 6^{th} – 10^{th} April. Voi experiences an early onset in the 2^{nd} pentad of October (6^{th} – 10^{th} October) while Kwale OND onset is in the 4^{th} pentad of October (21^{st} – 25^{th} October).

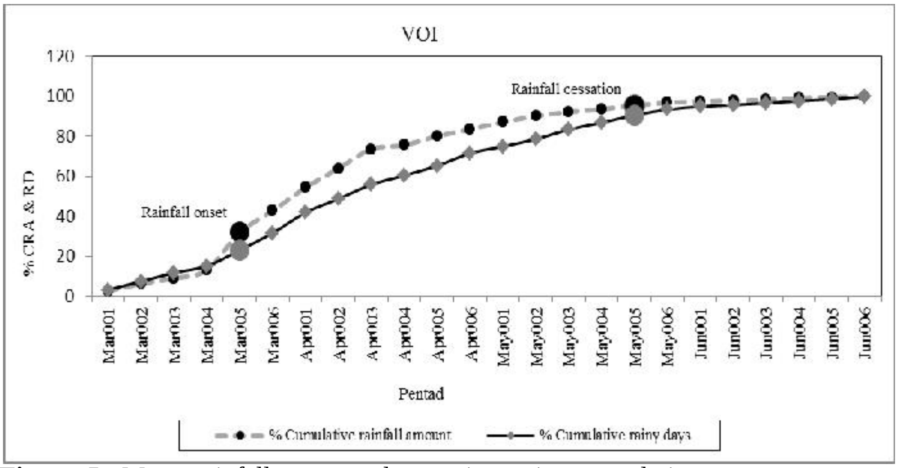

Figure 5: Mean rainfall onset and cessation using cumulative percentage mean for Voi MAM season
Source: Survey data, 2012

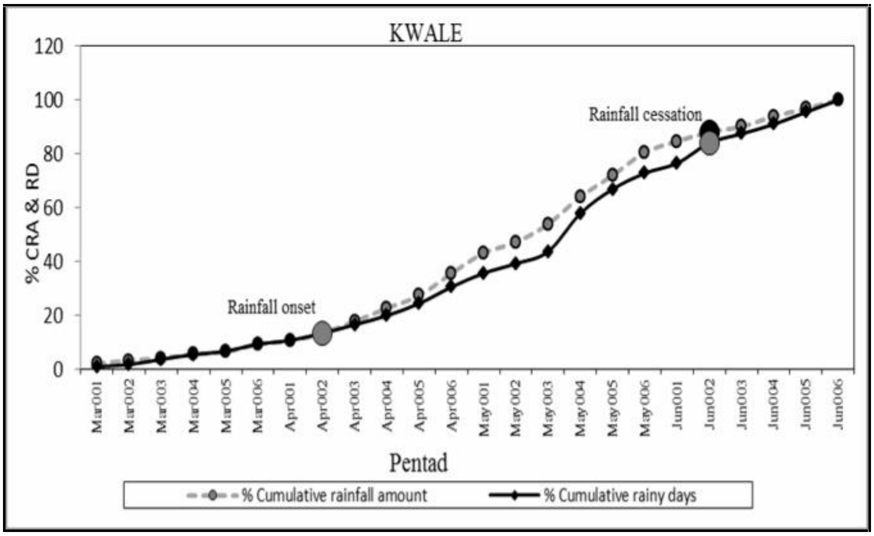

Figure 6: Mean rainfall onset and cessation using cumulative percentage mean for Kwale MAM season
Source: Survey data, 2012

Figures 5 and 6 further show that Voi MAM rainfall retreats in the 5th pentad of May around 21st – 25th May, while Kwale MAM rainfall has a late retreat in the 2nd pentad of June, around 6th – 10th June. Figure 7 indicates that Voi OND retreats in the 6th pentad of December (26th – 31st December) and Figure 8 shows that Kwale OND rainfall retreats in the 5th pentad of December, around 21st – 25th December. The retreat comes after approximately 95% of rains have been received. Kwale experiences late retreat which can be attributed to strong localized influences such as the presence of Shimba-Hills forest and the Indian Ocean (Mugalavai *et al.,* 2008). The variability in the onset and cessation dates implies that the planting dates across the AEZs in Kwale County are not uniform. This is important for effective and efficient planning of agricultural activities across the agro-ecological zones in Kwale County. This information is important to farmers to establish when and what to plant to ensure maximum utilization of rain water and possible increase in yields. It is also useful in determining the type of crops to grow and livestock variety to keep based on the length and pattern of the rainy season within the agro-ecological zones.

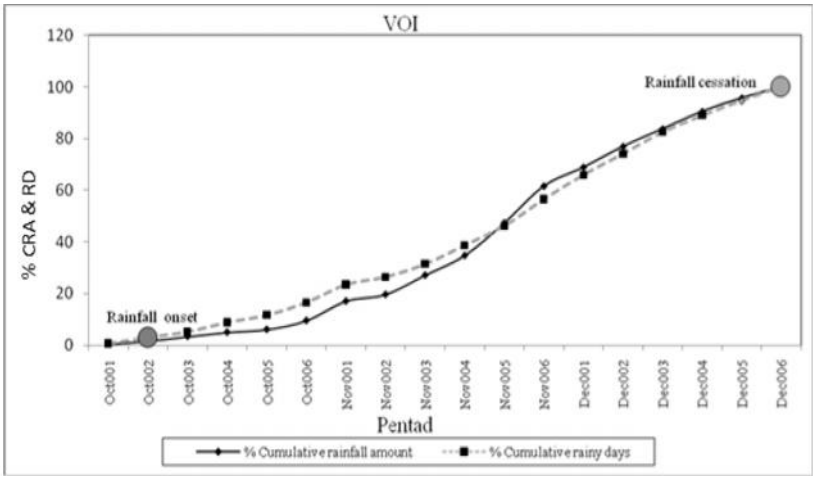

Figure 7: Voi OND mean onset and cessation using cumulative percentage mean
Source: Survey data, 2012

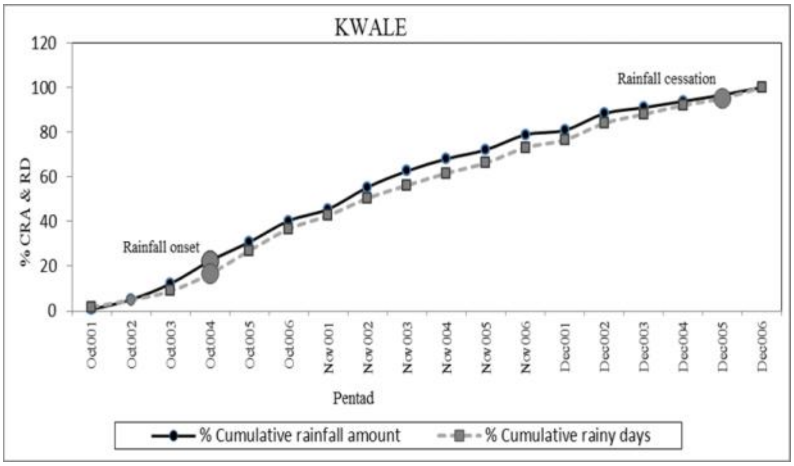

Figure 8: Kwale OND mean onset and cessation using cumulative percentage mean
Source: Survey data, 2012

Figures 9 and 10 display inter-annual variability for OND and MAM onsets for the period under study. OND and MAM onsets are highly variable at Voi and Kwale, respectively. The latest OND onset occurred at Voi in 2003 during the 16th pentad (16th – 20th December). There was no OND onset at Voi in 2005 and 2007, an indication that the OND rains failed leading to loss of crops and livestock. On average, Kwale exhibited early OND onsets compared to Voi. Though OND onsets at Voi show a decreasing trend, Kwale experienced almost constant onsets occurring in the 5th pentad (21st – 25th October) between 2004 and 2007.

MAM onsets depict a different trend with Kwale having an increasing trend and Voi an almost constant trend with most onsets during the 5th pentad (21st – 25th October). This is evidence of seasonal variability in OND and MAM onsets. A late MAM onset was recorded at Kwale in 2009 during the 20th pentad (6th – 10th June). Early MAM onsets were realized in 1995, 2000 and 2002 in the 1st pentad (1st – 5th March). The high variations that characterize rainfall onset make agricultural planning difficult for farmers (Recha *et al.*, 2012), but the smallholder farmers can find hope in improved skills of seasonal climate forecasts (Recha *et al*., 2008).

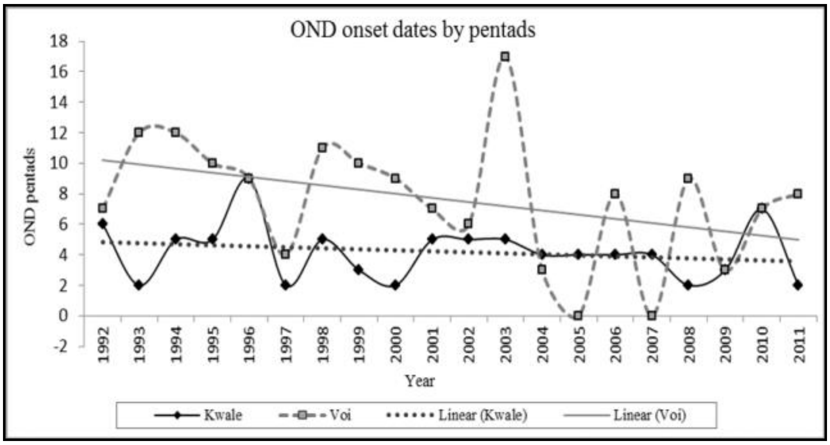

Figure 9: Estimated OND onsets by pentads
Source: Survey data, 2012

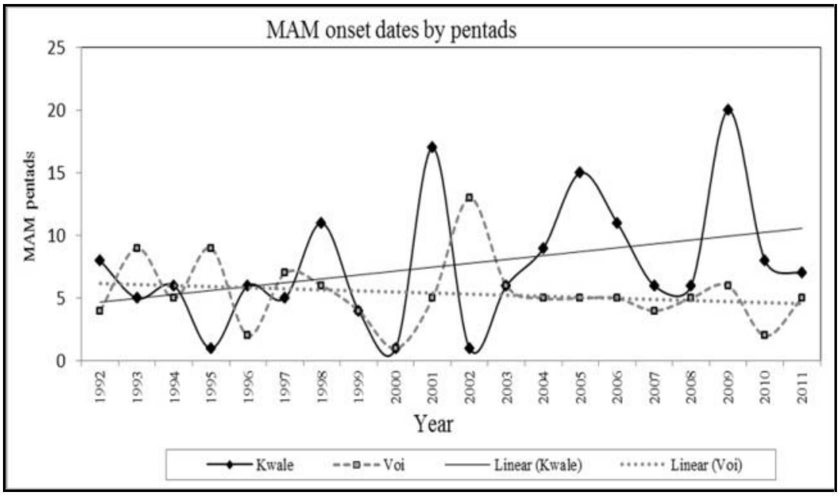

Figure 10: Estimated MAM onsets by pentads
Source: Survey data, 2012

Figure 11b indicates no OND cessation in 2005 and 2007 at Voi station. This is because there was no OND onset during the same period (Figure 9). While Kwale depicts an almost constant trend in cessation across the years under study, Voi depicts a decreasing trend influenced by the two outlier values (for 2005 and 2006). An almost constant trend in cessation for Voi is obtained when the two outlier values are eliminated (Figure 11a). Figure 11b exhibits inter-annual variability on OND cessation across the period under study, with most cessation dates occurring during the 18th pentad (26th – 31st December).

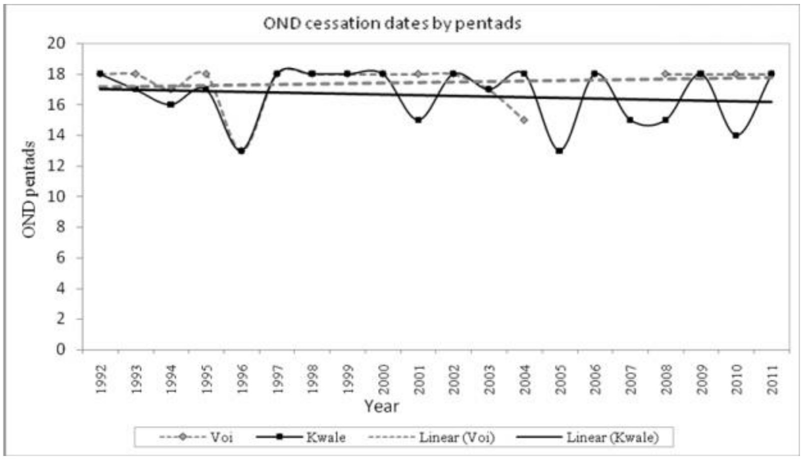

Figure 11a: Estimated OND cessations by pentads with edited outlier values
Source: Survey data, 2012

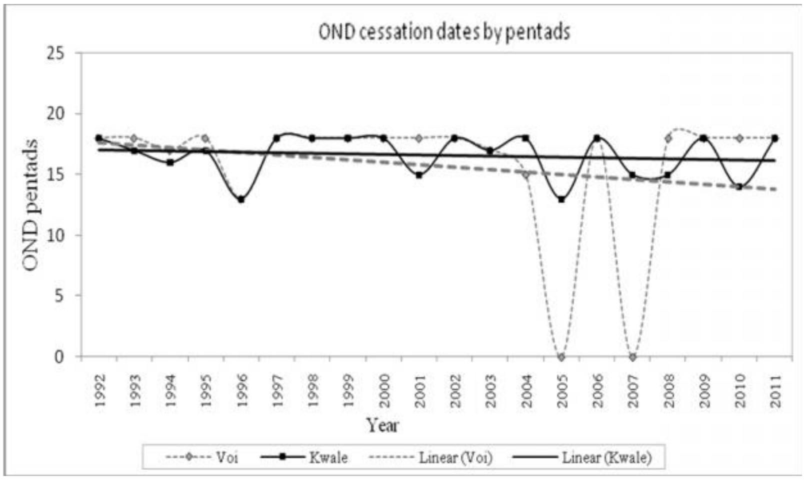

Figure 11b: Estimated OND cessations by pentads
Source: Survey data, 2012

Figure 12 shows that the MAM cessation dates for individual years are highly variable. It also reflects that on average, Kwale has late cessation dates across the period on record as compared to Voi. Late cessation dates were recorded at Kwale in 1993, 1994, 2003, 2004, 2009. The retreats occurred during the 24th pentad of MAM season (26th – 30th June).

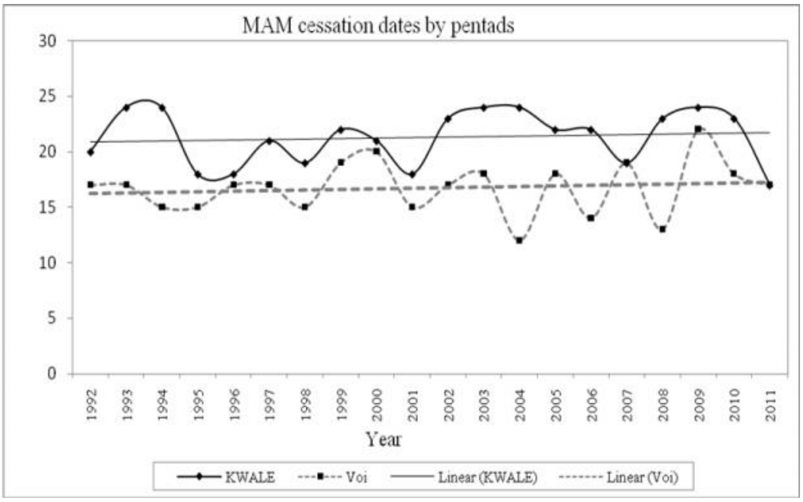

Figure 12: Estimated MAM cessations by pentads
Source: Survey data, 2012

CONCLUSION & RECOMMENDATION

Kwale County receives highly variable inter- and intra-seasonal rainfall in terms of rainfall amount, rainy days, onset and cessation dates. The pattern has negative effects on crop and livestock production in the study area. These areas can no longer support rain-fed crop farming during the MAM season, calling for implementation of various adaptation strategies to reduce vulnerability.

In view of the foregoing conclusions, it is important that this information is made available to the farmers and other stakeholders in a manner that is clear and understandable so that corrective actions are taken. The Government in collaboration with NGOs, and CBOs should come up with strategies and activities that would help to empower the small holder farmers.

