LUCID's Land Use Change Analysis as an Approach for Investigating Biodiversity Loss and Land Degradation Project

Survey of Water Quality Changes with Land Use Type in the Loitokitok Area, Kajiado District, Kenya

LUCID Working Paper Series Number: 35

By

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1.0 Introduction

Wetlands including rivers have unique structural and physico-chemical processes that distinguish them from other ecosystems. Each wetland is unique as its processes are dependent on its hydrology, which is the single most important determinant of its structural composition, physical and chemical processes. Wetlands, depending on their geographical location within catchment basins, hydro-geographic characteristics, hydrology and ecological characteristics have pivotal and diverse functions in the global environment. They are considered as resources themselves and within them contain other resources of great value to humanity. Their ability to provide resources sustainably, support to other ecosystems and stabilize food webs and sustain their critical ecological functions is closely linked to their biological, physical and chemical characteristics and the processes arising from the interactions of these characteristics. Negative impacts disrupting any wetland aspect have cascade effects on others, often altering irreversibly the structural elements and characteristics of the wetland ecosystem.

In arid areas, wetlands have diverse and pivotal functions, serving as habitats for wildlife, food chain support and stabilization, ground water recharge and discharge, nutrient export and support of other ecosystems. In such areas, wetlands are multi-product producing systems, providing a number of goods and services to ecosystems and people at the same time. They have high biological diversity contents and are critical in supporting the adjacent arid environments. They are centres of biodiversity containing rare species, and depending on evolutionary time scales, they may contain in some cases endemic species.

Water availability, fertile soils and their resources have over historical times, attracted human settlement and exploitation of wetlands. Agriculture, hunting and gathering of wetland products are the most common human activities in wetlands, with varying of impacts on wetland structure and functioning. Wetlands undergo natural processes of changes through sedimentation and hydrological alteration depending on prevailing climatic conditions. In last few decades, human induced changes have globally outstripped natural wetland evolutionary processes. The changes especially conversion to agriculture, affect wetland ecological functions, disrupt hydrological regimes, erodes the wetland resource base and negatively impact water quality. This is primarily through water abstraction, diversion of rivers for irrigation, discharge of irrigation water into the river channels and *in situ* water use within the river channel and wetlands. This study was carried out to investigate the impacts of land use types on water quality in a part of the Greater Amboseli ecosystem.

In the recent past, water resources in the Amboseli area were mainly used for domestic consumption, livestock watering and by wildlife. The associated riparian areas and swamps were favoured dry season grazing area for the pastoral community and refuge for wildlife during drought periods. Land use in the area has undergone rapid changes with an increased tendency towards sedentarization of the pastoral community and the incursion of irrigated horticultural agriculture along the rivers and within former swamps. The incursion of agrarian communities into the Loitokitok area has had significant impacts on land use in addition to the local community adopting a semi-nomadic lifestyle. The highland area in agro-ecological zones II and III have been cleared of their natural vegetation and converted to rainfed and irrigation augmented rainfed agriculture. Swamps and rivers passing through fertile plains have not been spared as the fertile soils and water availability has provided ideal opportunities for irrigated agriculture. Large areas of the swamps have been cleared, reclaimed and converted to irrigation fields, growing onions, tomatoes, maize and other horticultural crops. The influx of agrarian communities into the area has had significant impacts on land use patterns in addition to the local community adopting a more sedentary lifestyle and agricultural practices. The highland areas around Loitokitok town have been cleared rainfed agriculture and irrigation augmented agriculture in the drier mid-altitudes. Swamps and river systems in the arid lowlands have not been spared the intrusion of agriculture as their fertile soils and water availability has presented opportunities for irrigation. The high value crops grown require intensive use of pesticides, which eventually find their way into the streams affecting water quality. The competing demands for water resources, and the incidental human wildlife conflict for the highly nutritious crops has led to the erection of solar powered electric fences around agricultural areas excluding wildlife from watering points.

1.1 Study area

This study was carried out in Loitokitok division of Kajiado District, in Kenya (Figure 1). The study area bordered Tanzania to the south and the Chyulu Hills to the north. The area is arid and the basin where the most of the swamps are located fall within Agro-ecological zone II. Water samples collection was also undertaken in the high agricultural potential in the south around Loitokitok town falling in agro-ecological zone II and III. These areas, on the slopes of Mt. Kilimanjaro, receive higher amounts of rainfall compared to the low-lying areas.

The study area has spectacular landforms with Mt. Kilimanjaro in the south, consisting of volcanic uplands, foothill and piedmont plains. Below the foothills are plains of undulating to flat topography, the result of colluvation and alluvial deposition of materials eroded from higher positions. To the north, young volcanic activity is associated with the Chyulu system, consisting of a string of numerous ash and cinder cones, volcanic plugs and lava flows (Toubler, 1983).

There are a number of permanent swamps, streams springs in the study area with possible hydrological linkages to Mount Kilimanjaro. The southern part of the study area is drained by a number of small perennial rivers rising from the Mt. Kilimanjaro foot slopes, fed by melting snow, which join to form the Loolturesh River. The southwestern part of the area bordering Amboseli National Park constitutes an internal drainage system extending to northern Tanzania, with a number of permanent swamps and springs. These are mostly found in the lowlands. Numerous gullies and dry riverbeds, characterized by flash flood flow in the wet season also scar the landscape. The Chyulu range has no surface watercourses due to the extremely porous materials composing the hills, which allow 100% infiltration into the spongy soils. Water resources in the area are in one way or another associated with Mt. Kilimanjaro (Toubler, 1983).

Rainfall in the area is bimodal and precipitation increases with altitude. The lowland areas receive less than 500 mm of rainfall per annum and the higher elevated Mt. Kilimanjaro foothills receive about 1250 mm per annum. There are two rainy seasons with the long rains falling from March-May and the short rains from October- December. Dry seasons of variable duration occur between the rains. Pan evaporation in the lowlands as estimated at between 1800 mm and 2000 mm per annum, resulting in a precipitation-evaporation deficit of 1300 mm to 1500 mm. Mean temperature range from 30 ^{o}C in the lowlands to 22 ^{o}C on the foot slopes of Mt. Kilimanjaro.

Altitude, soil type, climate, human occupation and utilization of the land have influenced the distribution of the natural vegetation in the study area (Muchiru, 2003, in press). The main vegetation type consists of wooded grasslands and open grasslands. Patches and strips of riparian vegetation and gallery forests are found along riverbeds and the permanent swamps. *Penisetum stramipeum* dominates areas the covered Pleistocene volcanics (olivine basalts), comprising parts of the Kilimanjaro footslopes, piedmont plains and associated uplands. The higher elevated parts of the Kilimanjaro uplands are dominated by *Themeda triandra*. *Penisetrum mezianum* dominates in the imperfectly drained, cracking clay soils of the alluvial plains and bottomlands. On the Kilimanjaro footslopes, the woody vegetation is dominated by *Acacia nilotica* and *Combretum spp*. Common species in the lowlands include *Acacia tortilis*, *A. xanthophloea, Azima tetracntha* and *Suaeda monoica*, especially under saline sodic conditions. *Acacia melifera* is also a common plant species in the study area.

Soils in the study area are variable, with volcanic red soils on the Kilimanjaro foothills and volcanic pryroclasts in the Chyulu hills. Areas around swamps such as, Namalok, Leinkati and Kimana have alluvial quaternary sediments, associated with fluvial deposits and peneplains. The alluvial soils along river valleys, swamps and riverbeds are very fertile. The larger Amboseli ecosystem is an important wildlife assemblage area in Kenya and contains the world famous Amboseli National Park.