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Chemical Composition of Cactus (*Opuntia ficus-indica*) and Prosopis Species (*Prosopis juliflora*) as Drought-resilient Feed Resources in Kenya

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ABSTRACT

Lack of quality feeds is a threat to pastoral production systems that are central to the livelihoods of rural communities in Kenya. Inadequate feed quantity and deficiencies in feed quality are aggravated by the current weather variability due to climate change. Prosopis and Cactus plant species are drought tolerant and can be potential alternative feed resources for pastoral communities. The current study was carried out to determine the feed value of these two plant species. Sampling was done in Baringo, Laikipia, Naivasha and Machakos counties. Different plant parts were sampled for chemical analysis using Near Infra-red Reflectance technique. Old and young leaves, a ripe and unripe fruit of different cactus species, mature and young barks, green and dry leaves and pods and seeds of *Prosopis juliflora* were sampled for analysis. Dry matter ranged from 158 to 180 g/kg DM for young and mature cladodes of spineless Opuntia, respectively and 153 to 172 g/kg DM for young and mature cladodes of spiny Opuntia, respectively. Crude fibre (CF) ranged from 134 to 305 g/kg DM for spiny young and old Opuntia, respectively and 254 to 323 g/kg DM for spineless Opuntia species (young and mature cladodes). CF content of Opuntia species increased with increase in maturity. High content of starch was observed in all the Opuntia species. Higher starch content was reported in the mature cladodes than the young ones. Spiny Opuntia had higher starch content ranging from 61 to 243 g/kg DM (young and mature cladodes respectively) as compared to spineless Opuntia which ranged from 61 to 95 g/kg DM. High contents of starch was also observed in both ripe and unripe fruits of spiny Opuntia, ranging from 136 to 146 g/kg DM (unripe and ripe spiny Opuntia fruits respectively). Mature cladodes of spiny Opuntia had higher ash contents than young shoots, ranging from 39 to 54g/kg DM (young and mature cladodes, respectively). Old barks of *P. juliflora* had the highest ash content (144 g/kg DM) as compared to other parts, with 124 g/kg DM reported for the young barks. Prosopis seed had the highest crude protein (CP) content (400 g/kg DM), and starch contents (129 g/kg DM). High CP content (150 g/kg DM and 200 g/kg DM) was reported for dry and green leaf meals respectively. The study revealed high contents of starch in Opuntia spp, high CP content in Prosopis pods, seed and leaf meals. The high energy and CP pools available in Opuntia species and *P. juliflora* can be exploited as livestock feed supplements in rangelands experiencing energy and protein imbalances due to feed quality variability and frequent droughts posed by climate change.
Key words: Resilience, Climate change, Livestock, Feeds

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INTRODUCTION

The declining animal feed supply and quality in arid and semi-arid regions has been aggravated by scarce and erratic rainfall that limits the growth of herbaceous species and biomass in rangelands. Thus, livestock in such regions have to survive on recurrent shortage of feed resources of insufficient nutritional value for most of the year (Robles *et al*, 2008). These drought conditions, exacerbated by climate change will force pastoral communities to look for alternative plants species as forages. Cactus species and *P. juliflora* are such lesser-known and under-utilized feed resources in Kenya.

Although Prosopis species has been reported to improve livestock production in the Kenya's rangelands, pastoral communities have perceived it as a noxious plant responsible for decay of animals' teeth, with subsequent death due to starvation. The problem of *Prosopis* species has elicited mixed reactions by the communities in Baringo County (Syomiti, Unpublished data). In the absence of concrete information about the nutritional significance of Prosopis species in addition to negative community perceptions about its forage value there are many that have expressed the need for an external support to manage its spread or eliminate it altogether and replace it with desirable plant species. However, *Prosopis* species can provide many of the needs of populations living in dry lands of the world, and have the potential to provide much more if knowledge on their utilization is expanded. For instance, a feeding trial in India on livestock using rations containing up to 45% of *Prosopis* species components yielded a 1.5% of cattle body weight with acceptable live weight gains (Tewari *et al*, 2000).

On the other hand, cactus (*Opuntia ficus-indica*) is drought tolerant and makes use of little moisture in the rainy season to produce large quantities of forage and has high carrying capacity than any other drought tolerant fodder in arid and semi-arid areas (Tegegne, 2001). It remains green and succulent during drought thus supplying the much needed energy, water and vitamins to livestock in dry periods. *Opuntia ficus-indica* withstands severe defoliation and has good regeneration ability. This plant material can be easily and inexpensively established and is quite promising because of its low maintenance costs. Due to its anatomic and physiological constitution, Cactus withstands a wide range of soil types as well as harsh climatic conditions. Thus, the development of plausible pastoral systems should incorporate Cactus establishment as a suitable soil conservation plant material. It is also a promising plant for arresting desertification (Nefzaoui and Ben salem, 2001 and De kock, 1980). The fact that Cactus combines drought tolerance and water use efficiency, it produces a large quantity of forage that remains green and succulent in dry periods and makes it the best fodder option in the changing climatic situations (Nefzaoui and Ben salem 2001. The purpose of the current study was to establish the feed value of cactus species and *P. juliflora* as potential, alternative drought- resilience feed resources in Kenya's rangelands.

MATERIALS AND METHODS

Location of the Study

The study was carried out in four pilot administrative counties of Baringo, Laikipia, Naivasha and Machakos, Kenya. Purposive selection of these study sites was used due to availability of large tracks of spiny and spineless cactus species (Plate 2) and *P. juliflora* (Plate 1). These zones are located in agro-ecological zones IV and V, with annual rainfall between 500-1000 mm and 300-600 mm respectively.

Sampling of plant materials

Different parts of spiny and spineless cactus species and *P. juliflora* sampled for nutritional evaluation were; young and mature cladodes/shoots, ripe and unripe fruits, *P. juliflora* leaves (green and dry), pods (green and dry) and bark (from a mature and young tree stem). A duplicate sample weighing 500 g was collected and dried in an oven at 60°C for 48 hours, ground to pass through a 1-mm sieve and stored in plastic bottles at room temperature for subsequent chemical analyses.

Plate 1: Goats browsing on prosopis in Marigat (Source: Syomiti, Unpublished data)

Plate **2:** Cactus sampling activity in Baringo Source: Syomiti, Unpublished data

Chemical analysis

Dry matter (DM) content of the feed, crude protein (CP), crude fibre (CF), starch and ash were determined by the Near Infra Red reflectance (NIR), at Chrom Africa labs, Nairobi.

Data analysis

Statistical package for social sciences (SPSS) version 20 was used for data analysis for computation of nutrient means.

RESULTS

Cactus (Opuntia ficus-indica)

The chemical composition of different parts of Cactus species are shown in Table 1. The results indicated that chemical composition of different plant parts varied greatly between species and maturity stage.

Table 1: Chemical Composition of Different parts of Cactus and *P. juliflora* species (g/kg DM)

Species	Part	Chemical composition				
		DM	CP	CF	Starch	Ash
Spineless cactus	Mature cladodes	180	115	323	95	44
	New cladodes	158	145	254	61	26
Spiny cactus	Mature cladodes	172	120	305	243	54
	New cladodes	153	135	134	61	39
	Ripe fruit	120	111	327	146	9
	Un-ripe fruit	133	122	294	136	32
Prosopis species	Young leaves	890	263	142	110	98
	Mature leaves	900	143	192	42	20
	Mature green leaves	627	200	186	-	110
	Mature dry leaves	833	150	230	-	59
	Dry Pods meal	926	218	322	107	79
	Green pods meal	780	109	275	25	88
	Ground Seed meal	920	400	-	129	-
	Mature bark	910	0	860	126	144
	Young bark	890	33	584	79	124

The CP content of spineless Opuntia spp was higher than that of spiny Opuntia ranging from 115 to 145 g/kg DM (for mature and young cladodes respectively), and 120 to 135 g/kg DM (for mature and young cladodes) respectively. Variations were observed between CP content of young and mature cladodes of both spiny and spineless Opuntia species (Table 1). Low contents of dry matter (DM) and crude fibre (CF) were also reported in both spiny and spineless Opuntia species. Dry matter ranged from 158 to 180 g/kg DM (young and mature cladodes of spineless Opuntia respectively) and 153 to 172 g/kg DM (young and mature cladodes of spiny Opuntia species respectively). Crude fibre ranged from 134 to 305 g/kg DM for spiny Opuntia species (young and old Opuntia species) and 254 to 323 g/kg DM for spineless Opuntia species (young and mature cladodes).

Variations in CF were also observed in young and old cladodes of both spiny and spineless Opuntia species, with increase of CF content with plant maturity. However, higher content of starch was observed in all the Opuntia species cladodes. Higher starch content was reported in the mature cladodes than the young ones (Table 1).

Table 2: *Prosopis spp* pods in comparison with other sources of non-conventional animal feed ingredients

Feedstuff	ME (MJ/kg DM)	CP (%)	CF (%)	Cost (Kes/Kg)	Rank (Weighted Index)
Prosopis seed meal	9.9	399	7.3	-	1
Sunflower seed cake	7.95	27	28	24	3
Prosopis pod meal	12.95	21.8	20.1	-	4
Maize germ	11.51	12.4	10.2	21	7
Wheat bran	8.37	15.5	15	18.4	5
Molasses	9.8	2.9	0	35	10
Rice polishing	10.04	8.2	31.9	18	9
Acacia tortilis leaves	-	11.7	21	-	8
A. tortilis pods	9.19	14.5	24.7	-	6

Source: Kyuma, (2010), Syomiti, (Unpublished data)

Note: Calculation of a weighted index of the nutrient composition of key nutrients is commonly used in rating of feedstuffs

Spiny Opuntia had higher reported starch content ranging from 61 to 243 g/kg DM (for young and mature cladodes respectively) as compared to spineless Opuntia cladodes which ranged from 61 to 95 g/kg DM. High contents of starch was also recorded in both ripe and unripe fruits of spiny Opuntia species ranging from 136 and 146 g/kg DM (unripe and ripe spiny Opuntia fruits respectively). Mature spiny Opuntia cladodes had higher recorded ash contents than young shoots, which ranged from 39 to 54g/kg DM (young and mature Opuntia cladodes respectively).

Prosopis juliflora

The chemical composition of different parts of *P. juliflora* is shown in Table 1. Mature barks of *P. juliflora* had the highest ash content of 144 g/kg DM as compared to other parts, with ash content of 124 g/kg DM reported for the young barks (Table 1). Prosopis seed meal had highest reported CP content (399 g/kg DM) and starch contents of 129 g/kg DM (Table 2). Young Prosopis leaf meal had higher reported CP content of 260 g/kg DM as compared to 146 g/kg DM for older shoots.

DISCUSSION

Cactus (Opuntia ficus-indica)

Spineless Opuntia species had higher recorded levels of CP content than that of spiny Opuntia species. This can be attributed to the formation of the spines, which can be speculated that some of the plant protein is channeled to spine formation with subsequent lignifications of these spines. Variations observed between CP content of young and mature cladodes of both spiny and spineless Opuntia species (Table 1) is in agreement with Mustafa *et al (*2007) who reported higher CP content of soybean straws as the plant matured. Low contents of DM and CF reported in both spiny and spineless Opuntia species were expected. According to Ben Salem *et al* (1996), Opuntia species is a succulent plant with approximately 90% water, which can sustain livestock without water for about 60 days in drylands which experiences water scarcity.

The reported low CF contents of Opuntia is in agreement with findings by Firew *et al.* 2007, who reported average low CF content of 14.5% in Oputnia species. Strategic supplementation of Opuntia species with high DM content feeds such as cereal straws and hay is required to control bloat and oxalate poisoning in Opuntia (Nefzaoui and Ben Salem, 2001). Higher content of starch was observed in all the Opuntia species cladodes, with higher starch content reported in the mature cladodes than the young ones (Table 1). Opuntia being a succulent drought tolerant plant with high reported starch content can be effectively utilized as non-conventional feed ingredient in ration formulation in rangelands. Spiny Opuntia species had higher reported starch content (with higher reported levels for mature spiny cladodes than young spiny cladodes) as compared to spineless Opuntia cladodes. High contents of starch were also recorded in both ripe and unripe fruits of spiny Opuntia species.

These results reveal that starch content of Opuntia species increases as the plant matures. This would be useful information with respect to domestication and agronomic management of Opuntia as livestock feed. Higher starch content in spiny Opuntia can be attributed to the spines, which upon hydrolysis can be reduced to simple sugars. However, the spines pose a limitation as livestock feed. According to Kang'ara and Gitari (2010), the spines can be eliminated by passing the cladodes through a borne fire for livestock feeding. This is in agreement with reports by Syomiti (Unpublished data), where agro-pastoral communities in Nyeri North used cactus to feed their livestock during droughts and applied fire to remove the spines.

Prosopis juliflora

Highest ash contents reported in the mature barks of *P. juliflora* is an indicator of high mineral content. Prosopis seed meal was reported to have the highest levels of CP content, which is also higher as compared to those of other conventional feed supplements such as sunflower seed cakes (Table 2). This indicates that *P. juliflora* can be a valuable non-conventional protein supplement for livestock in dry lands. However, inclusion levels in feed rations is required due to the fact that livestock, mainly small ruminants were reported to lose teeth after consuming large quantities of *P. juliflora* (Choge *et al.* 2002), with subsequent starvation to death. Reports by Kyuma (2013) indicated that pastoral communities perceived prosopis species as a noxious weed. Prosopis leaf meal had substantial CP content in both dry and green leaf meals. Although higher CP content was recorded in green leaf meal of Prosopis species, it is reported to have high anti-nutritional factors owing to mainly condensed tannins, which reduces bioavailability of this nutrient to the animals. Slow drying in a shade can reduce the tannins levels thereby increasing the feed intake (Koech *et al*. 2011).

CONCLUSIONS AND RECOMMENDATIONS

The study confirms high energy and crude protein in cactus and Prosopis species respectively, which are deficient nutrients in arid and semi-arid regions. Therefore, cactus (Opuntia) species, Prosopis seed and pod meals are ideal non-conventional feedstuffs, and are recommended as alternative feed resources for substituting scarce conventional protein and energy feed sources in Kenya's dry lands.

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Assessment of the Effects of *Jatropha Curcas L.* on Food Crop Production in Kibwezi, Shimba Hills and Bondo, Kenya

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ABSTRACT

Bio-fuels are being promoted as a climate friendly alternative to conventional oil and *J. curcas* in Kenya has offered opportunity to remedy the protection of the environment and oil crisis. It is highly resistant to drought and therefore best suited for the harsh weather conditions. *J. curcas* is a well established plant in India that produces oil-rich seeds and is known to thrive well on degraded lands and requires limited amounts of water. This plant can be cultivated on degraded lands to produce oil suitable for use as a bio-fuel. However, there is little data on the impacts of *J. curcas* on the environment and food production in Kenya. The aim of this study was therefore to assess the effects of *J. curcas* on food production in Kibwezi, Shimba Hills and Bondo, Kenya. A cross-sectional survey research design was employed whereas data collection was by the use of structured questionnaires and observation schedules. Results show that in Bondo, Kibwezi and Shimba Hills, cultivation of *J. curcas* does not threaten food security hence does not affect crop production at household level. A combination of maize, pigeon peas and cassava was very common. Planting *J. curcas* would improve the vegetation cover of Kibwezi, Shimba Hills and Bondo. Farmers should be encouraged to plant *J. curcas* along with food crops to avoid clearing the natural vegetation as well as maintain household food crop production.

Key Words: *Jatropha curcas*, bio-fuels, climate change, impacts

INTRODUCTION

Economic, environmental and energy security concerns arising from the use of petroleum are forcing countries in the world to shift to alternative fuels such as the bio-fuels. Kenya, like other countries has been severely hit by the negative effects of climate change. *Jatropha curcas* is considered to be a viable bio-energy feedstock in Kenya due to its adaptability in arid and semi-arid areas. It is a multipurpose and drought resistant tree that can be used in the production of bio-fuels and reduce carbon dioxide emissions and make a country more self-reliant in its food needs. The trees are deciduous; shedding their leaves in the dry season (Maes *et al.*, 2009). The seeds can be pressed to obtain oil, with a resultant seedcake rich in nitrogen that can in turn be used as fertilizer. The seed oil can be used for soap production, an insecticide, for medicinal purposes, animal feed and to produce biogas (Heller, 1996). Because of its toxicity, it is not browsed by animals. *J. curcas* can be used to control soil erosion,

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especially in semi-arid areas as it increases vegetative cover to decrease soil erosion and land degradation (Tigere, *et al.,* 2007). *Jatropha curcas* plantations have an advantage especially where soil quality is poor and barely sustains other crops. In addressing food security issues in Kenya, extension service providers within the Government, NGOs, private sectors and community organizations have programs that empower farmers to identify their priorities and make demands on the service they need to solve their problems (Kinyua, 2004). If the Government of Kenya's policy concerning bio-fuel cultivation is well implemented and recommended only in arid and semi-arid regions, then the general conditions are supposed to improve especially in terms of economic situations and land rehabilitation. Shimba Hills, Bondo and Kibwezi fit well into these marginal lands and *J. curcas* can be adopted as a biodiesel feedstock. So far more than 4,000 farmers in Kenya have embraced *J.curcas* cultivation.