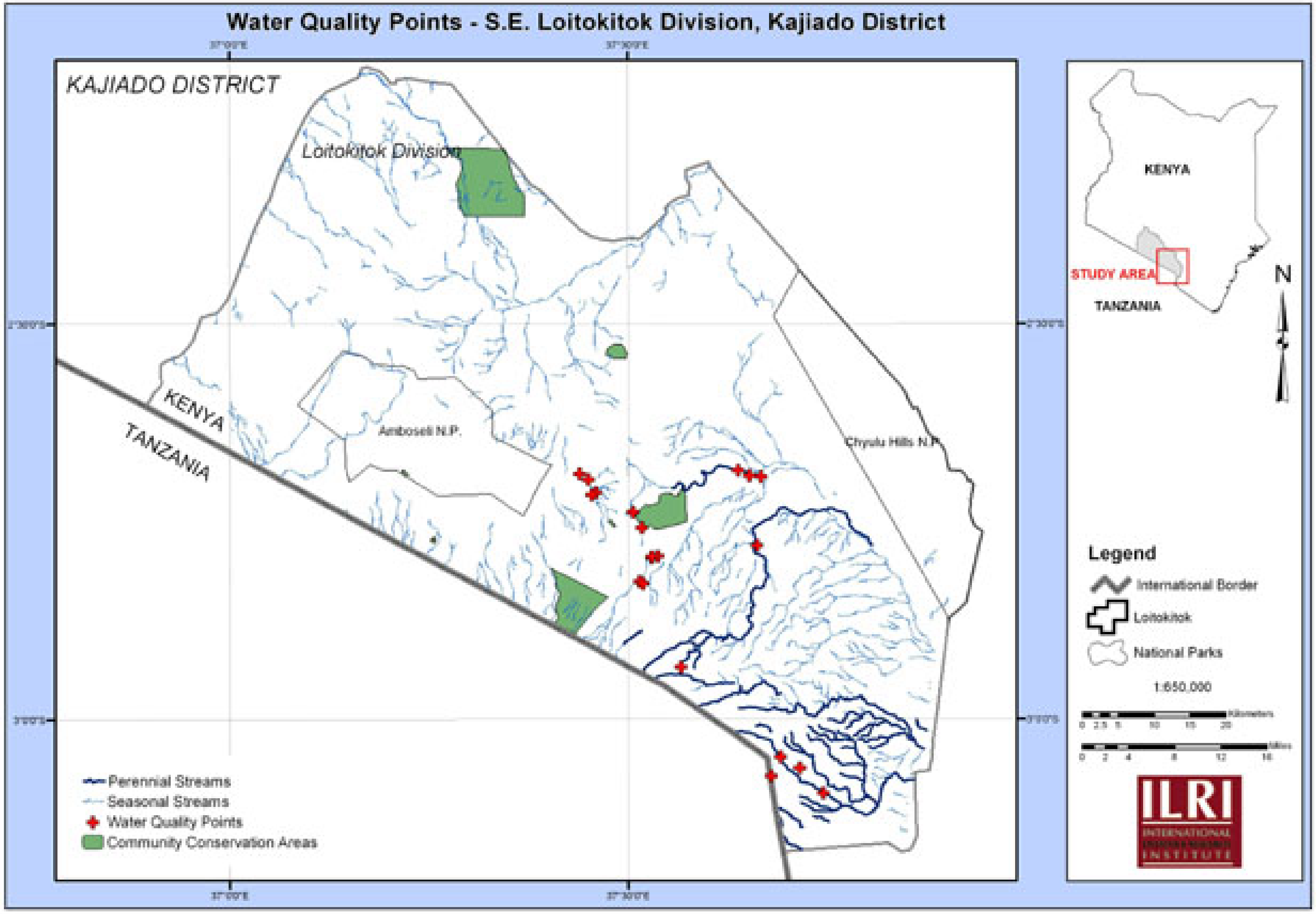

Figure 1. Loitokitok area, Kajiado District

The population density in Loitokitok division where the study area is located is 42 persons per square kilometre, with higher densities in agricultural highlands and low densities in the lowlands. The distribution of the human population is influenced by water availability, as settlements are concentrated along water points. Settlements are also located near urban and rural trading centres as well as along roads (GoK, 2002).

1.2 Land use
Pastoralism is the dominant land use in the arid lowlands but large areas have been set aside in the group ranches for wildlife conservation and ecotourism activities. Swamps and rivers in the lowlands support a thriving irrigated horticultural agriculture, growing onions, tomatoes, maize, bananas, oranges and papaws. This horticultural agriculture is particularly well developed in Namalok and the Kimana. Around Loitokitok town, rainfed agriculture predominates and a combination of rainfed and irrigated agriculture is practiced in Rombo.

2.0 Study design
The land use types in the study area potentially affecting water quality were categorized as agriculture, livestock and wildlife conservation. These land use types or their combinations were assigned to the sampling points in the water bodies studied based on field observations and interviews with the local community (table 1).

Table 1. Land use types in the selected rivers and swamps in the study area.

	Namalok Swamp	Kimana	Leinkati	Lolturesh River	Rombo
Wildlife		X	X	X	
Livestock	X	X	X	X	X
Mixed wildlife/livestock		X	X	X	
Rainfed Cultivation		X			X
Irrigated agriculture	X	X	X	X	X
Mixed C/L/A		X	X	X	

2.1 Hypotheses
1. Impacts on water quality varies with land use type
2. Agriculture in and around swamps extracts large quantities of water affecting wetland ecosystem structures, flow and use by both livestock and wildlife.
3. Use of agricultural inputs such as pesticides and fertilizers has negative impacts on water quality, reducing its value for human, wildlife and livestock utilization.

3.0 Sampling methods
3.1 Vegetation and general characteristics
Vegetation structure at each sampling location was described and herbarium specimens taken for those species that could not be identified in the field. The canopy cover of riparian woody vegetation was determined for 10x10 m plots at each sampling point. A quadrat (0.25 m^2) was used to determine percentage cover by herbaceous species and macrophytes at transects placed perpendicular to the water channel. Surveys of crops grown where agriculture was practiced were carried out. Residents were interviewed to find out whether changes in water quality have occurred with time, previous land use types and agricultural inputs used by farmers. Discarded pesticide containers were collected to find out the commercial pesticide brands used and their active ingredients. Photographs were taken at the sites and their geographical position read from a

GPS. A form with details of bank stability, extent of erosion, substrate composition and general water characteristics was filled prior to collection of water samples and parameter measurement.

3.2 Water samples collection
The study was carried out in the dry season in March 2003 to minimize confounding effects arising from surface runoff contamination of the water bodies during the rains. The sampling sites were carefully selected to ensure that the samples reflected the impacts of land use types in the immediate vicinity and upstream of the sampling point. In each water body a sample was collected upstream of the land use type, within the land use type and down stream. Channelled flow was selected and points where springs emerged on the surface. Samples obtained from spring sources and channelled flow upstream of land use types were taken as reference samples to assess changes in water quality arising from land use type. Channelled flow was obtained in Kimana, Leinkati and Namalok swamps as well as, Rombo and Nolturesh rivers. Samples from emerging springs were obtained in Namalok, Rombo, Nolturesh and Kimana. Other samples were obtained from irrigation canals and where possible at water flow termination points.

3.3 Field determination of water quality parameters
Water quality parameters including pH, dissolved oxygen concentration, electrical conductivity, temperature and oxidation-reduction potentials were determined ***in situ*** using portable field electronic meters. Electrical conductivity was measured using a Kasagau conductivity meter with a cell constant of 0.903, and auto temperature/salinity compensation. A Kasagau meter, Model UC-23 with a combined pH-ORP port was used to determine pH and ORP values. Dissolved oxygen concentration in the water samples was read from a Jenway meter calibrated in milligrams per litter and percentage oxygen saturation. All the probes had electronic temperature display functions and there were minimal variation between the instruments.

3.4 Laboratory based analysis
Collected water samples were preserved for laboratory-based analysis of nutrients, heavy metals, total dissolved solids (DS) and suspended solids (SS), and biological (BOD) and chemical oxygen demand (COD). Samples for heavy metal analysis were collected in acid-rinsed glass bottles and stored at room temperatures. BOD samples were collected in BOD bottles and along with other samples stored under dry ices. Nutrients determined in the water samples included nitrate, nitrite, total phosphate and orthophosphate. In the laboratory, analysis was performed according to conventional procedures for water and wastewater (Greenberg ***et. al.*** 1992).

4.0 Results
4.1 Vegetation and general characteristics of the water bodies sampled
4.1.1 Kimana system
Source Springs
Two sampling points located 10 meters apart were selected to represent the springs from which water draining into Kimana irrigation scheme originated. The spring, supplying water to Kimana dispensary and an adjacent stream emanating from a similar spring had a 100% cover by riverine vegetation, consisting of *Acacia xanthophlea, A. senegalensis, Trichlia emetica,* and *T. ventricosa*. The streambed had a rocky and gravely substrate and the banks were barren. The springs were used for domestic water supply, livestock watering and were utilized by wildlife, deduced from an elephant wallow hole and footprints. Land use activities upstream of the sampling point comprised of wildlife and livestock grazing.

Irrigation weir and diversion
This sampling point was within the Kimana irrigation scheme, which is completely fenced off from wildlife with a solar electric fence. The weir is a concrete barrier constructed across the river and collects water from the irrigated fields and redistributed again to other irrigated fields downstream (plate 1). The riverine vegetation here consists of *Ficus sycomorus* with some isolated *Acacia senegalensis* trees, and most individuals attained heights of about 35m. Large portions of the riverbed were dry, as the water had been diverted for irrigation. Some of the

riverine trees were dry and others were observed to be undergoing water stress. The stream substrate was consisted of silt and alluvium and the banks were severely eroded. Land use upstream of the weir was classified as livestock and irrigated agriculture.

Kimana Bridge
Water samples were collected at a bridge along the Kimana-Isinet road, downstream from the Kimana irrigation scheme. The river below this point flowed into a swamp within the Kimana wildlife conservancy. The riverbed was exposed as there no overhead vegetation cover, the streambed, however, had a 10% cover by *Cyperus imensus*. The banks were bare and the site was utilized as a watering point by of livestock. Land use upstream was categorized as irrigated agriculture and livestock.

Isinet Bridge
This sampling point was located at the bridge close to Isinet trading centre along the Kimana-Isinet road. It was selected as it flowed into the same swamp with the discharge from Kimana, coalescing to form the into the Leinkati swamp. A barrier composed of rocks and sand bags across the riverbed diverted the entire flow from the stream to irrigated fields adjacent to the shopping centre (plate 2). *A. xanthophlea* trees within the swamp dominated by *C. papyrus* were observed to be drying. The sampling point had a 50% cover by *A. xanthophlea* trees and the substrate was consisted of alluvium, with slightly eroded banks. Land use upstream of the bridge, which was used by residents for domestic water supply, was classified as livestock, irrigated agriculture and livestock.