MATERIALS AND METHODS

Descriptions of the Study Areas

Kibwezi, Eastern Province

Kibwezi (Figure 1) is a dry and hot area with little rainfall (550-670 mm) and high temperatures of 24°C. The district experiences high temperatures during the day and low temperatures at night. Most parts of the region are semi-arid although areas below 670 metres above sea level are generally arid. Soil types vary between sand, loam and clay. The major economic activity is mixed farming mainly for subsistence purposes. The area experiences crop failure due to drought (Drought Monitoring Bulletin, 2009). The major food crops grown are maize, beans, pigeon peas and cow peas. The main cash crops grown in the district are coffee and cotton. Horticultural crop farming is also undertaken but in small holdings on individual farmer basis though surplus may be exported. The major sources of energy in the district are diesel driven generators, wood-fuel, and charcoal. Solar energy and biogas sources of energy are not very common. *J. curcas* has been growing in the region mainly as hedges (GTZ, 2008).

Shimba Hills, Coastal Province

Shimba Hills (Figure 1) is a hot and dry area with medium to high agricultural potential. Most parts of Shimba Hills fall in the semi-humid zone with average rainfall of 400-1300 mm. Soils vary with topography and geology of the area. The sandstone and grit on the coastal range yield a fairly good, that is well stated for cultivation. The average annual temperature range from 25°C to 26.6°C. Vegetation cover is sparse with overgrazing, being a major contributor to soil erosion. Most of the farming in the region is small scale. The major economic activity is farming, with maize, cassava and rice as the main food crops, while coconut, cashew nuts and cotton are the main cash crops (DSA, 2009). The most common source of energy in the district is fuel wood; however, it is becoming scarce as the existing bush lands are cleared for farming (Kwale District Development Plan, 1997-2001).

Bondo, Nyanza Province

Bondo region falls in agro-climatic zones ranging from humid in high altitude areas (1,400-2,000 metres), sub-humid (1,200 to 1,400 metres) and semi-humid (1,100 to 1,300 meters) (Figure 1). This region has diverse soil types, though mainly loamy and black cotton soils. Vegetation type is mostly bush land and dry woodland. The district experiences a bimodal rainfall with an average of 1100 to 1350mm and means temperatures of 22°C. Humidity is relatively high.

The county is a mixed farming area; however farming is done mainly for subsistence. The major cash crops in the district are sugarcane, cotton and coffee. Most cultivated land is under food crops such as maize, sorghum, beans, cassava, finger millet and sweet potatoes. Groundnuts, beans, and soya beans are dual purpose crops which serve as cash crops and food crop. The most important source of household energy in Bondo is wood fuel while other sources of energy are paraffin and electricity. The other alternative forms of energy such as biogas, solar and wind power are not much used for lack of appropriate technology. Industrialization has not taken firm root despite the potential in agro-processing industries and fish processing. *J. curcas* has been grown in this region and has always been used as a medicinal plant (Bondo District Development Plan, 1997-2001 and District Environment Action Plan 2006-2011 for Bondo District).

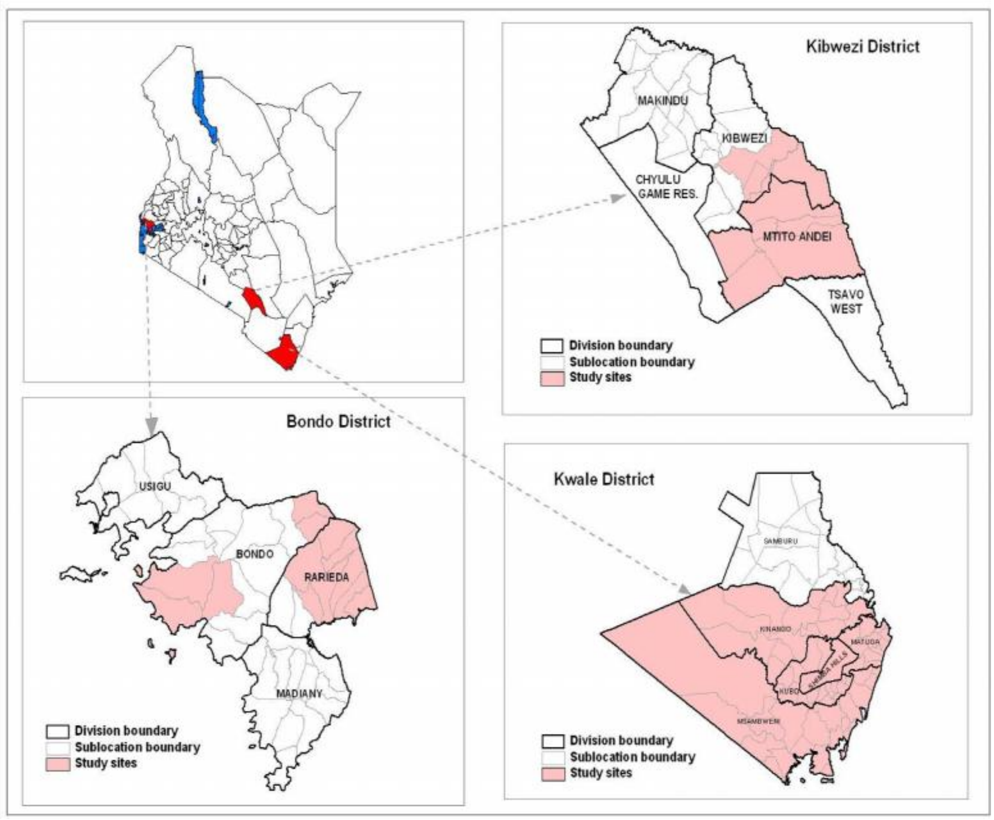

Figure 1: Map of Kenya showing Study Sites
Source: Centre for Training and Integrated Research for ASAL Development (CETRAD) office, 2009

The research involved fieldwork in Bondo, Kibwezi and Shimba Hills districts. The research design was a cross-sectional survey and data collection was by the use of structured questionnaire, focus group discussions with key informants and interviews with all farmers contracted to cultivate *Jatropha curcas* in Bondo, Kibwezi and Shimba Hills. To understand the effects of *Jatropha curcas* cultivation on food crop production, non-*Jatropha curcas* farmers were also interviewed. Existing literature was used as secondary source of information to complement the study. Information on food security was also collected.

The Study Design, Sampling Design and Sample Size

The study design was a cross-sectional survey. The sampling unit for the farmers were households. Purposive non-probability sampling was used to select two *J. curcas* growing locations in each study site to form the sample sites and this involved selecting two divisions from each county i.e. Bondo, Shimba Hills and Kibwezi which were selected based on the population of *J. curcas* farms after which a list of the farmers were prepared. A stratified proportionate sampling was used to select proportional number of farmers from each of the two divisions. At household level, simple random sampling was used to select the households to be interviewed. For comparison purposes, households were disintegrated into two, namely: those that practise *J. curcas* cultivation and those that do not.

Proportionate to size sampling methodology was used to determine the sample size as specified by Anderson et *al*., (2007) for an infinite population:

$n = z^2pq/e^2$

Where

n = sample size

p = proportion of the population containing the major interest (small holder *J. curcas* farmers)

q = the weighted variable computed as (1-p)

z = 1.96

e = acceptable error precision

For infinite population the sample (n) is as follows

$n = 1,962x0.5 \text{ x } 0.5/ (0.05)^2 = 385$

The exact population in this research was known. The total population of *J. curcas* farmers in all the three sites was 585. The proportionate to size sampling methodology ensured that all selected villages and households had an equal chance of being selected into the survey sample.

RESULTS

Shimba Hills had the highest practise of intercropping at 60.83% followed by Bondo at 43.8% and Kibwezi at 36.4%. Use *of J. curcas* as hedge does not interfere with food production as it is mainly used to protect their farms from livestock. Since the hedges are planted on land that is not under cultivation, there is no competition with food crops. Furthermore, farmers with limited land holdings grow it as a hedge with the same reasons of economic purposes and domestic use. Growing *J. curcas* as a hedge requires minimum care therefore enabling farmers spend most of their time attending to food crops (Plate 1).

Plate 1: J.curcas as a hedgerow in Shimba Hills, Kenya

The highest percentage in use of *J. curcas* as a hedge was observed in Kibwezi at 34.5%. This was followed by Bondo at 21.9 % and 7.8% for Shimba Hills. The least practise of *J. curcas* monoculture was observed in Kibwezi at 29.1% (Figure 2).

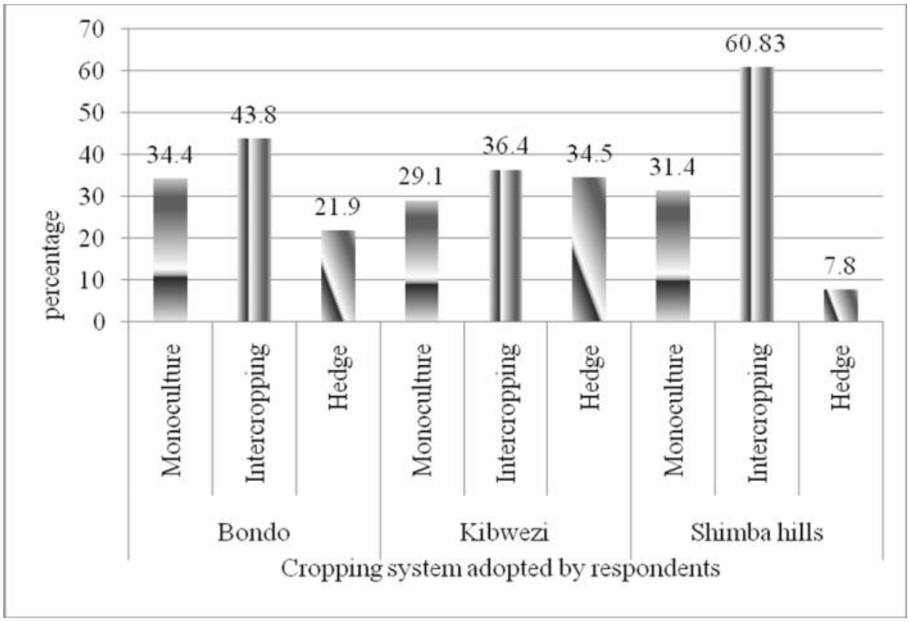

Figure 2: Cropping systems adopted by respondents

Intercropping provide acceptable means of controlling erosion up to 20 to 30% (Young, 1989). Soil protection and land reclamation can be enhanced as growth of biomass feedstock can help restore degraded land such as agricultural lands withdrawn from food production. Another variable that was used to determine food security was the percentage allocation of *J. curcas* with other crops.

A majority of the farmers from the study intercrop *J. curcas* with other crops at a ratio of 1:1 as shown in figure 3.Over 90% of respondents in Kibwezi (91.7%) and Shimba Hills (93.2%) practised intercropping at a ratio of 1:1 whereas 83.3% of Bondo farmers practised the same. A ratio of 1:2 meant that two rows of other crops were planted between the spaces of *J. curcas* plant. The 1:2 ratio was highest in Bondo at 16.7% followed by 8.3% and 6.8% in Kibwezi and Shimba Hills respectively. Crops that were mostly intercropped with *J. curcas* included: maize, beans, cassava, sorghum, groundnuts, cowpeas and bananas (Figure 4).

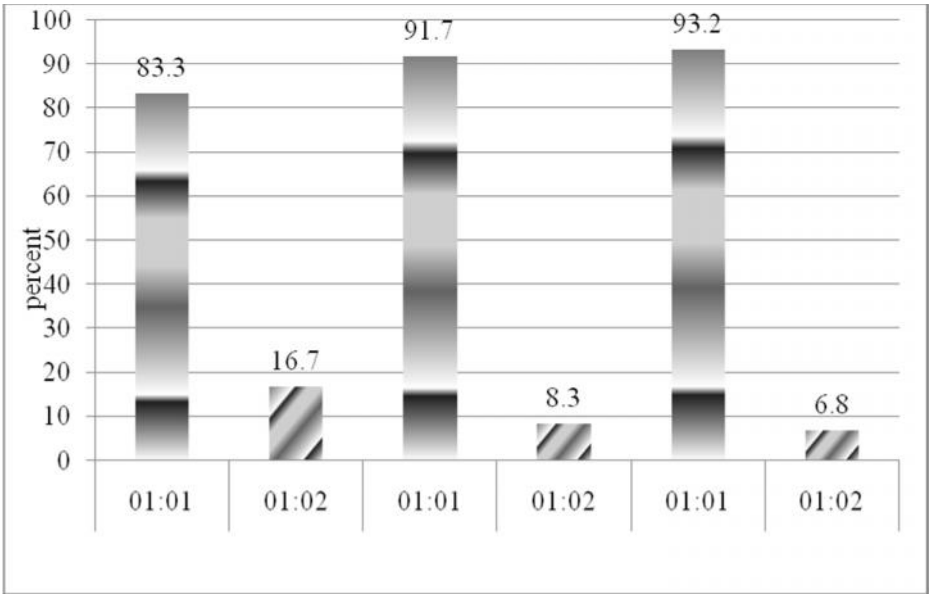

Figure 3: Ratio of intercropping between *J.curcas* and other crops

Differences in intercropping of *J. curcas* with other crops were also observed within each study site. Some farmers intercropped *J. curcas* with one crop while others intercropped with more than one crop. Intercropping of *J. curcas* with groundnuts is observed to be high in Bondo at a rate of 37.5%. The second important crop was cassava at 25%. Maize, vegetables and a combination of more than one crop was at 12.5% each. In Kibwezi 33.3% of cowpeas was intercropped with *J. curcas*, bananas and a combination of more than one crop at 22.2% while maize and beans at 11.1%. Shimba Hills had 33.3% of maize, sorghum, cassava, bananas and a combination of more than one crop at 11.1%. The choice of crop to be intercropped depended on the soil suitability, climatic conditions and local market demand.

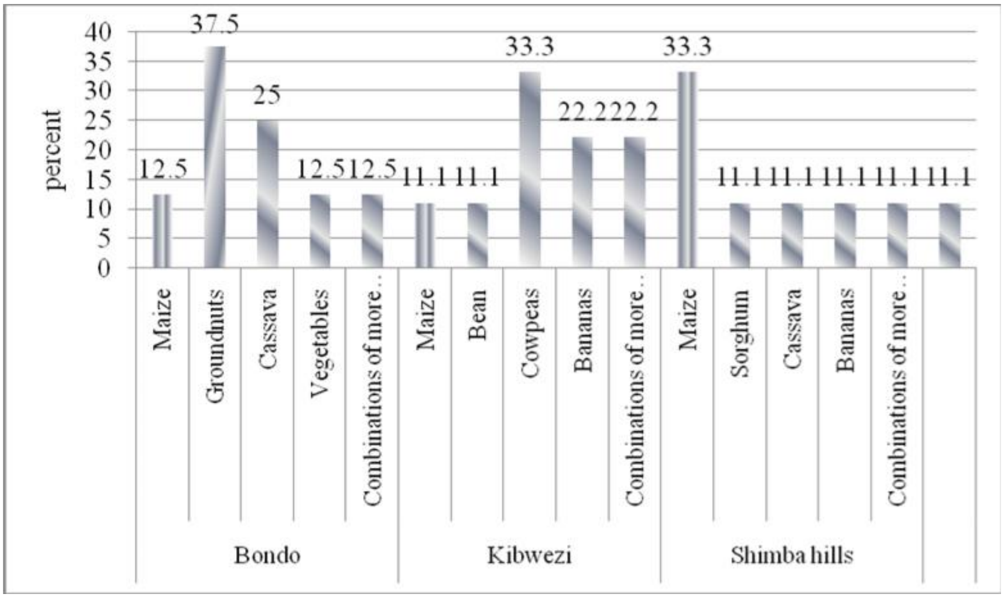

Figure 4: The different types of crops intercropped with *J. curcas* in the three study sites

Plate 2: *J. curcas* intercropped with cassava in Bondo, Kenya

DISCUSSIONS

Results show that in Bondo, Kibwezi and Shimba Hills, cultivation of *Jatropha curcas* does not threaten food security hence does not affect food crop production at household level. An alternative hypothesis is that smallholders would not jeopardise their own food security, would grow bio-energy crops alongside food crops, incorporating their production into their current land use systems, increasing cash flow and thus permitting them to purchase inputs to intensify food production. Respondents in Kibwezi, Shimba Hills and Bondo however, support growing of *J. curcas* along with food crops since the crop yields would not be affected.

Intercropping is successful in Nigeria where farmers intercrop *J. curcas* with maize and cassava (Yammama, 2010). In Tanzania, Uganda and Madagascar, *J. curcas* is intercropped with vanilla (*vanilla planifolia*) to serve as a pole for vanilla vines and to provide shade for vanilla leaves (Tomomatsu & Swallow, 2007). According to Phalan (2009), *J. curcas* can be combined with other suitable species comprising the agricultural, horticultural and herb components to result in an ecologically viable, economically profitable and socially acceptable agro-forestry system. One of the advantages of intercropping is that crops can benefit from each other. Studies in India and Tanzania have shown that some of the recommended crops for intercropping with *J. curcas* are legumes for improving soil productivity through nitrogen fixation although a variety of crops can be intercropped (Mitchell, 2008). They do cover the soil and so help control soil erosion. This is well illustrated in the cases of Bondo and Kibwezi where groundnuts and cowpeas are mostly used. Intercropping provides farmers with a form of insurance against crop failure. The growing period of one crop is usually different from that of the other, so if the rains are late for one crop and reduce its growth they may arrive in good time for the other crop (Yammama, 2007).