4.1.2 Leinkati Swamp
This swamp was located several kilometres downstream of the Kimana irrigation scheme, south of the Chyulu Hills and it was hydrologically linked to the Kimana system through the Kikarankor River. The Leinkati swamp receives water from both the Kimana and Isinet river systems, which joined to form a large open water swamp that was, unfortunately, not accessed during the sampling. A sampling a point before the Kikarankor River water was diverted into irrigation canals was designated as the baseline sample for water entering the Leinkati swamp. Land use upstream of this point was designated as livestock/wildlife although it was a continuation of the Kimana and Isinet irrigation schemes. The bank vegetation at this point consisted of grass, sedges, and riverine trees with a stream cover of 80%. The substrate was composed of alluvium and the banks were moderately eroded with livestock dung and footprints on the bare areas.

The second sampling point was located within an irrigation canal that collected water from the cultivated fields. Land use at this point consisted of irrigated fields where onions and tomatoes were grown. The water canal was clogged with a floating macrophyte, *Azolla sp*, and floating mats and scum of filamentous algae and sedges were rooted in the canal. A transect perpendicular to the irrigation canal and extending into the swamp vegetation of *Typha domingensis* was established and vegetation cover estimated at 10m intervals using a 0.25 m^2 quadrat. The percentage herbaceous cover by *Typha domingensis* from the canal bank to the swamp vegetation increased from 10% to 100% at the edge of the swamp after 40 m. The percentage cover by the sedge, *Scirpus maritima,* fell from 40% at the edge of the canal to 10% at 40 m from the canal edge. Extensive areas of the swamp had been burnt and several hundred heads of cattle were observed feeding within the swamp. The last water sample was collected where channelled flow exited from the irrigated maize, tomato, cowpeas and onion fields and overflowed into marshes. The marshy area was utilized by livestock, wildlife and for domestic consumption. The channel at this point was clogged with *Azolla,* floating algae and rooted sedges. This point was designated Leinkati end and land use classified as irrigated agriculture/livestock/wildlife. Water for domestic purposes was observed being drawn at various points within the Leinkati irrigated areas.

Plate 1. Water diversion in the Kimana irrigation scheme. The riverbed below the weir is dry and the banks eroded.

Plate 2. Simple water diversion weir at the Isinet bridge.

4.1.3 Namalok Swamp

The Namalok swamp is an internally heterogeneous system consisting of a spring source, a floating *Papyrus cyperus* swamp and irrigated field growing different types of crops. The water emerged for an underground stream into a concrete collection tank from where it flows into the papyrus swamp (plate 3). The baseline water sample for the Namalok swamp was obtained from a water pipe at this point, serving also as domestic water source. The swamp was fringed with *A. xanthophlea* trees and *Ficus spp.* and it was inhabited by hippopotamus and supported several bird species. Water drained from the swamp through a channel after which it was diverted into canals leading to the irrigated fields. A new concrete lined channel was under construction near the earthen channel. This sampling point was designated as the Namalok swamp exit and water samples were taken to determine water conditions after passing through the swamp and for comparison with spring samples and discharge from the fields under irrigation. The exit point had a well-developed macrophyte community consisting of *Sphaeranthus suaveolon, Marsilea macrocarpa, Hydrocotyle ranunuculoides* and *Papyrus imensus* interspersed with *Cynodon dactylon*.

Water samples were obtained from the middle of the irrigation scheme after passing through irrigated fields growing maize, tomatoes, onions and bananas (plate 4). The main irrigation canal sampled had copious growth of the water fern, *Azolla sp., Marsilea macrocarpa* and various sedge species. The canal banks had a 100% cover of *Cynodon dactylon*, and were lined with *A. xanthophlea* saplings. Water flow from Namalok terminated in a pond adjacent to papaw and banana fields, emptying into a livestock-watering trough (plate 4). The entire irrigated area was completely fenced with off with a solar electric fence to keep off wildlife. There were other spring systems adjacent to the Namalok swamp although possible hydrological connections could not be established.

4.1.3 Rombo River System

The water emerged from underground in a ravine, where it was collected for domestic consumption and laundry washing within the water channel. There could have been other spring sources in the area but only those springs near the Illasit trading centre were sampled. A dense grove of mature dominated by *F. sycomorus* trees attaining heights of over 35 m lined the ravine banks. The water was diverted into fields where maize, bananas and other crops were grown. A number of canals were encountered within the irrigated area but their hydrological connectivity could not be established. Water samples for analysis were collected at the spring source, two discharge points from irrigation fields and a channel designated as the exit. The irrigation in this system augments rainfall during the dry season.

4.1.4 Nolturesh River

Virtually the entire water discharge constituting the former Nolturesh River has been diverted through a water pipeline to supply the Kitengela based export-processing zone (EPZ). A spillway flowing into the former riverbed supplies a small volume of water that however, does not reach the former extensive swamp at Laika. The spillway channel had a gravely substrate with a 40% cover by sedges. It was utilized as a domestic water source and a livestock watering point. Water samples were collected at the spillway channel and further downstream after passing through irrigated fields. The last point downstream where water was encountered had a 90% cover by riparian trees dominated

The water from the springs flow into this swamp before exiting through a natural channel, besides which a new concrete is being constructed, into the irrigated agriculture area. by *A. xanthophlea, A. senegalensis* and *F. sycomorous*. The banks were severely eroded by livestock and the substrate consisted of alluvium, while the adjacent areas were severely overgrazed (plate 5).

Plate 3. *Papyrus cyperus* swamp at Namalok.

Plate 4. The water pool at flow termination point in Namalok swamp.

Plate 5. Water flow from Nooltureshi River termination point. Note the murky appearance of the water and severe overgrazing along the riverbanks.

4.2 Water quality analysis results

4.2.1 Kimana system:

The Kimana system is made up of a series of springs within the Kimana Group Ranch, that join to form a sizeable stream that flows into a swamp next to the Kimana conservation area. A stream flowing past the Isinet shopping centre joins it further downstream to eventually form the stream that ends at Leinkati swamp. Water samples were taken at various points along this system, comprising of different land use types. Figure 2a-e show the changes in parameters along this system. Two other samples were obtained upstream of the irrigation scheme, one at the bridge at the Kimana–Amboseli bridge and at a stream near Loitokitok town that was assumed erroneously to be the headwater of the Kimana system. BOD in the water samples from the baseline spring sources was 130 mg/lt. with a COD of 248 mg/lt. (fig.2a). The stream at Loitokitok had a BOD of 73 mg/lt. and a COD of 200 mg/lt. A mean dissolved solids content of 242 mg/lt. was found for the spring sampling points. The stream had a lower COD content of 120 mg/lt. that reflected its surface flow origin compared to the springs emerging from underground. The mean suspended solids for the sample from the Amboseli Bridge and stream adjacent to the dispensary water uptake point was 118 mg/lt., in contrast to that from the water intake point at 1,594 mg/lt. (fig. 2b). The latter higher value could have arisen from the impoundment constructed around it to tap the water and accumulation of litter fall from the riverine vegetation. Suspended solids content at the stream near Loitokitok town was 558 mg/lt., enhanced by flushing of materials into the stream by rains that fell the previous night. Electrical conductivity for the spring baseline samples was 193 μS/cm (fig. 2c), with a pH of 7.34 (fig. 2d). Nutrient was also different in the various sampling points (fig. 2e). Nitrate concentration at these springs was 5 mg/lt., with a corresponding nitrite concentration of 0.0097 mg/lt. The total phosphate concentration was found to be 3.74 mg/lt. and orthophosphate at 3.16 mg/lt. Iron was the only heavy metal found in these water samples at a mean concentration of 0.14 mg/lt.

Water samples obtained at the weir within the Kimana irrigation scheme had COD and BOD values that were high compared to the source springs at 270 mg/lt. and 624 mg/lt., respectively. Dissolved and suspended solids were similarly higher than at the spring sources at 468 mg/lt. and 104 mg/lt. The electrical conductivity value increased to 237 μS/cm and the pH to 7.46. The nitrate levels were however found to be lower than at the spring sources at 3 mg/lt. The total phosphate concentration however rose to 5.42 mg/lt. as a result of the agricultural activities within the Kimana irrigation scheme. Water sample collected at the bridge on the Isinet –Kimana road before entry into the swamp system at the Kimana conservancy, revealed a decline in the dissolved solid content to 168 mg/lt. The electrical conductivity increased to 386 S/cm.

The concentration of nitrate the source springs and Kimana irrigation weir did not show any marked changes, remaining at a mean of 3.13 mg/lt. There was an increase in this nutrient between the weir and the Kimana Bridge to 7 mg/lt., increments that can be ascribed to irrigation schemes downstream of the weir. Nitrite concentrations increased from a mean of 0.013 at the springs to 0.02 at the Kimana weir, declining further to 0.008 at the Kimana Bridge. Total phosphate concentrations declined within the Kimana irrigation to 3.07 mg/lt., and declined further to 2.66 mg/lt. at the Kimana Bridge. Orthophosphate showed a similar declining trend between the source springs and the Kimana Bridge, with no peak attributable to irrigation activities.

The water from the Kimana irrigation scheme and Isinet stream coalesced flowed into an extensive wetland with extensive areas under irrigation near Isinet. The wetland had open water further downstream surrounded by irrigated areas. The Leinkati swamp was considered as an extension of the Kimana water system and in this swamp, samples were collected at three points. The baseline sample was taken at a point before diversion into the irrigation channel. The other sample was obtained from a canal draining water from irrigated plots and the last one taken, at the extreme end of the cropped area used for livestock grazing. The dissolved solids content in the river was high before its entry into the irrigated fields at the Leinkati swamp at 1,016 mg/lt., declining to 184 mg/lt. in the last

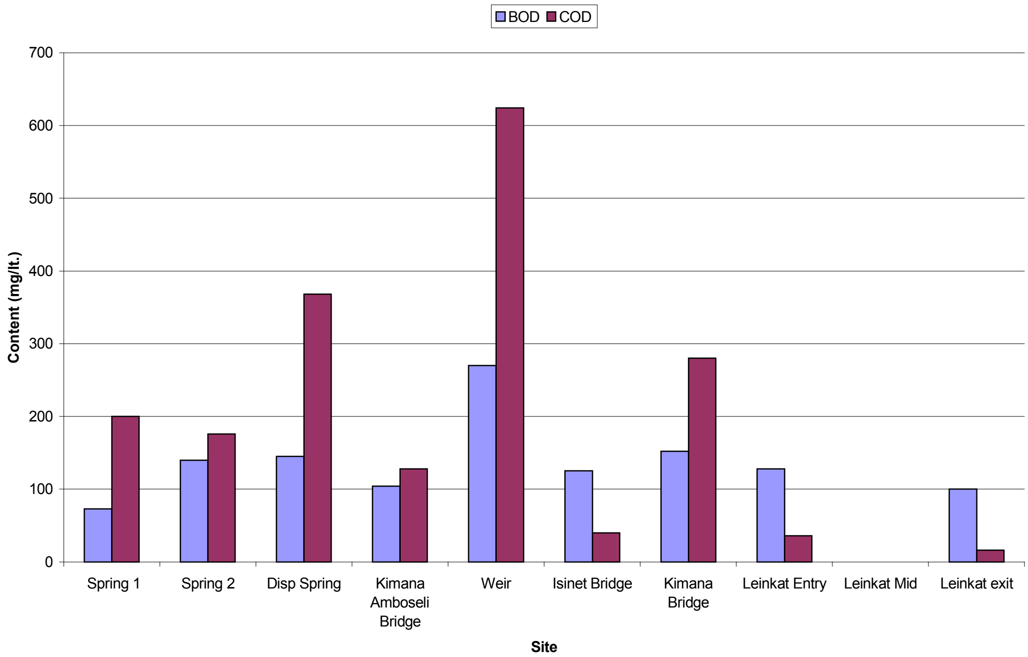

Figure 2a. Chemical and biological oxygen demand at various sampling points in the Kimana System.

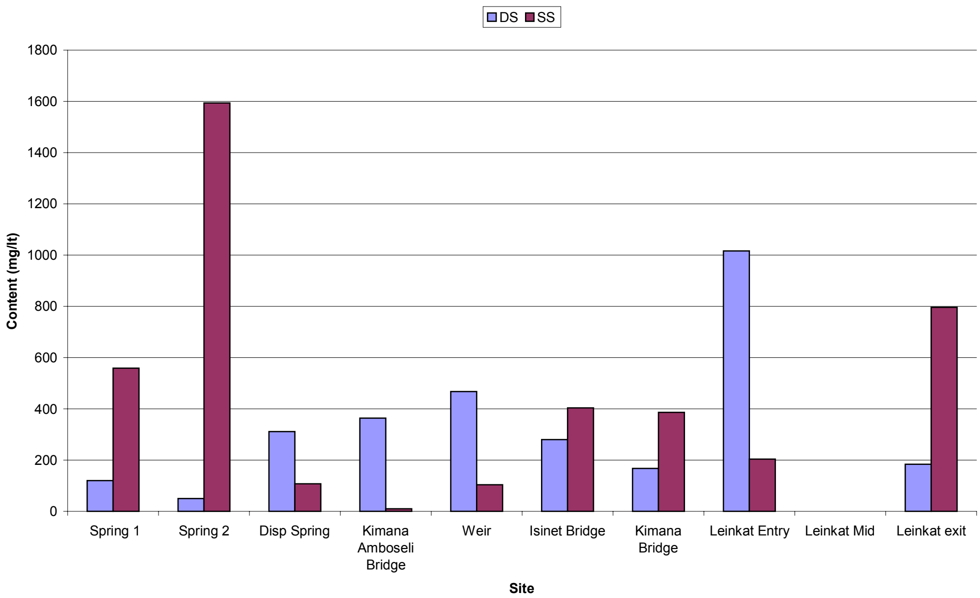

Figure 2b. Dissolved (DS) and suspended solids (SS) loads in water samples obtained at different locations in the Kimana system.

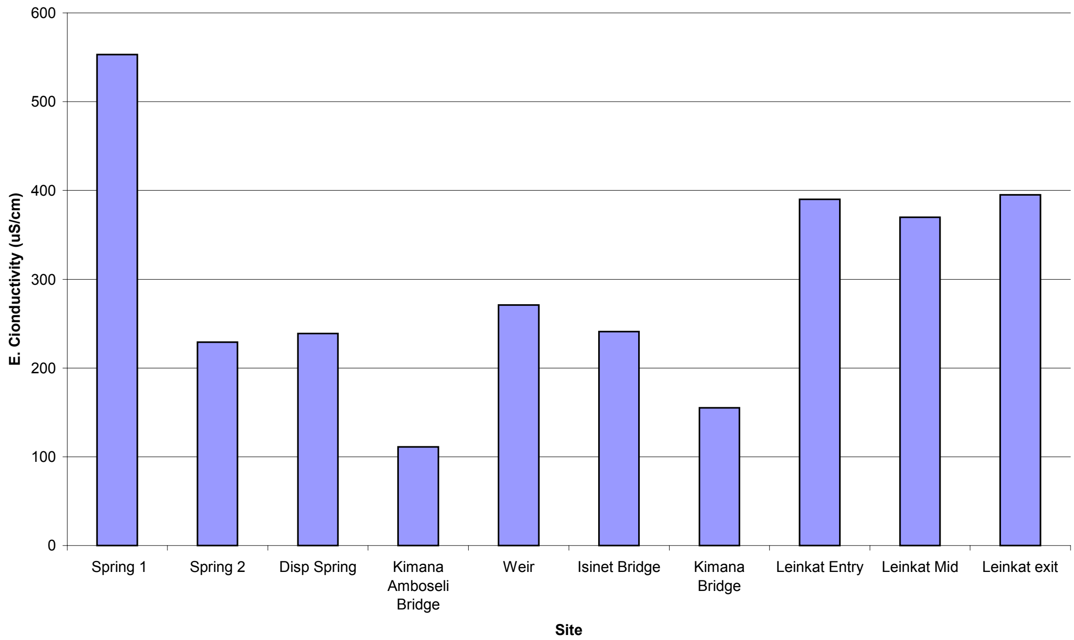

Figure 2c. Changes in water electrical conductivity (µS/cm) in the Kimana system at various points under different land uses

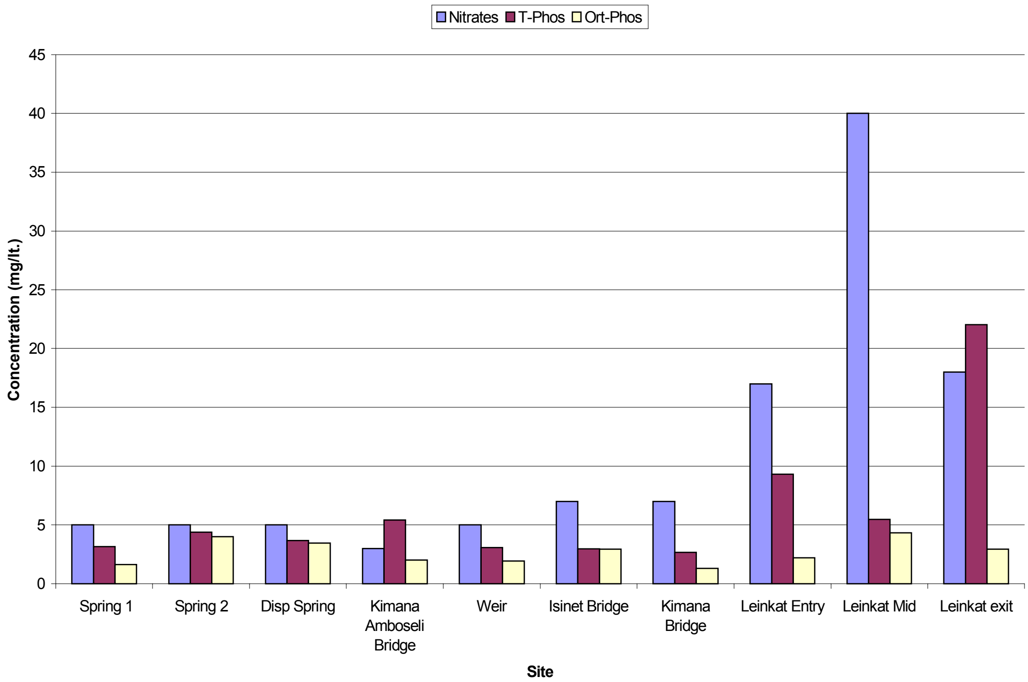

Figure 2d. Variations in nutrient concentrations in the Kimana system at the different sampling sites.