Where no crops can be intercropped, grass is encouraged (see plate 2). Harvey and Wood, (1996) and Owino (2002), suggest that the use of leguminous contour hedgerows combined with grass strips is a possible intervention to improve fertility through leaf biomass and soil erosion. Hedgerow trials carried out in the Philippines using trees and grasses reported a reduction of soil runoff and soil erosion loss by 58 and 65%, respectively (Hernandes *et al.,* 1996). This resulted to improved crop productivity due to nutrient retention. References recommend spacing for hedgerows or soil conservation to be 15cm-25cm x 15cm-25cm in one or two rows respectively and 2m x 1.5m to 3m x 3m for plantations. Thus 4,000 to 6,700 plants per km for a single hedge row and double that when two rows are planted (Kumar, 2004). In Kenya, farmers have adopted 3m x 3m spacing. According to Mboya *et al.,* (1999), most of the soils are characterised by low fertility due to continuous cultivation coupled with soil erosion. For sustainable production, there is a need to replenish the soil with nutrients and conserve them from losses through erosion.

Compared to other oil plants, *J. curcas* oil is non-edible making it less competitive with food crops therefore, unlikely to threaten food security unlike countries like Brazil and the United States whose bio-fuel production is derived from food crops such as maize or sorghum which can lead to food scarcity hence food insecurity (Peters and Thielman, 2008). Nevertheless, farmers themselves are reluctant to abandon food crops hence showing an attitude for food security. As indicated, almost all farmers practise intercropping with one or a combination of more than one crop. This further indicates that *J. curcas* probably does not push other crops but rather is an addition to the farming activities. *J. curcas* growing fits into most activity calendars so that regular food production may not be disadvantaged by its cultivation. To achieve food security, (Peskett *et al*., 2007; UN-Energy 2007 and Pingali *et al*., 2008) highlight the continuous stress on the policy to achieve this link, highlighting the need for carefully designed policies that maximize the positive effects on food security and prevent the negative effects.

However, the net effect of continued, or expanded, bio-fuel production on food security remains unknown (UN- Energy, 2007; FAO, 2008). Whereas conclusions reached by other researchers have not been strong, many have concern that bio-fuels have the potential to shatter food security for the poor, who spend the majority of their income on food (Naylor *et al*., 2007; Runge and Senauer, 2008). But from the results of this research, *J. curcas* does not show that there is a threat to food security.

CONCLUSIONS

In terms of the results on ratio of intercropping and percentage of land allocated to food crops, it can be concluded that *J. curcas* neither threatens food security nor competes with food production, but instead it serves as a remedy for marginal lands rehabilitation as it is suitable in ASALs where there is constant crop failure. By intercropping, this overcomes the potential competition with food crops especially in the first three years when the tree is not yet giving its full yield hence an indicator to show that there is food security. Due to its ability to grow on marginal lands, *J. curcas* in this study was found not to compete with food production and farmers should be encouraged to plant *J. curcas* along with food crops so as to avoid clearing of natural vegetation and also improve on food security. It can be concluded that food security due to *J. curcas* is not currently at risk.

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An Evaluation of Water Hyacinth Control Methods: A Case Study of Lake Naivasha, Kenya

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ABSTRACT

Water hyacinth was first reported on Lake Naivasha in 1988. Given its high proliferation rate it has spread to cover about 30% of Lake Naivasha. It has caused significant negative impacts that include: increased evapo-transpiration, physical obstruction of water transport means, loss in quality of fish and other products leading to reduced incomes; increased operational costs attached to fishing activities resulting from loss of nets and boat engine breakdowns; reduced fish reproduction; and being a breeding ground for many disease-causing organisms. These have in turn affected the environment and the socio-economic status of the communities around the lake. Two control methods, namely, biological and manual have been tried in Lake Naivasha. There is therefore an urgent need to have comprehensive economic data on costs and effectiveness of these methods. Given the limited resources, it is unjustifiable to continue undertaking control of the water hyacinth in Lake Naivasha without evaluating the most cost-effective strategy. It is against this premise that this study sought to conduct environmental economic analyses and made comparisons among the two control methods being used in Lake Naivasha. The study made simulations of the potential combination of these water hyacinth control methods and undertook sensitivity analysis meant to develop an analytical procedure that will hopefully guide policy makers on deciding on the best control strategy in future. The mechanical/manual method was found to be strongly supported because it has a superior C: E ratio and it reduces the drudgery associated with manual labour. A combination of the two methods (manual and mechanical) could of course be more reliable as the risks and uncertainties that may arise are reduced. Biological method is not the most cost-effective option, but it is the cheapest in terms of cost per hectare per hour. The study concluded that the task of eradicating the waterweed is an enormous one. It calls for a more responsible approach by the government and the affected communities. The government should look for financiers who can give long-term loans to undertake the exercise since the required investment is huge. The most certain strategy is to undertake a full-blown use of the mechanical and manual methods to fight the weed, protect the environment and create jobs for the local communities. Lastly, public awareness in all aspects of the weed is of paramount importance. According to the survey, the view people have for the government has been undermined because many people do not know that the government is fighting very hard to eradicate the weed.

Key words: Lake Naivasha, Biological control, Manual control, Water hyacinth

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INTRODUCTION

Water bodies continue to endure water hyacinth (*Eichhornia crassipes*) invasions globally. The intricate and unique structure of *Eichhornia crassipes* makes it one of the most resilient aquatic plants enabling it to infiltrate major water systems throughout the world (Cohen, 1995). Resilient water hyacinth like many invasive non-native species continues to invade waterways and ecosystems throughout Kenya. Numerous methods of controlling the invasive plant have been developed throughout the world such as biological, mechanical, physical, and chemical treatments (Wade, 1990).

The first case of water hyacinth in Kenya was reported in Lake Naivasha in 1988 (Njuguna, 1991). By early 1989 the plant had progressively spread in the lake and in 1992 it became the dominant weed species (Harper *et al.,* 1992). So far, the weed has adversely affected lake transport and the fishing industry. Water hyacinth has the ability to root in damp mud and so in Lake Naivasha, as in other locations it has colonized the littoral zone which is overwhelmingly dominated by the plants (Adams *et al.,* 2000). The dominance has a physical stability, for, as water level changes, rooted plants can float and vice versa. It is thus possible that the classic zonation of vascular plants from land to the open water, described for Naivasha by Gaudet (1977), has been altered. Gaudet classified 108 plant species in a primary successional sequence from the lake edge to dry land after a period of naturally low water levels that occurred between 1971 and 1973. The zones were: the seedling zone dominated by *Nymphae nouchali* (Adams *et al.,* 2000) seedlings that did not survive further drying; the sedge zone dominated by *Cyperus papyrus* (Adams *et al.,* 2000) the composite zone dominated by *Conyza*, *Gnaphalium* and *Sphaeranthus.*

African governments spend millions of dollars testing various physical (shredding or removal by hand), chemical (herbicidal spray that could potentially affect the surrounding environment), and biological (introducing biological control agents such as weevils or moths for natural removal) means of control (CAB International, 2000). None have been satisfactorily successful because of hyacinth's extraordinary persistence and survivival mechanisms.

Eichhornia crassipes grows at considerable speeds. It floats on the water's surface and grows outwards, extending its stolons to produce a new plant. Flowering is the sexual method of reproduction. The hyacinth is capable of self-fertilizing which makes it even more difficult to control. The seeds produced are viable for 20 years (Julien, 2001). The water hyacinth eventually covers the surface of the water body therefore decreasing the amount of light penetration. This, in turn, will decrease algal growth which ultimately decreases the amount of dissolved oxygen available in the water for aquatic fish and other organisms to use (Toft, 2003). The harsh conditions create an anoxic environment making it extremely difficult for organisms to survive. The water hyacinth has inflicted enormous negative effects not only on the country's environment but also on the health status and well-being of many people who seek livelihoods from the infested waters and the country's economy in general. Therefore, eradication of the water hyacinth is highly advocated the world over. However, its fast growth rate, the eutrophic status of lakes in Kenya that facilitate its growth, and seeds that remain viable for over 30 years are manifestations of the difficulty associated with its complete eradication.

Experiences of other countries indicate that all the control methods tried are very costly and not as effective as they seem to be. For instance, in Sudan manual control takes 500 men to clear a hectare a day. Only 20 square metres can be cleared a day (equivalent to 350 kg on a wet basis) to maintain access to a fish landing site. Further, labour costs are quite high (Gopal, 1987). As for biological control, the water hyacinth has no effective predators in Kenya or Africa because it is not indigenous to Africa and as such has no natural biological enemies. The weevils *Neochetina bruchi* and *Neochetina eichhornia* have been identified as absolutely specific to the hyacinth and they have been tried in Lake Victoria and on Lake Naivasha. Research on these weevils is being carried out at Kenya's National Agricultural Research Institute (KARI).

There is lack of satisfactory empirical research results to guide policy makers on an economical control method. It is against this background that this paper analyses the costs and limitations of individual control methods in Lake Naivasha with the aim of identifying a less costly and effective water hyacinth control measure.

REVIEW OF LITERATURE

Water hyacinth grows best in neutral conditions especially where, water is high in macronutrients, warm temperatures (28° to 30°C), and high light intensities. It can however, tolerate pH levels of between 4.0 to 10.0 (Haller and Sutton, 1973; Muramoto *et al*., 1991). The plants survive frost if the rhizomes don't freeze, even though emergent portions may succumb (Webber, 1897). Prolonged cold kills the plants (Penfound and Earle, 1948), but re-infestation from seed follows during later warmer periods. Ueki (1978) matched the northern limit of water hyacinth to the 1^{o} C average January isotherm in Japan. Growth is inhibited at water temperatures above 33°C (Knipling *et al*., 1970). Plants stranded on moist sediments can survive several months (Parija, 1934).

Biological control of water hyacinth

In recent years institutions around the world have put more focus on the use of biological agents to control water hyacinth. Many researchers (Wright and Skilling, 1987; Harley, 1988; Jayant, 1988; Thompson and Habeck, 1989; Harley, 1994; Chikwenhere and Forno, 1994; Mpofu, 1995; Mpofu, 1997) have conducted studies with biological agents used to control rapid spread of water hyacinth. These studies, conducted in countries such as South Africa, Kenya, Sudan, India, USA, Australia and Zimbabwe, have demonstrated that these host specific biological agents may offer effective strategies to contain water hyacinth. Focus has generally been directed at two weed eating beetles that belong to the genus called *Neochetina.* According to Harley (1994) two weevils *Neochetina eichhorniae* and *N. bruchii* are safe and have been used successfully to control water hyacinth in Australia and other countries. Jayant (1988) demonstrated reductions of 90% in weed infestation within three years of introducing the weevil *N. eichhorniae* in Banglore India. Ochiel *et al*., (1999) demonstrates reductions of 80% in water hyacinth infestation within four years of introducing *N. eichhorniae* in Lake Victoria. The use of other biological agents such as moths has also been investigated (Chikwembe, 1994). Biological methods to combat water hyacinth infestations have been a subject of much interest and research in Kenya. Several researches (Ochiel *et al*., 1999; Julien *et al*., 1999) have investigated the use of these weevils to control the water hyacinth.

A major concern of propagating and using exotic biological agents is the possible negative ecological effects. The concern mainly relates to the possible impact on non-target species and the subsequent spread of these agents as pests themselves, especially after current infestations of water hyacinth are exhausted. Julien (1999) has, however, shown that the exotic weevil species *N. Eichhornia* and *N. bruchii* are host specific for water hyacinth. Similarly, the Kenya Agricultural Research Institute (KARI) in 1997 conducted experiments with other biological control agents, the moth *Niphograpta albiguttalis*, the mite *Orthogalumna terebrantis* and the hemipteran bug *Eccritotarsus catarinensis*, to augment biological control efforts by *Neochetina* weevils, and demonstrated that they were safe for use in Kenya (Ochiel *et al*. 1999).

Research on the use of weevils to combat water hyacinth has continued to be spearheaded by KARI. For instance as early as 1993, KARI imported water hyacinth weevils, *Neochetina bruchi* and *N. eichhorniae*, from the Plant Health Management Division of the International Institute for Tropical Agriculture in Benin. These weevils, considered the most important biological control agents against the water hyacinth, have had notable success outside East Africa (Harley 1990; Julien and Griffiths 1998; Julien *et al*., 1999). However, host-specificity tests were ordered in Kenya and Uganda, before releases in Lake Naivasha and Lake Victoria were allowed. *Neochetina* weevils were released in Lake Kyoga, Uganda in 1993 (Ogwang and Molo, 1997, 1999) and in Lake Victoria in 1996 (Mailu, 2001). However, the first weevil releases in Kenya were in Lake Naivasha, which had water hyacinth since the mid 1980s (Njuguna, 1991). *Neochetina* weevils were released in the Kenyan part of Lake Victoria in 1997 (Ochiel *et al*., 1999; Mailu *et al*., 1999), while in Tanzania, Mallya (1999) reported the releases of *Neochetina* weevils in the Pangani and Sigi rivers in 1995, and in Lake Victoria in 1996.

KARI conducted field trials on the use of the two weevils to control water hyacinth on Lake Victoria and Lake Naivasha between 1998 and 1999. These weevils were introduced to selected sites and their establishment and effectiveness to control water hyacinth monitored. Results from that study demonstrated that *Neochetina spp.* can be effective agents to control water hyacinth in Kenya. Other biological agents such as the moths *Sameodes albuguttatus* and *Cercospora rodmanii* are also being investigated as control agents for water hyacinth.

Center *et al*., (1990) observed that biological agents are not always successful nor do they give consistent results because of variations in plant quality. The same observations were supported by a study by Center and Dray (1992). Other factors such as nutrient levels, proximate composition of the plant tissues and the physiology of the control agents also affect results (Hag and Habeck, 1991).

In view of this, it is increasingly being recognized that multi-disciplinary approaches offer the best long-term management of water hyacinth. This calls for integrated approach where a combination of biological and chemical agents is used. Mpofu (1995) demonstrated that weevils can be used in association with saprophytic and parasitic fungi and bacteria which infest damaged plant tissue. The impact of microorganism on water hyacinth has been shown to increase when plants are attacked by weeds (Charudattan *et al*., 1978). The work by Mpofu (1995; 1997) examined water hyacinth growth subjected to weevils (*N. Eichhornia* and *N. bruchii*) in association with two potential bio-herbicides, *Fusarium solani* and *F. pallidoroseum*. The results demonstrated 50% and 30% decreases in areas covered by water hyacinth relative to untreated controls, for combinations of weevils with *Fusarium solani* and *F. pallidoroseum*, respectively. Plants subjected to these treatments were shown to be thinner and had extensive damage to the petioles. Plants subjected to independent treatments of weevils, *Fusarium solani* or *F. pallidoroseum* showed 9.8%, 6.0% and 3.8% reductions in water hyacinth reductions relative to untreated controls. Mpofu (1995) also observed declines in water hyacinth populations within 5 months compared to 3-6 years suggested by Harley (1990). The effectiveness of these methods to combat water hyacinth is due to injuries inflicted on plants by the insects which predispose the plants to infection by the microorganisms (Carter, 1997). The pathogens gain entry into the plant tissues along side weevil larvae as they burrow through the plants.

Cost-effectiveness Analysis (CEA)

According to Walters (1962), economic theory defines costs as payments made to induce factors of production to continue in their employment. Derbetin (1980) and Koutsoyiannis (1979) categorize costs as fixed and variable. In support, Hornby, Cownie, and Gimson (1987) state that though in the long run all costs are variable, in the short run some are fixed and others variable.

Cost-effectiveness analysis (CEA) is a technique to assist in decision-making. It involves assessing the gains (effectiveness) and resource input requirements (costs) of alternative ways of achieving a given objective (Creese and Parker, 1991). Broadly, cost-effectiveness analysis is any analytic tool designed to assist a decision-maker in identifying a preferred choice among possible alternatives (Dixon *et al.*, 1994; Mishan, 1988; Quade, 1967; Winpenny, 1993). It had its origin in the economic evaluation of complex defence and space systems (Kazanowski, 1974). Much of the philosophy and methodology of the cost-effectiveness approach are derived from cost-benefit analysis (Fabrycky and Tuesen, 1974; Mishan, 1988). Whenever cost-benefit analysis becomes impossible, since the benefits cannot be valued, it is useful to compare the costs of providing the beneficial outcome in different ways. The basic concepts inherent in cost-effectiveness analysis are now being applied to a broad range of problems in defence, public health and the environment (Dixon *et al.*, 1994; Lanyard and Glaister, 1994).

Specifically, cost-effectiveness analysis involves comparison of alternative courses of action in terms of their costs and their effectiveness in attaining a specific objective. Usually it consists of an attempt to minimize cost subject to some goal; or conversely, to maximize some physical measures of output subject to a budget constraint (Dixon *et al.*, 1994; Mishan, 1988; Quade, 1967).