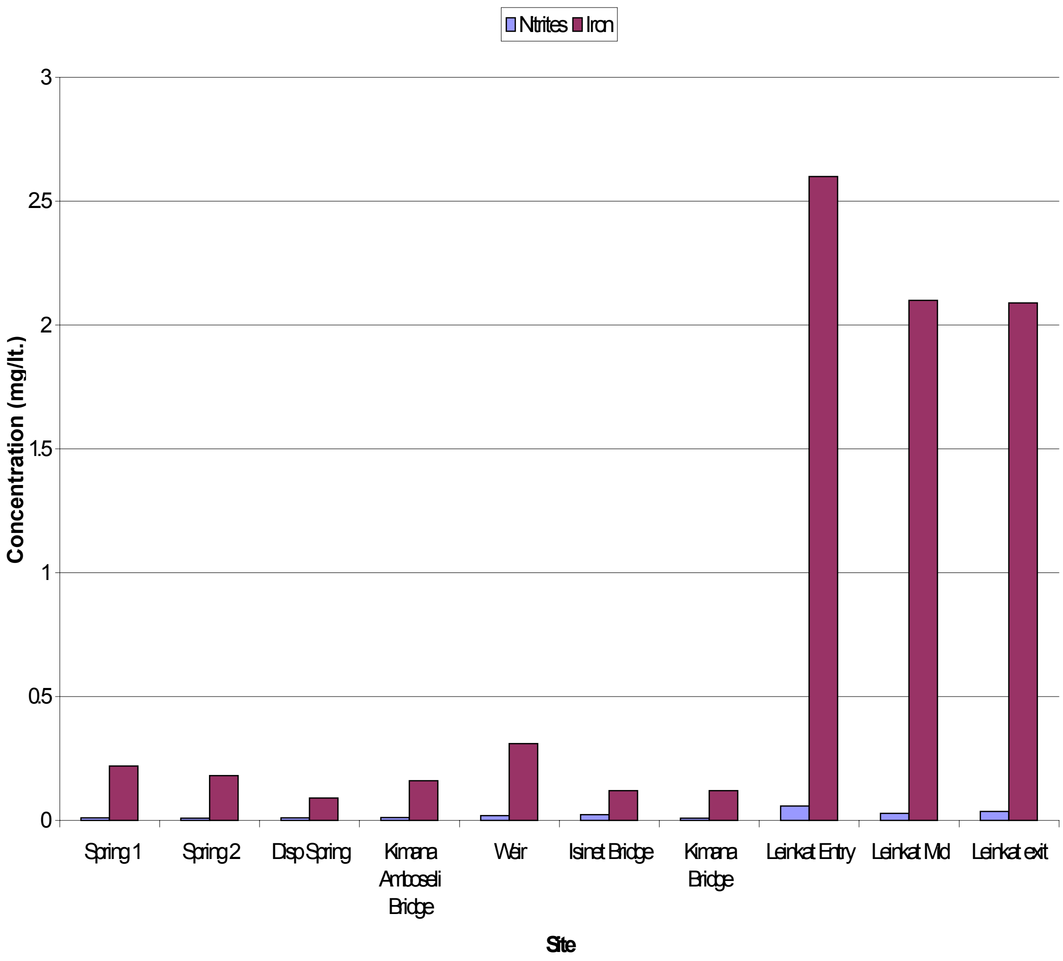

Figure 2e.Variations in iron and nitrite concentrations in water samples obtained from different locations in Kimana canal in the livestock grazing fields.

The dissolved solids content in the middle of the irrigated area could not be determined as the sample was accidentally spilt during analysis. The suspended solids load was 204 mg/lt. at the entry point and rising to 796 mg/lt. at the final sampling point. Conductivity underwent minor changes from a mean of 199 µS/cm at the two bridges to 390 µS/cm at the Leinkati first sampling point. The conductivity declined to 370 µS/cm in the irrigation canal before increasing to 395 µS/cm at the last sampling point. The pH within Leinkati ranged from 8.64 in the first sampling point declining to 8.05 within the irrigated area to 7.5 at the last sampling point. The oxidation-reduction potential changed from –40 mV at the fist sampling point to –20 mV in the middle and increased to –7 mV at the last sampling point.

The concentrations of nutrient underwent the most significant transformation between the bridge sampling point and the Leinkati system. The nitrate concentration increased from 7mg/lt at the Kimana Bridge to 17 mg/lt at the first sampling point in Leinkati. Nitrate concentration in the discharge from irrigated fields in Icahalai was determined at 40 mg/lt., which declined to 18 mg/lt. at the last sampling point. Nitrite concentration increased to 0.02 (740.7%) in the irrigated fields discharge compared to 0.0081 at the entry point, before declining to 0.028 at the last sampling point. The total phosphate concentration doubled from 2.66 mg/lt. to 5.46 mg/lt. in the middle, with a concentration of 22.03 mg/lt., at the last sampling point, an increase of 400%. Within the Leinkati area, the mean iron concentration was about 2 mg/lt.

4.2.2 Namalok Swamp

Water quality parameters in Namalok swamp had dichotomies arising from water passage through two distinctly different systems comprising of the papyrus swamp and the irrigated area. The biological oxygen demand (BOD) declined gradually from the source point at 153 mg/lt. to 32 mg/lt. at the exit from the irrigation system but the chemical oxygen demand (COD), increased from 32 mg/lt. at the spring to 80 mg/lt. at the swamp exit (fig. 3a). A slight decline in the COD occurred within the irrigation area, but increased to 312 mg/lt. where water flow terminated (fig. 3b). The dissolved solid load declined gradually from 460 mg/lt. at the spring to 200 mg/lt. at the flow termination point.

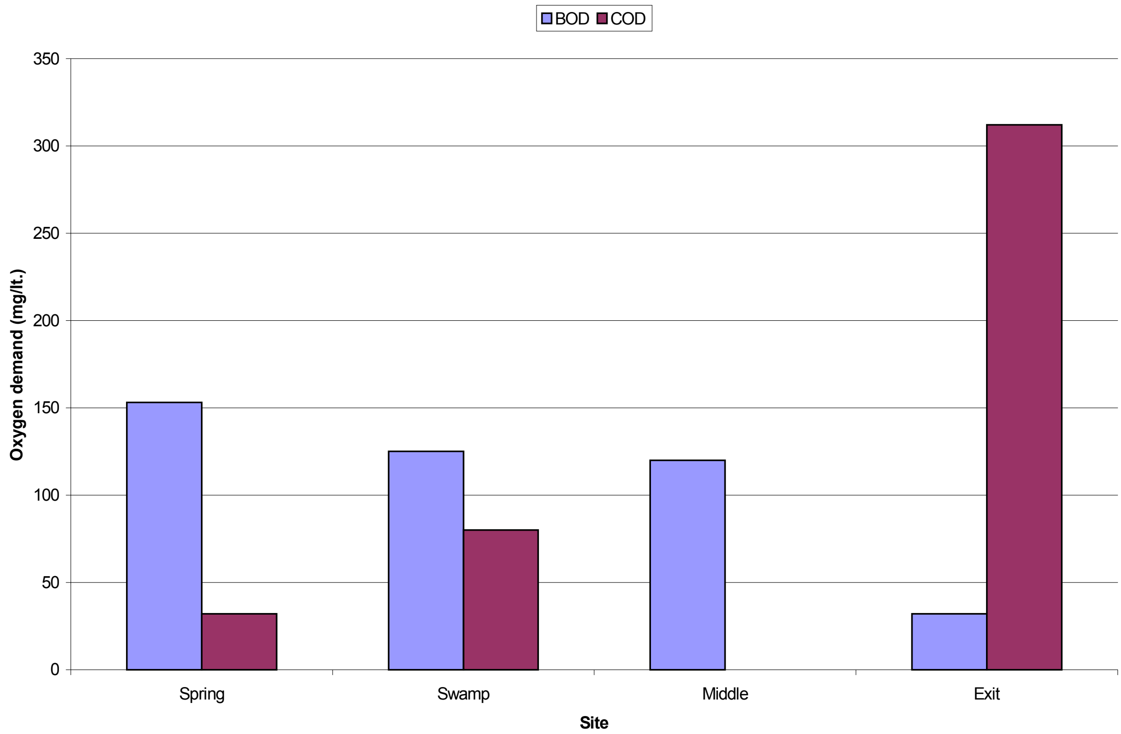

Figure 3a. Chemical (COD) and biological (BOD) oxygen demand changes in the Namalok swamp.

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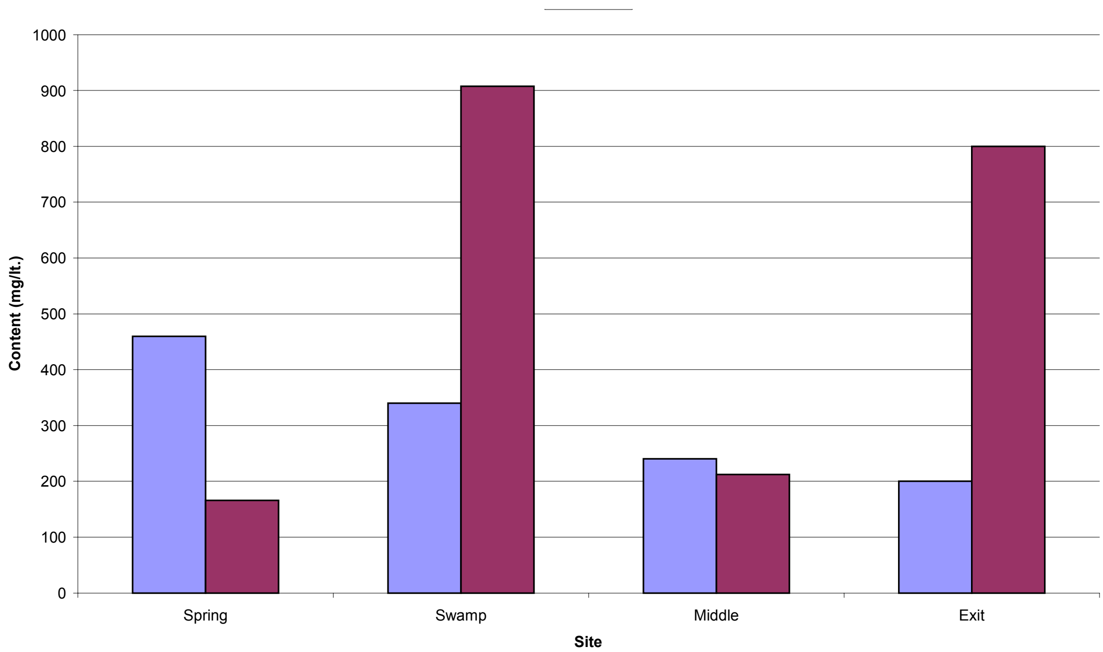

Figure 3b. Changes in dissolved and suspended solids content (mg/lt.) variations in the Namalok swamp

Two peaks in suspended solid concentrations were found in Namalok swamp where it was highest at the swamp exit (908 mg/lt.), with a decline in the irrigated area to 212 mg/lt. before increasing to 800 mg/lt. at the flow termination point. Electrical conductivity increased from 104 µS/cm at the spring to 310 µS/cm at the swamp exit, attaining a value of 316 µS/cm within the irrigated area to 384 µS/cm at the water flow termination point (fig. 3c). Figures 3d and 3e show changes in pH and oxidation-reduction potential in the Namalok swamp. In the swamp, pH increased from 7.2 at the source springs to above 8 within at the last sampling point. Oxidation-reduction potentials were positive between the source point and the swamp exit, at 7 mV and 24 mV respectively, but were negative at –33 mV and –39 mV within the irrigation scheme and the flow termination point. This indicates that there was an accumulation of organic matter giving rise to negative redox potentials. Dissolved oxygen concentration was at its lowest at the swamp exit (1.79 mg/lt.), and rose within the irrigated field to 3.98 mg/lt. before falling to 2.44 mg/lt. at the flow termination point.

Total phosphate concentration in Namalok was high at the spring source at 5.95 mg/lt. and increased further to 8.25 mg/lt. at the swamp exit (fig.3 e). The high concentrations are due to the nature of the spring source passing through underground rocks, reflected in the relatively high dissolved solids and high temperature of the water at the spring. The concentration, contrary to expectations, declined to 4.28 mg/lt. and 4.2 mg/lt. in the irrigation scheme and the terminal point. The declines can be partly due to its removal from water column by the floating and rooted macrophytes in the irrigation canals.

Orthophosphate concentrations were high in water samples collected at the exit from the swamp and in the middle of the irrigation scheme at 3.91 mg/lt. and 3.48 mg/lt. respectively. The changes in phosphorus concentrations within the swamp demonstrate its role in nutrient export and transformation to downstream communities. The high orthophosphate levels within the irrigation scheme are indications of its derivation from applied artificial fertilizer, which contains high concentration of available phosphates as orthophosphate.

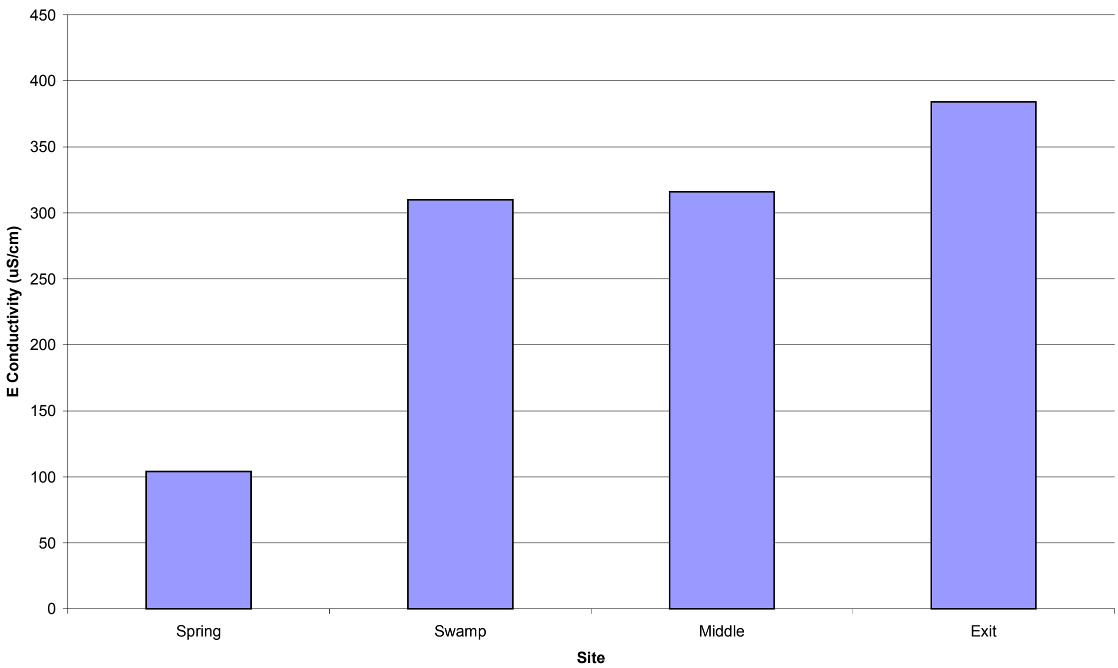

Figure 3c. Changes in electrical conductivity in water samples obtained in Namalok swamp.

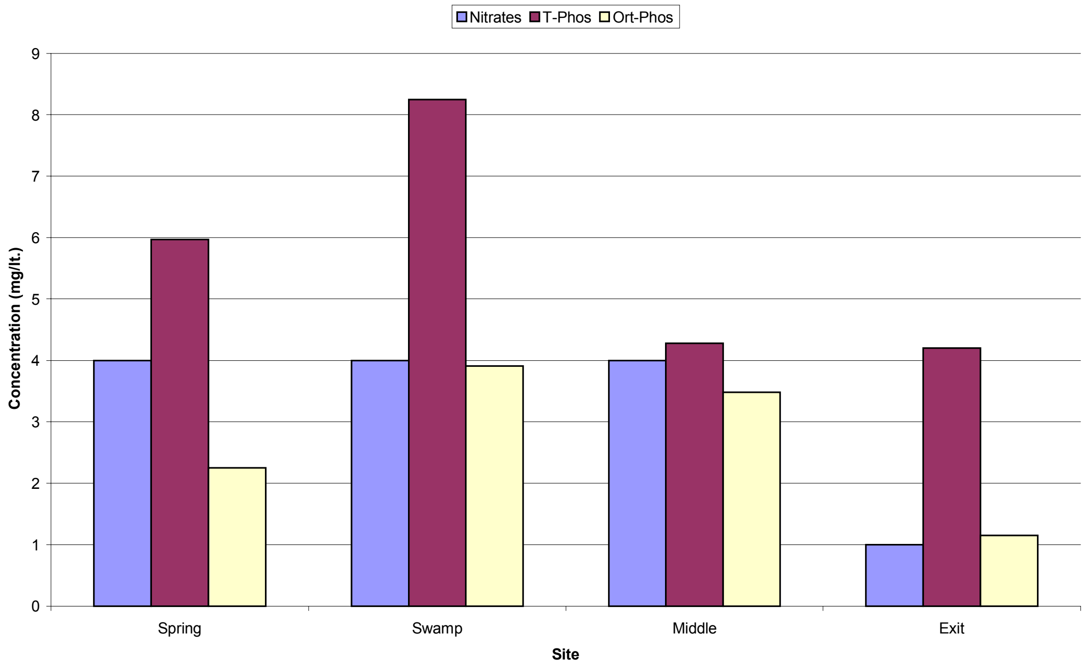

Figure 3d: Nutrient variations in water samples obtained in the Namalok swamp.