In applying CEA, three requirements must be satisfied. Firstly, the systems being evaluated must have common goals. Secondly, alternate means for meeting the goals must exist. Finally, the capability of bounding the problem must exist (Fabrycky and Tuesen, 1974).

There are certain steps that constitute a standardized approach to cost-effectiveness evaluations. These steps are useful since they define a systematic methodology for the evaluation of complex systems in economic terms. They are:

(a) Definition of the objective(s). Since the method is undertaken primarily to choose a course of action, it is important to know the objective(s) the decision-maker is trying to attain (Dixon *et al.* 1994; Kazanowski, 1974; Layard and Glaister, 1994).

(b) Alternative concepts and strategies must be developed (Dennis and Williams, 1993; Kazanowski, 1974; Mishan, 1988). The alternatives are the means to attain the objective(s). If alternatives do not exist, CEA cannot be used as a basis for selection (Fabrycky and Tuesen, 1974; Winpenny, 1993).

(c) Establishment of evaluation criteria for both the cost and the effectiveness aspects of the strategies/methods under study. This refers to a rule or standard to rank the alternatives in order of desirability and choose the most promising. It provides means for weighing cost against effectiveness (Dennis and Williams, 1993; Layard and Glaister, 1994; Mishan, 1988; Quade, 1967).

(d) Selection of the approach. Two approaches are available: fixed-cost and fixed-effectiveness. In the former, selection for the best method depends on the effectiveness obtained at a given cost; while in the latter, it depends on the cost incurred to obtain a given level of effectiveness (Kazanowski, 1974).

(e) Candidate strategies are analysed based on their merits. This may be accomplished by ranking the systems in order of their capability to satisfy the most important criterion. Often this procedure may eliminate the least promising candidates (Dixon *et al*., 1994). The remaining ones can then be subjected to a detailed CEA.

Study Area

Lake Naivasha is located at 0°42' - 0°50'S /36°16' - 36°26 'E (Figure 1) and has an area of 15,600ha (including islands), at an altitude of 1884m a.s.l. It is believed that some 6000-13,000 years ago, Lake Naivasha was part of a much larger lake that encompassed the present lakes Elementaita and Nakuru, and discarded down the Rift Valley southwards. The lake is a fresh water lake with a catchment of 2,378 km^2. Other temporally watercourses descent from the forested slopes of Oldoinyo opuru ridge, and extends eastward from Mau escarpment, across the valley north of the lake. The principle water supply to the lake is from Aberdare Mountains. The Malewa River has a catchment of 1,730km^2 and provides 90% of the inflow. Ground water seepage, particularly along the north and northeast shores is reputedly responsible for up to 16% of the total influx.

Lake Naivasha was designated as a RAMSAR site in 1995 and is managed by the local property owners under the Lake Naivasha Riparian Association formed in 1934. The lake provides diverse habitats for a variety of mammals, birds and fish (tilapia, black bass, and cray fish). Fishery is conducted for both domestic and commercial purposes. Commercial fishery makes an annual production of 75 tonnes valued at Kshs 2.5 million.

The lake provides a lot of water for irrigation which supports one of the most expansive horticultural industry in this part of the world and which employs more than 250.000 people. The horticulture exports are the second largest foreign exchange earner for the country after tourism. Tourism is also a major sector in the lake and its catchment basin.

The lake’s environment is fragile but dynamic and supports tourism and geothermal power generation from deep-rooted stream jets among other economic activities. Lake Naivasha's biodiversity is critically threatened by human induced factors, including: habitat destruction, pollution (from pesticides, herbicides and fertilisers), sewage effluent, livestock feeding lots, acaricide, and water abstraction. A population of over 250,000 people lives around the lake. The high population has encroached upon wetlands and converted them into agricultural lands, residential areas, and tourist hotels. The continued harvesting of papyrus along edges has in particular destroyed the natural state of the lake. Current research findings show that the lake cannot sustain further development activities on the scale seen over the last fifteen years.

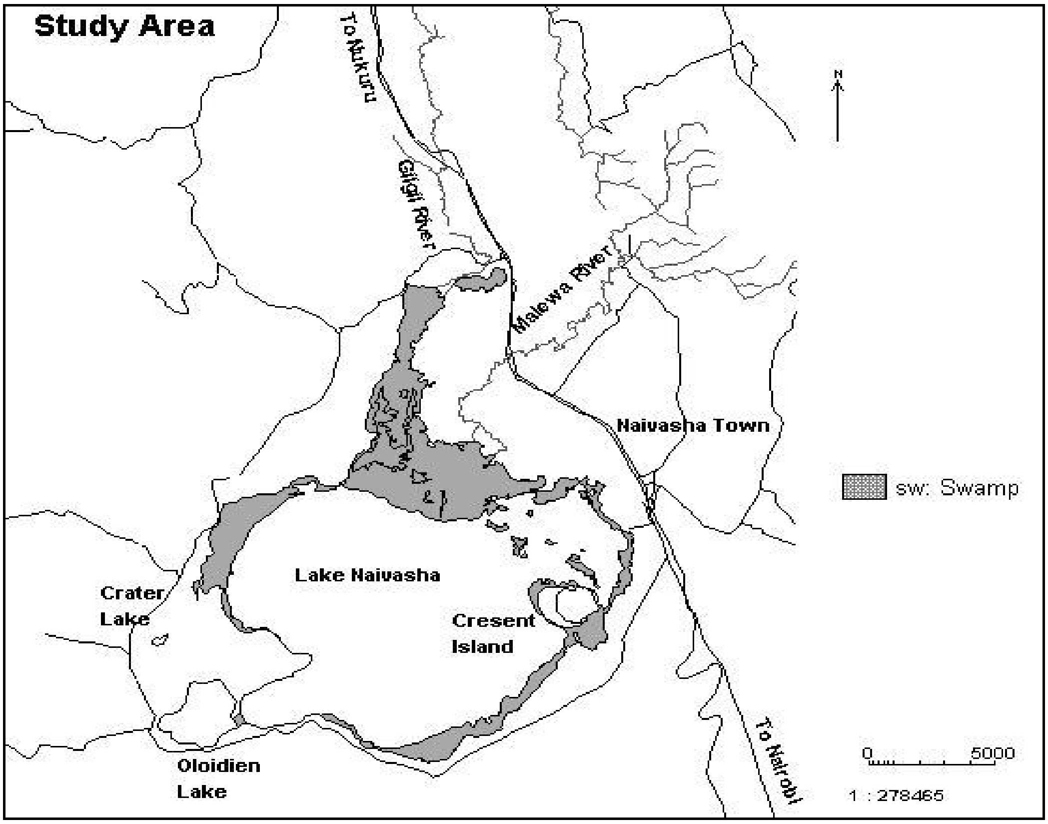

Figure 1: Map showing location of Lake Naivasha, Kenya.

Data and Methods

Research Design

This study was based on both primary and secondary data. Secondary data was obtained by reviewing of literature on similar studies conducted within the study area or elsewhere. Journal articles, Ministry of Environment and Natural Resources Annual Reports, Population Census Reports, Theses, and other relevant materials provided the secondary sources. Primary data was obtained through formal and informal interviews of randomly selected farmers, fishermen, members of the riparian community and key informants.These sources provided background information that included the nature of water hyacinth and its possible origin, social and economic implications, and strategies for control and government policy.

A sampling frame of fishermen in Lake Naivasha was developed from lists provided by local leaders out of which 45 were randomly selected. Fifteen key informants were selected and interviewed, using non-probability sampling procedure. These were selected from among; Senior Officers – Kenya Marine and Fisheries Institute, Kenya Wildlife Institute, Kenya Agricultural Research Institute, Kenya Generation Company, Lake Naivasha Riparian Association, Elsamere Foundation, District Fisheries Office, Ministry of

Tourism, Ministry of Health and Ministry of Water. All the interviews were preceded by two focus group discussions (FGDs), which were aimed at getting the general perceptions of the efficacy of the control measures.

Sampling Procedures and Data Collection

The data collection tools included a structured questionnaire and FGD schedule. Structured interview method was used in collecting primary data. This targeted the fishermen and other key informats in giving insights to the history, spread of water hyacinth in Lake Naivasha. Information from this source was sought to aid in triangulating data obtained through other sources. Among those interviewed were officials of - Kenya Marine and Fisheries Institute, Kenya Wildlife Service Training Institute, Kenya Agricultural Research Institute Naivasha, Kenya Electricity Generating Company, Lake Naivasha Riparian Organization, Elsamere Foundation, District Fisheries Office, Ministry of Tourism, Ministry of Health and Ministry of Water. These were identified as having information on water hyacinth control in Lake Naivasha. The open-ended nature of the interview schedule allowed respondents' freedom to go beyond simple responses to the questions asked and to give their views in the way they wished. The questions deviated from the original plan and centred on points that seemed important according to the researcher. Results obtained from structured interviews did not lend themselves readily to quantification but did help to generate and clarify many issues in water hyacinth control.

Another method used to collect data for the study was group discussions. The discussions were held on 26th August 2009 at Naivasha Town. Sixteen participants attended the discussions. The researcher engaged the group in a free discussion on the subject of control of water hyacinth in Lake Naivasha.

To meet the objectives of the study, probing questions were asked on the history and spread of water hyacinth, knowledge of the impact of water hyacinth, constraints and measures to improve response to water hyacinth control and management in Lake Naivasha. The group was able to fully discuss the history, spreading patterns and problems faced in the control of water hyacinth. The attendants identified lake eutrophication as the main factor contributing to the spread of water hyacinth in the lake despite the control measures in place. The results obtained through group discussions mainly helped to explain, reinforce and enrich the survey results.

RESULTS AND DISCUSSIONS

45 fishermen (42 male and 3 female) were interviewed. Although in most developing countries full time specialization in one field may be of great economic risk (Twongo, 1993), 100 per cent of those interviewed were full time fishermen. The education background of the fishermen is shown on Table 1. Respondents' level of education refers to the actual number of years spent in school. It is observed from Table 1 that more than 40 percent of the respondents have obtained up to primary education, while 31.2% percent have not obtained any formal education. A lower proportion (26.6%) had obtained secondary and post secondary level of education. The distribution shows that up to 73.4 percent of the fishermen had primary level education and below. The finding indicates that most fishermen in Lake Naivasha have low formal education and this affects the way in which they relate to new information and receive innovations.

Table 1: Summary of background information of the fishermen

Variable/ Response	Number of Respondents	Percent
Background Information		
Sex		
- Male	42	93.3
- Female	3	6.7
Education		
- O – A level	12	26.6
- P. 7 and below	19	42.2
- None	14	31.2
Fishing Status		
- Full time	45	100.0
- Part time	0	0.0

The fishermen were interviewed on the origin of the water hyacinth weed. 28.6 % of the fishermen think that malicious individuals dropped it into Lake Naivasha, where it has continued spreading along various sections of the lake, more so to the areas suitable for fishing. Others (14.3%) think it was brought in as an ornamental plant because of the beauty of its flower. 57.8% of the respondents claimed to have first seen the weed on Lake Naivasha around late 1980s and early 1990s (Table 2).

Table 2: Summary of the responses from the fishermen

Variable /Response	No. of resp	%
Public Knowledge of the Weed		
How did the weed get into the lake?		
Ornamental by people	6	14.3
Thrown into the lake by strangers	13	28.6
Don't know	26	57.1
When was it first seen?		
Late 1980s	7	15.6
Early 1990s	19	42.2
Don't know	19	42.2
When did the weed become a problem?		
Late 1980s	0	0.0
Early 1990s	32	71.4
Can't remember	13	28.6
What individuals have done		
Involved in sensitization of the masses	3	13.0
Participated in Manual removal	30	71.4
Nothing	12	15.6
Whether one has attended meetings		
Yes	6	15.5
No	39	84.5
Ranking of the methods in terms of costs (cheapest first)		
Mechanical, Biological, Manual	15	11.1
Biological, Manual and Mechanical	9	17.8
Manual only	13	28.9
Chemical only	8	13.3
Ranking in terms of effectiveness (most effective first)		
Mechanical, Biological, Manual	6	13.3
Mechanical, Manual, Biological	12	26.7
Mechanical, Manual, Biological	6	13.3
Manual only	13	28.9
Effect of the weed on price of fish		
Increased	8	17.8
Decreased	32	71.1
No effect	5	11.1

Analysis of data from Table 2 indicates that the fishermen had to carry more ice to maintain the quality of fish during water hyacinth infestation period as evidenced by 32 (71.1%) of the respondents. The overall effect of this was reduced supply of the fish vis-à-vis increased domestic and export demands. This led to higher costs of obtaining fish from the lake.

Table 2 shows that six of the respondents (13%) had been involved in sensitizing the riparian community about the weed; 32 of them (71.4%) participated in manual harvesting of the weed, but lack of facilitation undermined their efforts. The rest did not contribute much towards its eradication. Meetings to discuss weed control have not been well attended. They had held 20 meetings since they started manually removing water hyacinth and only seven (15.5%) had regularly participated in such meetings.

Ranking with respect to costs indicated that 13 (28.6%) advocated only manual control and believed that this would be the cheapest. Eight respondents (17.8%) ranked the methods in this order: biological, manual and mechanical. They did not commit themselves to chemical control. Five respondents (11.1%) ranked them: mechanical, biological and manual.

In terms of effectiveness, 13 of the respondents (28.9%) advocated for manual harvesting. This is probably due to the high unemployment rate and the fact that some of the respondents have been involved in it. The other respondents (26.7%) were for the following order: mechanical, manual and biological. Mechanical, biological and manual together with mechanical, manual, chemical and biological in that order of effectiveness shared an equal number of responses (13.3% each).

Generally and as a result of water hyacinth infestation, accessibility to land and water has been hindered, resulting in reduced fish catches, especially of tilapia and mudfish which are found mainly along the shores. 28.6% of the respondents reported increased fish catches of tilapia, S*ynodontis, protopterus* and *Labeo spp.* from suitable breeding grounds provided by water hyacinth. There is, however, need to clarify this conflicting information, in more areas around the lake. A reduced fish catch would have an adverse effect on the quality of life of the communities around the lake and consequently affect sustainable development in the area.

The impacts on the environment were not apparent and thus not well perceived by most of those interviewed among the communities. However, those impacts that affected the communities directly and posed health risks were indicated as water quality degradation (foul smell, debris), increased siltation and potential for flooding. However, other less obvious impacts included interference with diversity, distribution and abundance of life in aquatic environment.

Key Informants

Non-probability sampling procedure was used in the selection of ten key informants. These were selected from among; Senior Officers – Kenya Marine and Fisheries Institute, Kenya Wildlife Institute, Kenya Agricultural Research Institute, Kenya Generation Company, Lake Naivasha Riparian Association, Elsamere Foundation, District Fisheries Office, Ministry of Tourism, Ministry of Health and Ministry of Water. The selected officers offered insights relating to the infestation of Lake Naivasha with water hyacinth. Their views are discussed in the next sections.

Biological Control

Through the recommendation of the National Task Force on Water Hyacinth (NTFH), 600 adult weevils from each of the two weevils (*N. bruchi and N. eichhornia*) were imported in July 1993 from IITA. The weevils have since been mass reared and released in over 20 sites on Lake Naivasha. They were taken in batches of about 1,000 - 1,500 monthly to the various landing sites.

The weevil adults are nocturnal and feed on the upper surface of the leaf lamina and upper one third of the petioles, which causes desiccation of the leaves. Oviposition is in petioles and legules. Larvae tunnel towards the base of the petioles and into the crown. Pupation occurs under water in a cocoon. The generation time for *N. bruchi* is 96 days while that for *N. eichhornia* is 120 days. Heavy attack causes the plants to float lower in water and can lead to water logging, rotting and plant deaths. The plant populations are slow to develop, while destruction of the weed takes 3-5 years.

(i) Costs

The picture on costs would be more complete if all the costs incurred on research and development of the essential inputs were considered; however, it is difficult to obtain data on research and development of machines and so on. Therefore, only procurement and operating costs, which include both capital and recurrent costs, are considered (Table 2). Capital costs are apportioned since they last for more than one year. The procedure of annualisation, i.e., the costs of capital items in terms equivalent to recurrent costs, is therefore required. Annualisation requires information on the current price of the item and its useful life. For biological control, only a vehicle is taken as a capital cost. Its daily depreciation is taken as the daily cost attached to the method:

Price of a vehicle (4WD) in 1994 = US $20,000
Useful life (years) = 8
Annualisation coefficient = 0.15478
Annual costs = US $20,000 X 0.1547 =US $3,094
One day's cost = US $3,094 / 365 = US $8.5

(ii) Effectiveness

3,750 weevils take 3 - 5 years to achieve recognisable coverage per hectare. This period needs to be converted to hours in order to match it with those of other methods whose effectiveness are in hours.

(a) Conversion to days: 3 years x 365 days = 1,095 days

(b) Conversion to hours: 1,095 days x 8 hours = 8,760 hours

The biological control day is equivalent to 8 hours since the adult weevils are nocturnal and therefore active at night.