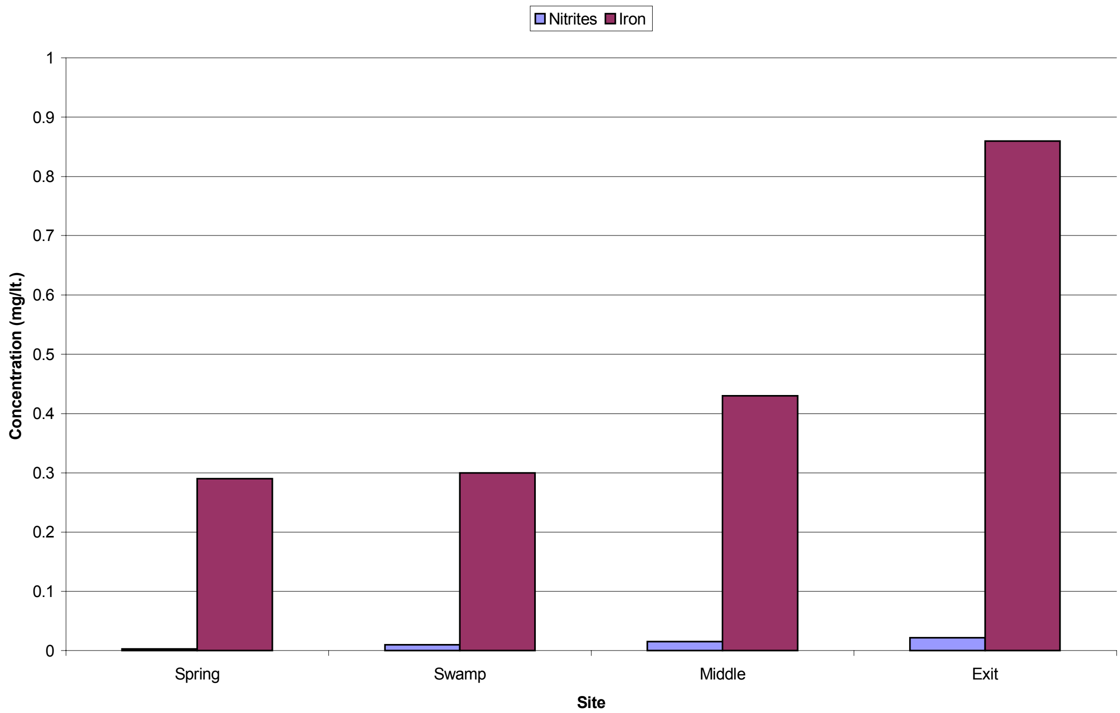

Figure 3e: Variations in nutrient concentrations in nitrite and iron concentrations in Namalok swamp.

Nitrates concentration were constant conservation for the three first sampling sites at 4 mg/lt., declining sharply to 1 mg/lt. at the flow termination point. Nitrites accumulated in the water column gradually to attain a concentration of 0.022 mg/lt. at the flow termination point compared to the spring at 0.003 mg/lt. build up from the source point to flow termination point, while iron concentration increased steadily to the exit point.

4.2.3 Rombo River

Water samples were collected at the springs where it emerged from underground near Illasit centre and at three other points. Two of these were from irrigation channels and the last, one along a stream that was designated Rombo exit. BOD at the point where the springs emerged was found to be 90 mg/lt. while the COD was 60 mg/lt. At these springs, the dissolved solids and suspended solids content were 252 mg/lt. and 198 mg/lt., respectively. The electrical conductivity was higher compared to other springs sources at 354 µS/cm and a pH of 7.15, with an ORP of 22 mV. The nitrate content at the springs was high at 8 mg/lt., while total phosphate concentration stood at 7.75 mg/lt. Within the irrigation canals, the BOD and COD levels increased markedly, with values of 143 mg/lt. and 332 mg/lt. at the two points sampled. The dissolved solids content rose to 344 mg/lt, and the suspended solids load was 349 mg/lt. The increase in electrical conductivity was modest to 368 µS/cm compared to the source springs at 336 µS/cm. In one of the canals from the irrigated fields, the pH was found to be 8.4, with a redox potential of –50 mV. The nitrate concentration in the irrigated water discharge was 9 mg/lt. while nitrites remained virtually unchanged compared to the springs. Declines in the concentrations of total phosphate and orthophosphate were detected with values of 5.04 mg/lt. and 2.25 mg/lt. in the water samples from irrigation canals. The iron concentration was high at 1.06 mg/lt. in the samples from the irrigated fields.

4.2.4 Nolturesh River

The BOD content increased from 153 mg/lt. at the spillway to 166 mg/lt. at the riverbed sampling point, while the COD increased by 375% from 32 mg/lt. to 120 mg/lt. Dissolved and suspended solids also increased downstream to 460 mg/lt. and 166 mg/lt. respectively. Electrical conductivity increased to 171 µS/cm from 104 µS/cm and pH from 6.67 to 7.6. The redox potential dropped to –3 mV at the riverbed from to 40 mV at the spillway. Nitrate was undetectable at the riverbed while an increase in the total phosphates content and orthophosphate occurred to 11.68 mg/lt. and 2.18 mg/lt., respectively. The iron concentration in the water increased from 0.25 mg/lt. at the spillway to 2.38 mg/lt. at the riverbed

4.3 Water Quality Changes with Land Use Type

Data on the various water parameters from the different land use systems studied was pooled to investigate the changes in water quality associated with land use type. This analysis was, however, slightly biased by inherent variations in basic water parameters between the different sources. Changes were still detected in all the parameters analysed in this report, showing that land use in the study area negatively impacted water quality, as well as a definite reduction in water availability.

Changes in COD, BOD, TSS and DS with land use type are shown in figure 4a. The source sites also used as domestic water sources have the lowest COD and BOD, indicating low pollution levels with means of 124 mg/lt. and 129 mg/lt., respectively. The dissolved solids load was however, slightly higher than that in irrigated areas as a consequence of their subterranean origins with dissolution of salts from rocks and soils. The highest mean COD of 429 mg/lt. was found in water samples collected from irrigated fields' discharge canals. Livestock/wildlife land use types had mean dissolved solids contents of 564 mg/lt., due to excreta from the animals as well as high background dissolved solid contents. The highest suspended solids loads were found at sites where land use comprised of livestock and agriculture at 660.7 mg/lt. The sites with this type of land use comprised of irrigated agriculture upstream draining fields under fallow irrigation, livestock grazing and watering within the water channels. These activities generate large amounts of suspended solids from soil erosion within the fields and substrate disturbance by livestock. The colloidal nature of the soils prevents rapid flocculation of the suspended particles accentuating the suspended solid concentration values.

The highest electrical conductivity values were determined in water samples discharged from the irrigated fields at 338.6 S/cm corresponding to high dissolved solid concentrations (fig. 4b). The elevations in conductivity were due to dissolution of artificial fertilizer applied in the farms, evaporative concentration of irrigation water by high temperature prevalent in the area and the elution of crystallized salts from the soils in the field. Salanization of the soils in the irrigated farms was evident from the salt deposits in fields that had watered a few days previously. The pH was elevated where land use consisted of irrigated agriculture and livestock/wildlife with a mean value of 7.8 (fig. 4c). Artificial fertilizer inputs, alkalization of the slightly alkaline water and urea inputs from livestock could have been responsible for the rise in water pH. The pH declined slightly to 7.58 where land use comprised of livestock and agriculture. There was a build up of organic matter in canals collecting water from the irrigated farms leading to the high BOD content, low-oxidation reduction potentials and the slight decline in pH. The negative reduction potentials in areas under irrigated agriculture, livestock/wildlife and livestock agriculture indicate enhanced organic loading in water under these land uses types, from phytoplankton and bacterial growth under the eutrophic conditions. The greatest lowering in ORP was found in water samples collected in canals channelling water from the irrigated farms at –17.4 mV in comparison to samples collected at the source springs with a mean +2.9 mV (fig. 4d). Background concentrations of phosphate in the spring sources sampled were with a 5.44 mg/lt. (figure 4d)

Nutrient concentrations variations with land use types demonstrate the impacts of nutrient increments from land use activities as well as removal by aquatic vegetation (figure 4e). The concentration of nitrate in water samples from areas under irrigated agriculture increased by 302.1% from concentrations of 4.8 mg/lt. at the source springs to 14.5 mg/lt. within irrigation canals. The nitrate concentration values were also high in areas where land use consisted of livestock and agriculture. Anthropogenic activities that include irrigated agriculture are primary sources of nitrates in the study area, although background levels are still high.

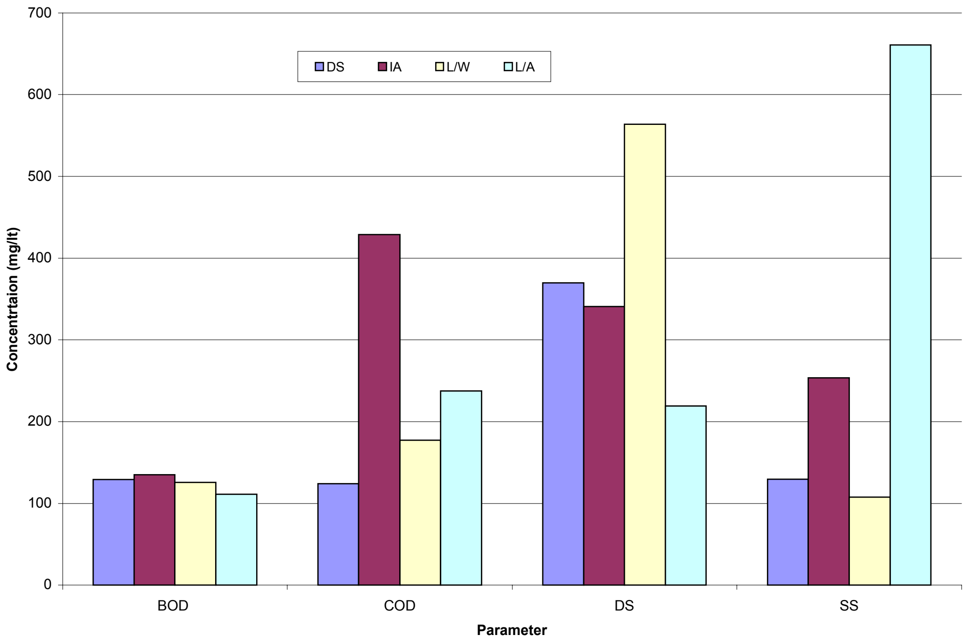

Figure4a. Chemical oxygen demand (COD), Biological Oxygen demand, Dissolved and Suspended solids.