Total cost per hectare per hour = US $911.4/8,760 = 0.104

(c) Effectiveness indicator (Area (m2)/time (hours))

= 10,000 m^2/8,760 hours

= 1.142 m^2/ hour

Table 3: Costs for effecting biological control based on 1994

Category	**Units**		**Amount (US $)**
Personnel			
In charge's allowance	per month		200.0
Junior staff allowance	per month		200.0
Driver's allowance	per month		150.0
Labourer	per month		100.0
Vehicle	A Day's depreciation		8.5
	Fuel	Litres	170.0
	Sub-total		828.5
Miscellaneous others	(10% of 828.5)		82.9
Total			911.4

NB: Total costs per hectare = US $911.4

(iii) Cost- effectiveness ratio

Costs in dollars divided by effectiveness in hours **= US $0.104/1.142 = <u>0.091</u>**

Manual Control

This involves manual removal of whole plants from the water and throwing them on the banks, wheelbarrows and / or tipper lorries that ferry them to destinations where they dry up. It has been tried on many landing sites. Given the health problems related to this exercise, the workers need to be well protected and well paid (Table 4).

(i) Costs

The concept of annualisation is considered here. For those capital items with useful life of less than 2 years, a straight-line method of depreciation, which assumes uniform

depreciation throughout the life of the item, is subjected on the cost item.
Capital costs include**:**

Manure forks (500 each at a price of US $10)
- Price of the forks = US $5.000
- Useful life = 2 years
- Annualisation coefficient = 0.5378
- Annual cost = US $5,000 x 0.5378 =US $2,689
- One day's cost = US $2,689 / 365 = US $7.4

Long sleeve gloves (500 pairs each at a price of US $15)
- Price of the gloves = US $7,500
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $7,500
- One day's cost = US $7,500 / 365 = US $20.5

Long boots (500 pairs each at a price of US $15)
- Price of the gloves = US $7,500
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $7,500
- One day's cost = US $7,500 / 365 = US $20.5

Wheel barrows (20 each at a price of US $50)
- Price of the forks = US $1,000
- Useful life = 2 years
- Annualisation coefficient = 0.5378
- Annual cost = US $1,000 x 0.5378 =US $537.8
- One day's cost = US $537.8 / 365 = US $1.5

Rakes (500 each at a price of US $6)
- Price of the rakes = US $3,000
- Useful life = 1 year
- Annualisation coefficient (not applicable)
- Annual cost = US $3,000
- One day's cost = US $3,000 / 365 = US $8.2

Table 4: Summary of costs for manual control per hectare

Category/Item	Units	Amount (US $)
Implements		
Manure forks	500 x10	7.4
Long gloves	500x15	20.5
Long boots	500 x15	20.5
Wheel barrows	20 x 50	1.5
Rakes	500 x 6	8.2
Sub-total		58.1
Remuneration Allowance	500 x 2	1,000.0
Miscellaneous (10% of 1, 058.1)		105.8
Total		1,164.0

NB: In manual control method a working day is equivalent to 10 hours.
Total cost per day = US $1164.0
Total cost per hectare per hour = 1,164.0/10 hours = US $116.4

(ii) Effectiveness
It takes about 10 hours for 500 men to clear one hectare. The effectiveness indicator therefore is:
Effectiveness indicator (Area (m^2)/time (hours))
=10,000 m^2/10 hours = 1,000m^2/hour
(iii) Cost-effectiveness ratio
Costs in dollars divided by effectiveness
= US $116.4/1,000 = 0.116

Respondents' Perceptions of the Role of the Government in Controlling the Weed
The participants suggested that they should have been sensitised more about the weed, the funds received from lake should have been ploughed back and local participation should have been emphasised. Many unemployed people could have been utilised and paid say Kshs.15-40 per kg. Operational funds should have been handled by representatives from the fishermen and

other affected people instead of by absentee officials who may misuse the money. Government officials should have visited the landing sites more frequently to know more about the problems. Lastly, most participants thought that if the government released enough funds and the unemployed people were hired, the weed could be removed manually.

Observations from Fisherman

Forty five fishermen were interviewed and responses on how the weed has affected fishing and other activities were: failure of boats to sail through waters covered by the weed given the thick mats created by the meshed roots, which lock up the boats and fishermen sometimes for days. This leads to economic losses due to increase in catch delivery time. These delays have at times resulted in deterioration of the quality thus a reduction in the prices, and at most complete spoilage of the fish rendering it unsafe for human consumption. Fishermen have had to carry ice to maintain the quality. Higher costs to operators have also resulted from use of more fuel. Maintenance costs of engines have also increased due to knocks from the weed sucked into the engines.

Opinions on Government Policy

The majority of the respondents (80%) thought that the government has not done its best to eradicate the weed. They asserted some officials gain from the problem and thus did not act fast and vigorously enough.

An evaluation of water hyacinth control methods

Two control methods, namely, biological and manual have been tried in Lake Naivasha. There is therefore need to have comprehensive economic data on costs and effectiveness of these methods. Given the limited resources at our disposal it is unjustifiable to continue undertaking control of the water hyacinth in Lake Naivasha without evaluating the most cost-effective strategy. It is against this that this study sought to conduct environmental economic analyses and made comparisons among the two control methods being used in Lake Naivasha (Table 5).

Table 5: Summary of the costs, effectiveness and C: E ratio of the two control methods used in Lake Naivasha

Method	Costs ($/ha/hour)	Effectiveness (m^2/hour) (E)	Cost: Effectiveness ratio (C:E)
Biological	0.104	1.142	0.091
Manual	116.4	1,000.0	0.116

The costs per hour are seemingly high because of the low scale of operation considered. As the scale of operation increases, economies of scale are utilized thus reducing the costs of clearing additional units. A 10% value on expenses was allowed as miscellaneous to cater for incidentals. It is obvious from the Table 5 that used independently and irrespective of the environmental effects (for which we are not sure about); the biological method is the most cost-effective since it has the smallest C: E ratio of 0.091. Therefore, less is spent to achieve a similar level of effectiveness compared with the manual method. Further analysis indicates that the biological method has the lowest cost of US $0.104 per hour. This is why it is assumed that it is the most cost-effective option. The method ranks second in terms of effectiveness, as it takes long for the weevil populations to build up and destroy the weed. Ogwang, Molo, and Ebuu (1995) observed that biological control remains the most viable and sustainable long-term option for controlling the water hyacinth. However, the time it takes to establish itself creates skepticism among policy makers and the local populace. Further, it is evident that the differences between the control methods in terms of costs are big. For instance, the difference in cost between the manual and the biological methods is US $116.3. These pronounced differences undermine the sensitivity analysis of potential combinations, as one chooses the less costly option. Therefore, the biological method is the most cost-effective, followed by the manual method in Lake Naivasha.

POLICY IMPLICATIONS, CONCLUSIONS AND RECOMMENDATIONS

Policy Implications

Agricultural sector policy objectives target self-sufficiency in food production and export diversification, industrial development enhanced by agricultural growth, and enhancement of rural development aimed at equal share of the national income between rural and urban sectors. However, government policies have not been implemented consistently with stated policy objectives. For instance, fish is a major food to many people but the weed has undermined the self-sufficiency target in terms of nutrition and food availability.

Revenue from the fisheries sub-sector has increased from a low figure in the 1980s to over US $70,000, implying that the dependency on coffee income had been reduced. There is greater demand for fish because of population growth, rapid urbanization and improved infrastructure. Its contribution to the GDP is significant and it generates substantial incomes for many Kenyans engaged in fish processing and marketing. However, recent developments indicate that if the weed problem is not addressed, whatever little had been achieved will be lost. Firstly, fish exports to Spain were recently banned due to high bacterial content. Fish exports to the European market will dwindle and even the domestic demand will fall. This will result in the closing down of the fish processing industries. It can be argued that the government is not fully committed to exploring all the possibilities regarding the weed control methods. It is imperative that more research on the problem be supported. Scientists working on these control methods must be facilitated to undertake the research.

Many Kenyans feel that the weed problem would not have reached such a level had the government acted more promptly. Since its appearance, the government, through MAAIF, has done a lot to control its spread. The following are notable: surveillance to establish distribution and abundance of the weed on our waters; sensitisation of the public on dangers of the weed; community mobilization for manual removal, though with limited facilitation; seminars and workshops to assist in drawing up control programmes; enlistment of financial and material support for the control programmes; limited provision of tools and equipments for manual removal; breeding of biological control agents through facilitation of NAARI. The problem remains effective communication to the people on what has been achieved so far.

CONCLUSIONS AND RECOMMENDATIONS

The manual control method is strongly recommended because it creates employment for the local communities and ensures local participation. Fishermen and local communities residing near affected lakeshores should be mobilised and facilitated to undertake weed control. This is likely to bring the situation under control since such groups are the immediate beneficiaries. The government should spearhead the process of soliciting funds, which should be handled by officials duly appointed by the groups concerned.

Biological method is not the most cost-effective option, but it is the cheapest in terms of cost per hectare per hour. This method could be employed on a limited scale as more research is being carried out to investigate its potential in other pest, disease and weed control regimes for the future.

The task of eradicating the waterweed is an enormous one. It calls for a more responsible approach by the government and the affected communities. The government should look for financiers who can give long-term loans to undertake the exercise since the required investment is huge. In the analysis, only a hectare was considered for simplicity. If the total area of the weed on both lakes is considered (about 90,000 ha) about US $32 million is required to implement the recommended scenario. Mechanical control with the least C:E ratio (0.016) requires about US $14,4 million to eliminate the weed. Manual, biological and chemical control methods require about US $105, 187 and 269 million, respectively.

These figures would tremendously reduce if implementation were done over a longer period. If a period of one month (300 working hours) were considered, the recommended scenario would require about US $106,000. Manual, biological and chemical controls used alone would require US $350,000, 623,000 and 890,000, respectively. Such amounts of money may seem to be high but considering the anticipated revenue from the sale of fish, they are not so high. If the government cannot raise the money immediately, the short-term solution would be to borrow. The incomes resulting from the weed-free lakes will be sufficient to pay back any loan with interest within a short period.

The most certain strategy is to undertake a full-blown use of the mechanical and manual methods to fight the weed, protect the environment and create jobs for the local communities. Researches on chemical and biological use need to continue to get convincing results.

Lastly, public awareness in all aspects of the weed is of paramount importance. According to the survey, the view people have for the government has been undermined because many people do not know that the government is fighting very hard to eradicate the weed.

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Sengwer Community and their Dependency on Kapolet Forest Resources of Cherangani Hills, Kenya

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ABSTRACT

Forests are of great significance to the local people especially in the rural areas. Majority of Kenyans depend on forest resources for their livelihood, particularly for fuel wood, timber, Non-Timber Forest Products (NTFP) and other ecological functions. Sengwer is one of the indigenous communities predominantly found on the slopes of Cherangani hills, Kenya. The objective of this paper was to document the benefits and types of forest resources accessed by the forest community in Kapolet forest. Data was collected by administration of questionnaires to the household heads in the study area with a sample size 112 households from an accessible population of 1,126 individuals. Field observations and interview with a total of 16 key informants was also used in data collection with the key informants being selected based on their experience and knowledge on forest resources utilization. Descriptive and inferential statistics were used for data analysis using Statistical Package for the Social Sciences (SPSS version 17). The findings show that 96.4 % of Sengwer community living adjacent to Kapolet forest depends on the forest resources for their livelihoods. The major product harvested from the forest was fuel wood as 76.4 % of the community members indicated they obtained firewood from forest. Other products included honey, herbs used for medicine, water, building poles, charcoal, bush meat and pasture for livestock grazing. There was a significant relationship between household income and charcoal production ($P=0.00$, $\chi^2=19.702$) and between household income and harvesting of building poles ($P=0.017$, $\chi^2=8.200$). The findings also indicate that the Sengwer are still dependent on the forest for survival despite 59. 8 % of the community members shifting from their traditional hunting and gathering to agriculture and livestock keeping. Therefore, alternative sources of livelihoods should be provided to the community to ease the pressure on the forest resources.

Keywords: Indigenous, alternative livelihoods, non-timber forest products, culture

INTRODUCTION

Forests are vital for the existence of life on earth. Tropical forests alone serve as a habitat for more than 13 million distinct species (Hammond, 1996). Forests cover almost one third of the world’s land area and nearly all are inhabited by indigenous and rural communities who have customary rights to their forests and have developed ways of life and traditional knowledge that are attuned to their forest environments (Forest Peoples Programme, 2012). At present, the world’s forests cover about 4 billion hectares, which accounts for 31 % of the world‘s land area, while Other wooded land covers about 1.1 billion hectares (FAO, 2010). In Africa, forests cover is about 21.4 % of the land area (FAO, 2009), which corresponds to 674 million hectares (FAO,

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2010). In Eastern Africa, approximately 13 % of the land area is covered by forests and woodlands which make the resources rather limited. Kenya is the most forested country in Eastern Africa with a forest and woodland cover of 17 million hectares which corresponds to a third of the land area (UNEP, 2006). Despite this fact, closed forest cover only 1.7 % of the land area in Kenya (WRI, 2007).

The Food and Agricultural Organization country report on forests (FAO, 2001), reveals that most of the closed canopy forests are concentrated in the high and medium potential zones of Kenya where, incidentally, the human population and agricultural production are also concentrated; hence high potential for conflict between closed canopy forest and agriculture. Within the arid and semi-arid zones, closed forests are fewer and are concentrated mainly on isolated mountain ranges and along river banks, both permanent and seasonal, with the rest of this zone being composed of woodlands, bush-lands and wooded grasslands (FAO, 2001). The management of the natural forests and the forest resources is generally governed by the Kenya forest act of 2005 (GoK, 2005) which is implemented mainly by the Kenya Forest Service, since most forest land falls under its jurisdiction as gazetted forest reserve. The Kenya Wildlife Service (KWS) has management responsibility for all indigenous forests falling within national parks, national reserves and game sanctuaries (FAO, 2001).

According to the World Bank (2002), forest resources directly contribute to the livelihoods of 90 % of the 1.2 billion people living in extreme poverty worldwide. Forests also indirectly support the natural environment that promotes agricultural production and hence food supplies to nearly half the population of the developing world (World Bank, 2002). The World Commission on Forests and Sustainable Development (1999) estimates that some 350 million of the world's poorest people depend almost entirely for their subsistence and survival needs on forests. A further 1 billion poor people - about 20 % of the world's population - depend on remnant of woodlands, homestead tree gardens, and on agro-forestry systems for their essential fuel wood, food and fodder needs. Forests provide private goods for commercial trade (e.g., round wood, some NTFPs, and tourism services), private goods for subsistence (many NTFPs, fodder, fuel wood and construction poles, medicinal plants), local public goods (watershed management and soil conservation), and global public goods including biodiversity and carbon sequestration (World Bank, 2009).

Sixty million indigenous people worldwide and other communities living in forests depend on them for subsistence (WCFSD, 1999). The Sengwer also known as Cherangany is an ethnic minority hunter-gatherer indigenous people living along the slopes of Cherangani Hills, Kenya. The community depends on natural resources found in Kapolet forest for their livelihood and culture. Their traditional economies are based on herbal medicine, bee-keeping, hunting and gathering. The forest also offers cultural rights and spiritual anchorage (Kiptum and Odhiambo, 2007). Other indigenous communities that are dependent on forests include the Ogiek of Mau forest and Mount Elgon in Kenya, the pygmies of Congo, Hadzabe of Tanzania and the Batwa people of Rwanda.

Forestry laws often deny local people any rights of residence, ownership and even use of forests or subject them to complicated regulations which impede their access and make them vulnerable to manipulation (Forest Peoples Programme, 2012). The main focus of this paper was to document the benefits and types of forest resources accessed by the forest community in Kapolet forest in addition to determining the influence of household and socio-economic characteristics of local communities on forest dependency in Kapolet forest.

MATERIAL AND METHODS

Description of the Study Area

Kapolet Forest is located 1° 10' N latitude, 35° 10' E longitude. It is shared by the Counties of Trans-Nzoia, and Pokot, Kenya, and covers 10,800 acres (KAPAP, 2009). Kapolet Forest is 2,246 meters above sea level. The area experiences long rains between April and July, and short rains around September of every year (Gill Pirt, 2004). Kapolet being an indigenous forest is a source of Rivers Moiben and Kapolet (Ainopmaget) which are the tributaries of River Nzoia that drains into Lake Victoria. Similarly, rivers Muruny and Empop the tributaries of Kerio River which drains its water into Lake Turkana originate from Kapolet forest.

Kapolet forest is one of the thirteen blocks of Cherangani hills, which comprises the five major water towers in Kenya. The findings of this study will therefore seek to enhance sustainable forest resources utilization without compromising the indigenous Sengwer community's fundamental freedoms, human and indigenous rights.

Methods

The study adopted a social survey research design to collect primary data from the respondents using questionnaires. Field observations and oral interviews with key informants were also carried out. The survey was conducted between July and September 2012 from among 112 rural households which was the sample size, drawn from an accessible population of 1, 126 people living within a range of five kilometers from Kapolet forest. This was done with an assumption that they are directly or indirectly depending on the forest. Three locations (Kaibos, Makutano, and Talau) and a total of 14 villages were sampled. Proportionate sampling was used to determine the number of households to be sampled in the respective locations.

Data Collection

Primary data on resources obtained from the forest by community members and the demographic characteristics of the forest community was collected by administration of questionnaires to randomly selected household heads and spot field observations carried out concurrently. Simple random sampling was used to select the households to be interviewed (Mugenda and Mugenda, 2003). Interviews with 16 key informants were scheduled 12 of them being male and 4 female. The key informants were selected on the basis of their knowledge and experience on forest resources utilization. They included the area chiefs, village elders, zonal forest officers, forest guards and the county forest officers. The questionnaires were translated to the native Sengwer language for better understanding by the research assistants from the study area.

Data Analysis

Statistical Package for the Social Science (SPSS v. 17) computer software was used to analyze quantitative data obtained from the questionnaires at 95 % confidence level. Descriptive statistics were run to generate frequency distributions and percentages and results presented in form of tables and graphs. Chi-square test (χ^2) was performed to test the relationship between household dependency on the forest and their demographic and socioeconomic characteristics as it is the best tool for analysis of categorical data (Mugenda and Mugenda, 2003).

RESULTS AND DISCUSSION

Demographic and Socio-economic Characteristics of the Respondents

The household characteristics are important in the determination of the dependency of the residents on the forest for their livelihoods. It is assumed that households with low income are more dependent on the forest and its products than those with a higher income. The demographic characteristics investigated were gender, age, level of education and occupation of the respondents while the socio-economic characteristic included the income of the respondents. The table below (Table 1) shows a summary of the demographic and socio economic characteristics of the respondents.

Table 1: Demographic and Socio-economic characteristics of the Sengwer community around Kapolet forest (n=112)

Household characteristics	Number (n)	Percentage (%)
Gender		
Male	77	68.8
Female	35	31.2
Age (years)		
<25	16	14.2
26-35	35	31.3
36-60	46	41.1
> 60	15	13.4
Level of		
education	15	13.4
No formal	60	53.5
education	19	17
Primary	7	6.3
Education	7	6.3
Secondary	4	3.5
Education		
Certificate		
Diploma		
University		
Degree		
Occupation		
Farmers	67	59.8
Casual laborers	14	12.5
Civil servants	14	12.5
Small Scale	11	9.8
Enterprises	6	5.4
Students		
Income (Kshs)		
<20,000	62	55.4
21,000-49,000	48	42.8
>50,000	2	1.8

There were almost twice as many male (68.8 %) as female respondents (31.2 %) in the area. The high number of male respondents compared to females is due to the Kalenjin culture where the man is considered as the head in a family setting and the female can only take responsibility in the absence of the man. The forest communities of Kapolet who are mainly Sengwer have allocated different duties to each gender. The females are responsible for firewood collection, fetching water, and gathering fruits and other non-timber forest products while the males collect honey, building poles and graze the livestock in the forest. According to Makindi (2012), there are differences in responsibilities, user rights, legal status, division of labour and decision-making between men and women in different societies. The male population being greater than the female means there is more building pole harvesting and grazing inside the forest. This will reduce the tree cover and can negatively affect the forest undergrowth if it is not carried out in a controlled manner.

The results project an increase in population of the community as 72.4 % of the respondents lie between the ages of 26 years and 60 years. This will in turn increase the demand for forest resources to meet their daily needs for survival resulting to further degradation of the forest. Ongugo *et al.,* (2008) point out that conflicts tend to continue or even worsen with population growth as the forest communities will continue to use and scramble for the scarce forest resources. This is in agreement with Malthus' (1798) who postulated a theory on population dynamics and its relationship with the availability of resources. He stated that in the absence of consistent checks on population growth, scarce resources will have to be shared among an increasing number of individuals creating misery and wickedness that cannot be avoided hence conflicts. Thomson and Kanaan (2003), further note that during periods of uncertainty and intense competition, people highly dependent on forest resources may be more prone to engage in conflict.

The low numbers of individuals with tertiary education can be attributed to high rates of school dropouts in primary and secondary levels due to lack of school fees and early marriages in the case of girls. This increases their dependency on forest resources as most school dropouts are unemployed. This is in agreement with the findings of Obua *et al*., (1998) who indicated that people with higher education get employment in public and private sectors and do not use many forest products. Sixty percent of households with the low income were farmers whereas those with high income were civil servants. With 59.8 % of the respondents in the study area practicing farming as an economic activity, there is a clear indication that the sengwer community is slowly shifting from its traditional hunting and gathering lifestyle to agriculture.

The Chi-square test was used to determine the association between the income of the respondents and their dependency on the various forest resources as shown in the table below.

Table 2: The relationship between income and forest resources use

Socio economic characteristic	Forest product	χ2	Degree of freedom	P-value	Relationship
Income	Firewood	0.872	2	0.647	NS
	Medicine	1.297	2	0.523	NS
	Charcoal	**19.702**	**2**	**0.000**	**S**
	Building poles	**8.200**	**2**	**0.017**	**S**
	Honey	1.907	2	0.385	NS
	Water	1.005	2	0.605	NS
	Grazing land	2.711	2	0.258	NS
	Game meat	0.124	2	0.940	NS

The results depicted a significant association between the income of the respondents and their dependency on charcoal (P=0.00, χ^2 =19.702) and building poles (P=0.017, χ^2 =8.200). However, there was no significant relationship between the income of the respondents and their dependency on firewood, herbal medicine, honey and grazing land. Timber, fuel wood and charcoal constitute significant economic incentives which provide poor people with immediate and significant cash incomes (UNEP, 2012).

The association between respondents' income and their dependency on charcoal production and building poles is due to the availability of these resources at low or even sometimes no cost. This is in agreement with the findings of Urvashi *et al*., (2005), who suggested that resource dependence increases at all income levels with an increase in the level of common-pool biomass availability. Also the majority of low income earners (59 %) largely depend on the forest for their survival and efforts by the forest regulators to restrict their access on these forest resources could lead to conflicts. Dependency on the forest is influenced by income of the respondents. The less the income the more dependent they are on forest resources. Majority (65.1 %) of the respondents claimed the resources were somehow accessible in the sense that the users had to cover a distance of about 20 kilometers to the zonal forest offices to obtain permits in order to access the forest resources a process they deemed tedious.

Benefits and types of products harvested from the forest

It is evident from the results (Figure 1), that the forest communities greatly depend on the forest and its products for their livelihoods. Majority (94.6 %) of the residents indicated they obtained resources and benefitted from the forest. The respondents also cited several benefits from the forest. A number of the residents (39.6 %) associated the reliable rainfall received in the area to the presence of the forest while 7.5 % indicated the developmental projects initiated by the Kenyan government after the construction of a dam (with funds from Development Bank of Germany) along Kapolet river to supply water to Kitale town.

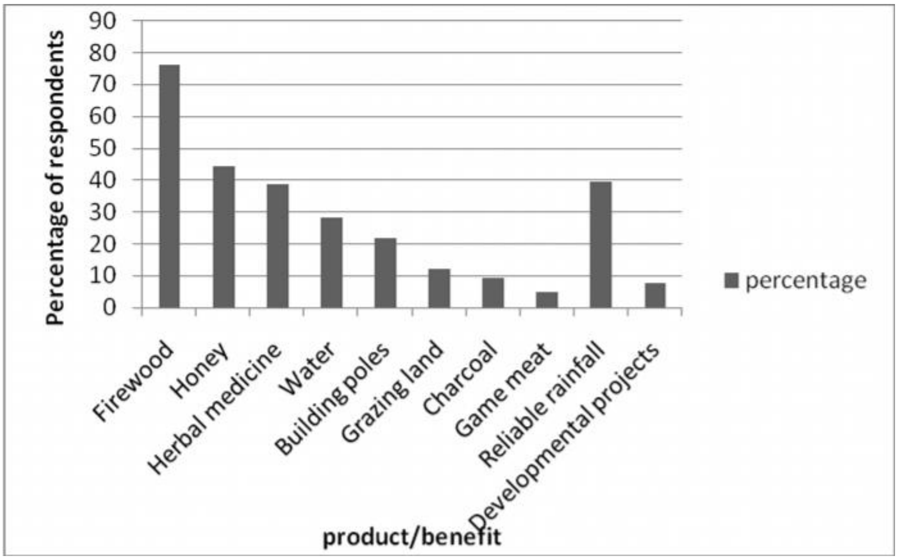

Figure 1: Benefits and types of products harvested from the forest (multiple responses)

The results of this study indicate that the forest is vital for the survival of the Sengwer community. This is supported by the World Commission on Forests and Sustainable Development (WCFSD, 1999), who found out that 300 – 350 million people are highly dependent on forests and live in or adjacent to dense forests on which they depend for their subsistence and income. Fuel wood was the most harvested forest product (76.4 %) as it is the most available source of energy for household use in rural areas including the study area. However, the respondents were unwilling to talk about engaging in charcoal burning and hunting for bush meat as they seemed to know the illegality of such activities and the consequent penalties imposed on the offenders by the forest administrators. Earlier studies by Obua *et al.*, (1998) in Budongo forest, Uganda and showed respondents reluctance in talking about charcoal production for fear of being apprehended.

Despite these benefits, there were also some negative effects associated with the forest. 90 % of the respondents claimed that the forest was a hiding ground for criminals, notably cattle rustlers who have been constantly terrorizing the local residents. The cattle rustlers take cover in the forest during the day and when darkness approaches they execute their raids in the nearby villages and drive the stolen livestock back into the forest. This has made it difficult for the police and the Kenya anti-stock theft unit to track them and recover the stolen livestock. Other notable negative effects include destruction of farm crops by wild animals (baboons, wild pigs, porcupines) and occasional bush fires which sometimes extend to the nearby villages thereby causing destruction of property.

Encroachment into the forest is confirmed by satellite images of the forest. There has been 4.4 % decrease in the forest cover between February 1984 and April 2001 as a result of human activities as shown in figures 2 and 3 below.

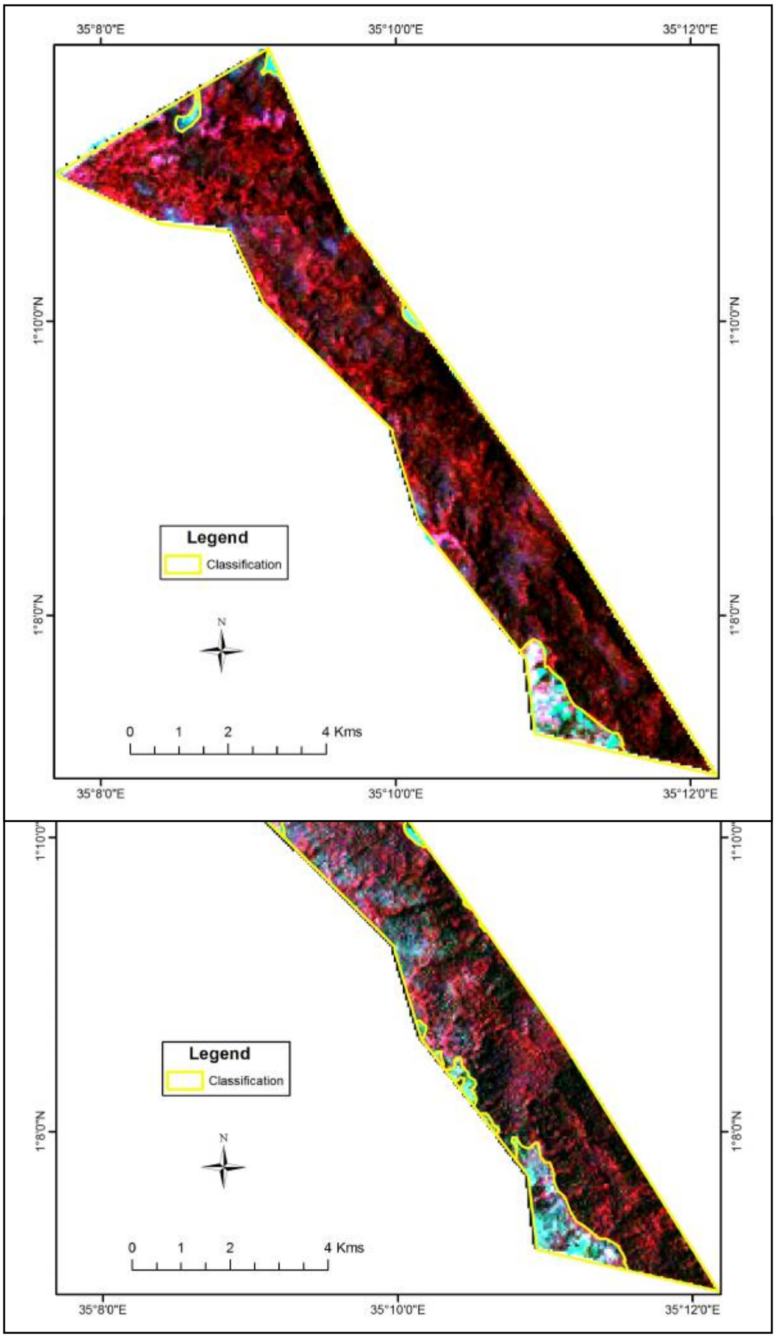

Figure 3: Forest cover in February 2001

Table 3: Classification of Kapolet forest

Kapolet forest			
Class Type	**1984 (Sq. Kms)**	**2001 (Sq. Kms)**	**Comments**
Forest	14.467	13.832	Decrease
Disturbed forest	0.821	1.458	Increase

The areas within the yellow outlined polygons represent the portion of the forest that has been cleared over the years. This translates to an increase in disturbed forest from 0.821 Square kilometers in 1984 to 1.458 Square kilometers in 2001. The major cause of change in forest cover is illegal timber logging by saw millers from the neighboring Kitale town. Illegal timber logging and charcoal burning has been ongoing and the residents attributed these practices to people from outside the community. They claim the loggers are usually given the go ahead by the very authority which is supposed to protect the forest upon receiving bribe. Livestock grazing in the forest by some community members has also led to degradation as it discourages undergrowth.

CONCLUSION & RECOMMENDATION

Most of the residents around Kapolet forest depend on the forest for their livelihoods with the dependency on the forest resources being influenced by the demographic and socio-economic characteristics of the residents. This is depicted by a significant relationship between income, age, level of education, occupation and utilization of some forest resources like charcoal, building poles and honey.

A wide range of alternative livelihoods should be provided to the forest community by the Kenya Forest Service to reduce their dependence on the forest products. With the projection of population growth the forest can no longer fully support the growing population. Viable alternative livelihood projects in the region that could improve the welfare of the community include bee keeping, dairy farming, agro forestry, horticulture, cash crop farming (tea, coffee and pyrethrum) and poultry keeping. Alternative sources of energy like solar and biofuel should also be adopted by the community members. Clean Development Mechanisms (CDM) projects should be initiated in the area to improve the local economy through employment creation and poverty alleviation via carbon credits benefits to farmers, in addition to promotion of renewable energy and energy access.

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Management of Fisheries Resources in Lake Victoria: An Assessment of Institutional Capacity in the Kenyan Fisheries Department

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ABSTRACT

There has been some major concern that the fisheries resources in the Kenyan sector of Lake Victoria are facing a drastic decline. Constant decline in the production of fisheries creates a sense of loss of a major activity among the local community which creates an obstacle to reduction of poverty. The decline can originate from overfishing due to inadequate enforcement of fishing regulations. This paper explores the concept and substance of Kenya Department of Fisheries institutional capacity in the context of management efficiencies. The main thrust of the paper is that an institutional approach, based on capacity assessments, could provide useful insights on the appropriate steps for resource management actions. This study analyzed the organizational capacity of the Kenya Fisheries Department so as to identify the binding constraints whose relaxation would have the largest impact on enforcement of fisheries regulations. Linear programming was used to identify the binding constraints. The findings show that the existing capacity of Assistant Fisheries Officers and Fish Scouts at the enforcement level is inadequate. We attribute overfishing in Lake Victoria to inadequate resources in the Fisheries Department which in turn contributes to ineffective management. We recommend incorporation of indigenous knowledge, including skills and manpower of the local people in the management of the Lake Victoria fisheries as well as enforcement of fishing regulations.

Key Words: Objective function, Slack values, Sensitivity analysis, Constraining factors, Dual price

INTRODUCTION

Lake Victoria basin supports one of the densest and poorest rural populations in the world, with human population density in the basin being well over 100km^2. It is thus the most heavily populated basin within the East African Rift Valley Lakes. Fisheries contribute to poverty reduction and economic growth at individual, household, community, local government and national levels, through employment, income, food security, and revenue-raising and foreign exchange earnings.

In Uganda,about 1,500,000 people are directly or indirectly employed in fisheries related activities; and about 5,000 people are working with industrial processing fisheries sector. Over 1.2 million people are directly dependent on the sub-fisheries sector as the main source of household income (Department of Fisheries Resources Records, 2010/2011).

In Kenya over 2 million people are supported by the fisheries and the annual

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fish consumption needs of almost 22 million people in the region are met by the lake alone, making a significant contribution to regional food security. The earnings from fisheries are estimated at Kshs. 32 billion at beach level. The country earns over Kshs. 4billion in foreign exchange and the fishermen over Kshs.7 billion, thus contributing to poverty alleviation in rural Kenya (Kenya Fisheries Department Records 2001). Lake Victoria supports about 50,000 fishermen (Kenya Fisheries Department Records 2001). There is also considerable social importance attached to fishing activities/fish species and fisheries products as they provide for improved nutrition and health of the communities. Fisheries also provide recreation through sport fishing and angling.

However, the trend shows that the Lake's fisheries are currently on the decline and the biological picture is one of great instability (Bwathondi *et al.*, 2001). The report clarifies that heavy fishing pressure has removed too many breeding adults and threatens to reduce stock even further. Lack of mature fish is probably due to overexploitation as reflected by laxity and weakness in enforcement of Fisheries Act. Other studies have concluded that the decline in fish production and species is due to fishing illegalities. Njiru *et al* (2006) note that fishing in Lake Victoria is not legally restricted and there is no limitation on the number of boats or gears used. With an annual population growth rate of about 3%, high unemployment rate, erratic rains, poor soils, tsetse fly infestation around the lake which make farming and keeping of livestock unprofitable, the lake resource remains the main source of livelihood (Njiru *et al.*, 2006).

The management plans proposed for sustainable fishing have addressed excessive fishing effort, use of destructive fishing gears, outdated laws in fisheries, inadequate enforcement and extension services. Other components considered are lack of trained manpower and resources capacitation, prospects for increased capacity and high demand for fish by the existing processing plants.

It is observed that the government of Kenya uses regulatory and fiscal measures (gear restrictions, close seasons and closed areas, taxation and levies etc.), catch and size restrictions, and regulation of access. The riparian governments have also attempted to revive declining catches from the Lake by enforcement of mesh size restriction, use of closed seasons and areas. Such measures have been very helpful but have not arrested the declining catch rates, especially with increasing fish demand on the world markets (Njiru *et al.,* 2006).

In mitigation, Kenya has also launched a fish farming enterprise rolled out in 140 constituencies to reduce the harvesting pressure on the Lake's fishery. In addition, the government has been investing in the industry to address technology and techniques for sustainable harvesting of fisheries resources. But, whether these actions taken so far are successful is open to debate and unless more actions are taken in the near future, the fishery is likely to recede to a fraction of its current level.

Resource managers observe that regulations, technology and techniques for sustainable harvesting of fisheries resources cannot make a complete sustainable management framework without considering the issues of institutional capacity of the regulatory body. From the economic management perspective, it must be a combination of human, institutional and technological factors that are capable of initiating resource conservation. This is because adequate personnel in the managing institution must be available for the enforcement of resource policies (FAO 2003 and Turner, 1997). In Kenya, the organisation of the fisheries sector has no clear central-local Government demarcation.

In the Fisheries Department the Director of Fisheries has two deputies; one for Capture Fisheries and the other for Aquaculture. Administration of the department is divided into four regions each headed by a Regional Director who is supported by Regional Assistant Directors responsible for a group of Districts. The Regional Assistant Directors have Senior Fisheries Officers who are in charge of districts and responsible for both extension and enforcement. Within the Districts are Divisions, where Fisheries Officers oversee the activities undertaken by Assistant Fisheries Officers. These have Fisheries Assistants who are in charge of the frontline groups. The latter group performs both enforcement and extension functions.

Many would argue that the entrepreneur is the most important factor of production the entrepreneur gathers and collates all the other factors of production and puts them to work. Karl Marx said in his book “Wage-Labour and Capital” that only under certain conditions does entrepreneur becomes a “slave", referring to the way in which capital is only a mere object which is transformed to a much more significant entity through the role of the entrepreneur. Adam Smith in “The Wealth of Nations” highlighted the importance of land as a factor of production. But, the Marxists place a greater importance on labour, since they believe that it is labour that actually does the work. Although all the four factors are important, in reality it has been observed that physical presence of labour is the one factor to make actions happen.

The theory of resource management by Clark and Munro (1979) was used in this study, which identifies the role of labour in resource management and argues that effective management is the situation in which fisheries regulations are successfully enforced. According to the theory, socio-economic characteristics, institutional capacity; and the presence of policies/and regulations have direct influence on fisheries managements.

Capacity is the ability to perform functions, solve problems, set and achieve objectives in a sustainable manner. Capacity development is, therefore, the process through which the abilities to do so are obtained, strengthened, adapted and maintained over time. Institutional and administrative capacity can be defined as the set of attributes related to both structural/systemic attributes and human capital/resources that collectively define the organization’s ability to perform its mandated functions. Within the public service, typical aspects of capacity are the quality of civil servants, organisational characteristics and the style of interaction between government and its social and economic environment.

The Kenya Fisheries Department’s administrative/organizational structure has Fisheries Officers divided into different levels. At the local level are the landing beaches under the supervision of the Fish Scouts. The second level falls under the district where the Fisheries Officers at the Divisional/District offices undertake the area patrols. The patrol team consists of a Fisheries Officer (FO) a Police officer, an Assistant Fisheries Officer (AFO), Fish Scout (FS), and a Coxswain (Kenya Fisheries Department Records, 2002). The Act of 1991 empowers the patrol team and states that failure of the fishermen to comply with the regulations; the offender (fisherman) is liable to a fine and /or imprisonment of not less than one year. Table 1 shows the existing staff cadres and the number of staff in Fisheries Department during the study period.

In Kenya, fisheries administration and the existing situation and future requirements have been a concern since the early 1960’s. Increase in staff and the availability of training facilities had been proposed since the colonial period. One way to approach the inherently systemic nature of institutional capacity is to analyze the functions that need to be performed to achieve a policy objective. The challenge of any policy process is therefore the ability to perform all the functions in an efficient manner, as they are interdependent. Thus, capacity is needed for each of these functions if the policy process is to be sustained over the years (Ste’phane and K. Baumert 2003).

MATERIAL AND METHODS

The information in this paper was generated through methods such as literature review, questionnaire administration and expert consultations. Secondary data was collected by reviewing records of fishery related institutions at both local and national levels. Literature review was conducted and discussions were taken with key informants. Data on the staff capacity was collected from Kenya Fisheries Department and the Department of Personnel Management. As noted by Ste’phane and Baumert (2003, an assessment of current capacities is needed to determine the extent of the capacity gap between current capacity and the capacity required for specific policy options. In table 1, we find data (as per the study period) related to the existing and the establishment required for effective management of the fishery.

Table: 1: Capacity in Kenya Fisheries Department in Kisumu in 2001

Category	Authorized/Establishment	In post/existing	Average
Fisheries Assistants	129	153	154
Coxswain	49	22	36
Fish scouts	491	189	340
Ship crews	8	0	4
Total	**677**	**364**	**534**

Source: Fisheries Department, 2001

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In addition, a questionnaire was administered to the Kenya Fisheries Department staff to collect information on the optimal number of staff that would be sufficient to manage the fisheries resources of Lake Victoria. The data gathered was compared with that proposed staff capacity by the inter-ministerial committee, the capacity required for effective management of fisheries resources in the country (Fisheries Department Records 2003).

The fisheries management strategies considered were taxing (X_2) the fishermen based on their catch, licensing (X_3), individual transferable quotas (X_1) and community based organization (X_4). Institutional capacity was analyzed using Statistical Programme for Social Scientists (SPSS) and LINDO programmes. It was found at the time of the study that the Lake Victoria fishery is faced with a general decline of 40936 tons of fish per year (Nzungi 2003). It was taken that the immediate goal of a management system is to maximize fisheries conservation at least by the current loss equivalent to the recorded amount of fish decline. Linear programming model was taken to identify the binding constraints in the management systems, the specific objective being to identify the staff category that effectively constrains the management of Lake Victoria fisheries. This framework identified the fact that:

- The number Regional Directors,
- The number of Senior Fisheries Officers,
- The number of Fisheries Officers,
- The number of Fisheries Assistants,
- The number of Assistant Fisheries Officers and
- The number of Fish Scouts

These could constrain the implementation of the fisheries regulations. A sensitivity analysis was taken to study how an optimal solution behaves with changes in individual numerical values of the constraints and objective row coefficients.

The Objective Function was thus given as:

$$\text{Max } Z = 40936\, X_1 + 40936\, X_2 + 40936\, X_3 + 40936\, X_4 \quad (1)$$

S.t:

$$a_1X_1+a_1X_2+a_1X_3+a_1X_4 \le rd \quad (2)$$
$$b_2X_1+b_4X_2+b_4X_3+b_4X_4 \le sfo \quad (3)$$
$$c_5X_1+c_5X_2+c_5X_3+c_3X_4 \le fo \quad (4)$$
$$d_6X_1+d_6X_2+d_6X_3+d_6X_4 \le afo \quad (5)$$
$$e_7X_1+e_7X_2+e_7X_3+e_7X_4 \le fa \quad (6)$$
$$f_6X_1 +f_6X_2 +f_6X_3 +f_6X_4. \le fs \quad (7)$$

Non-negativity $X_1 \ge 0, X_2 \ge 0, X_3 \ge 0, X_4 \ge 0$ (8)

Equation (8) rules out negative results of any management system and policy

These binding constraints/agents for management were expressed mathematically as follows:

Regional Directors
$$2X_1 + 2X_2 + 1X_3 + 0X_4 \le 4 \quad (1)$$

Senior Fisheries Officers
$$8X_1 + 1X_2 + 8X_3 + 0X_4 \le 16 \quad (2)$$

Fisheries Officers
$$16X_1 + 8X_2 + 8X_3 + 0X_4 \le 36 \quad (3)$$

Assistant Fisheries Officers
$$16X_1 + 8X_2 + 8X_3 + 0X_4 \le 13 \quad (4)$$

Fisheries Assistants
$$16X_1 + 8X_2 + 15X_3 + 0X_4 \le 70 \quad (5)$$

Fish Scouts
$$64X_1 + 150X_2 + 56X_3 +300X_4 \le 205 \quad (6)$$

Non-negativity
$$X_1 \ge 0,\ X_2 \ge 0,\ X_3 \ge 0,\ X_4 \ge 0 \quad (7)$$

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Where:

rd = Units of Regional directors required in each management system
sfo = Units of Senior fisheries Officers required in each management system
fo = Units of Fisheries Officers required in each management system
afo = Units of Assistant Fisheries Officers required in each management system
fa = Units of fisheries Assistants require in each management system
fs = Units of fish scouts required in each management system

RESULTS

Table 2 shows the critical/binding constraints.

Table 2: Results of LP Model on Management Systems for Lake Victoria

Objective Function Value - 1) 82076.680

Mgt systems	**Value**	**Reduced Cost**
ITQs	.00000	34386.24000
Taxation	.00000	12826.6100
Licenses	1.62500	.00000
CBOs	.380000	.0000
Constraints	**Slack/ Surplus**	**Dual Prices**
Regional Directors	2.375000	.00000
Senior Fish Officers	11.3335000	.0000
Fisheries Officers	23.0000	.0000
Assistant Fish Officers	.0000	4161.0000
Fisheries Assistant	45.625000	.0000
Fish scouts	.0000	136.4533

Source: Field survey data (2003)

The table shows that the Assistant Fisheries Officers and Fish Scouts are the binding constraints to the achievement of effective enforcement of fisheries regulations in Lake Victoria. The results also show that it would be more expensive to hire more Assistant Fisheries Officers than Fish Scouts which also would imply that Assistant fisheries officers would contribute more to the objective value of maximizing conservation than the Fish Scouts. This is probably because the Assistants are trained personnel with more knowledge on fisheries management compared to the Fish Scouts. Conversely, these results indicate that it is cheaper to increase the number of Fish Scouts than Assistant Fisheries Officers. The results indicate that the shadow prices for Regional Directors, Senior Fisheries Officers and Fisheries Officers are zero (0), meaning that the existing numbers of these categories are adequate.

From an economic point of view, slack refers to unused amount of the resource. In this case therefore increasing the numbers in these groups of labor would not necessarily lead to improvement in the conservation of fisheries. Results also demonstrate that there were no generative solutions. Usually, this occurs when a variable has both slack and dual price with values of zero. It would mean that more than the minimum number of constraints is binding.

However, in the case of Lake Victoria fisheries, there were only two critical factors; that on fish scouts and assistant fisheries officers. An increase of 50% of fish Scouts and Assistant fisheries officers was thus applied in the sensitivity analysis to see how the conservation level would behave. The results are as shown in the table 3 below.

Table 3: Results of Sensitivity Analysis of Management Systems

Objective Value - 1) 93453.220

Management system	Value	Reduced Cost
ITQs	.0000	19242.0000
Taxation	.824265	.0000
Licensing	1.458545	.0000
CBOs	.0000	21403.000
Constraints	**Slack/Surplus**	**Dual price**
Regional Directors	.892724	.0000
Senior Fisheries Officers	2.873096	.0000
Fisheries Officers	17.736720	.0000
Fisheries Assistants	.0000	1953.291000
Assistant Fisheries Officers	41.526910	.00000
Fish scouts	.0000	138.5313000

Source: Mokua (2003)

The table shows that there will be an improvement in the objective value when the binding constraints are relaxed. The results of the sensitivity analysis further identified the Fisheries Assistants and the Fish Scouts as the major binding constraints. The dual value indicates that the objective value would increase with an increase of Fisheries Assistants than with an increase in Fish Scouts. This means that higher levels of Fisheries assistants would lead to a higher level of fisheries conservation in Lake Victoria.

Fisheries records revealed that Kenya Fisheries Department operates with a budget that is exhausted within the first quarter of the financial year (Fisheries Records 2001). In the literature it is shown that understaffing, under funding and lack of adequate equipment has hampered effective implementation of fishing regulations since the colonial period (Geheb 1997). For example by 1953, Lake Victoria Fisheries Service (LVFS) had only three patrol boats, six Fisheries Officers and an annual budget of Kshs. 402,560 to regulate the entire activities of the Lake. The discussions also revealed that apart from under resourced departments, there is also inadequate budget allocations given that 100% of the budget is consumed within the first quarter of the financial year. The budget allocation exhausted within three months implies underutilized personnel. The expert consultations held with the Fisheries Officers found that these conditions of lack of adequate budgetary allocations and limited capacity in Fish Scouts have persisted over a period of time. The interviews further revealed that there is no adequate sharing of fisheries data and research information between the research institutions, hence weak linkage between the fisheries Department and other research institutions. This shows limited sharing of research information and findings that could strengthen the management of Lake Victoria fishery.

DISCUSSION

The findings highlight the fact that in order to achieve effective implementation of the regulations, staff levels of fisheries assistants and fish scouts must be increased. Institutional capacity limits effective implementation of fisheries management systems hence the current sustainable problems facing the Lake fishery. Shortages in staff, financial support and technical factors weaken/reduce the extent of efficiencies in applying the regulations. Although Njiru *et al* (2006) note that lack of mature fish is probably due to overexploitation as reflected by laxity and weakness in enforcement of Fisheries Act, this study concludes that the main weakness is that the level of personnel required implementing the regulations which falls below the recommended capacity level.

The role of institutional capacity in resource management hasbeen emphasized. USAID (2004) notes that the strength and performance of institutions, particularly as evidenced in the quality of governance and rule of law, are the primary determinants of development and that resource transfers in the absence of institutional capacity do not yield sustainable outcomes. Saasa (undated) observes that Capacity limitations in the field of Economic management is one of the most evident frailties of most African countries and for which capacity enhancement at both the institutional and human resource level require immediate attention.

Wangwe and Rweyemamu (2001) also observe that although there are numerous causes that underlie Africa’s profound economic malaise, the most fundamental is Africa’s severe lack of capacity. The authors note that despite some improvements in some African countries, the majority are still characterized by weak human and institutional capacity in formulating development projects and implementing strategic priorities. Therefore in the light of development challenges facing African countries, an appropriate and adequate human and institutional capability is necessary.

Wangwe and Rweyemamu (2001) conclude that indeed, the importance of capacity building for sustained economic development in Africa is now almost universally recognized as the “missing link” in Africa’s development. The findings of the surveys by Agbayani and Toledo (2008) showed the need for capacity-building and to prepare the islanders for socioeconomic, environmental, and policy interventions.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that multiple factors constrain the enforcement of fisheries regulation in Lake Victoria-Kenya. These included under capacity in the Kenya Fisheries Department, inadequate patrol boats and inadequate budget allocations. In addition, analysis also shows that there are major interdependence in the dimensions of institutional capacity. Another major clear conclusion is that the Kenya Fisheries Department have less institutional capacity although each category of personnel has its own set of institutional problems. It is recommended that community skills and capacity and the local environment be explored to complement the civil service for the enforcement of fishing regulations.

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