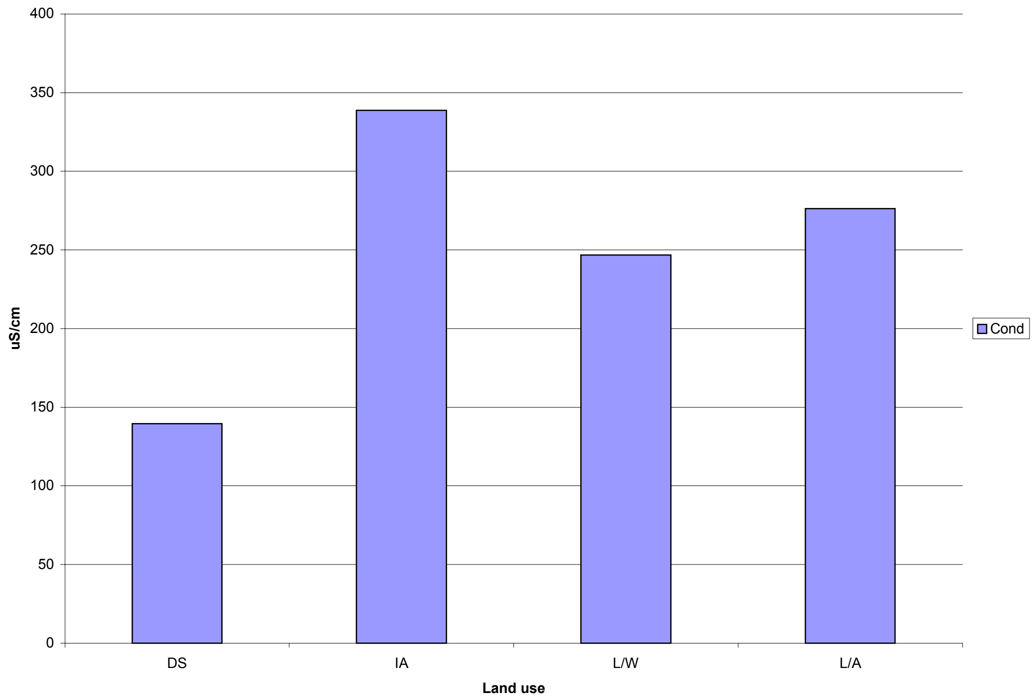

Figure4b. Electrical conductivity (µS/cm) in water samples from different land use types in Loitokitok area.

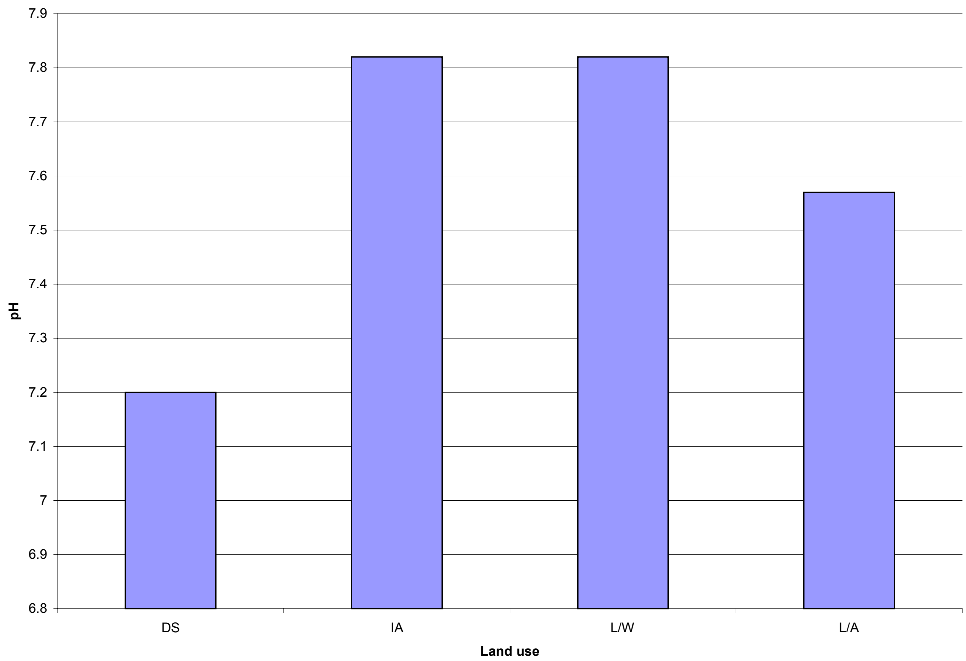

Figure 4c. pH values in water samples from different land use types in Loitokitok area.

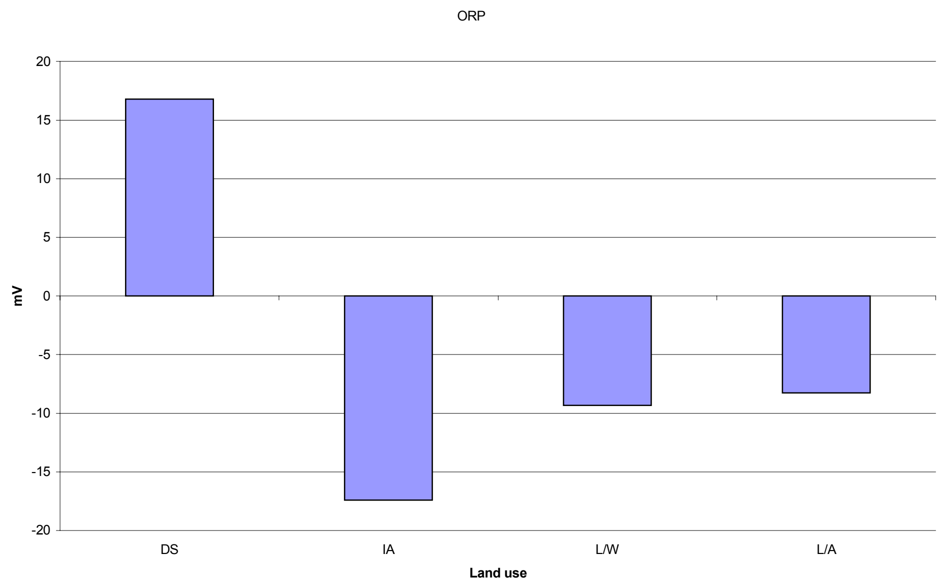

Figure4d. Oxidation-reduction values of water samples from different land use types

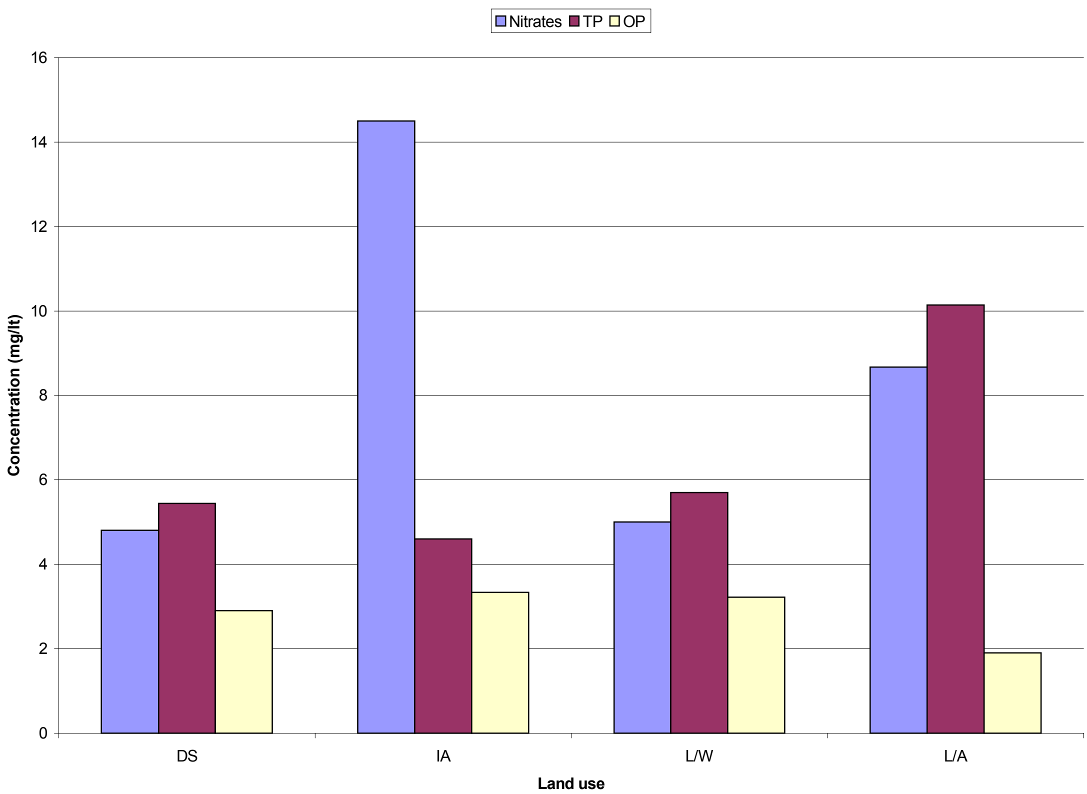

Figure4e.: Nutrient concentrations in water samples collected from discharge from different land use systems in Loitokitok area.

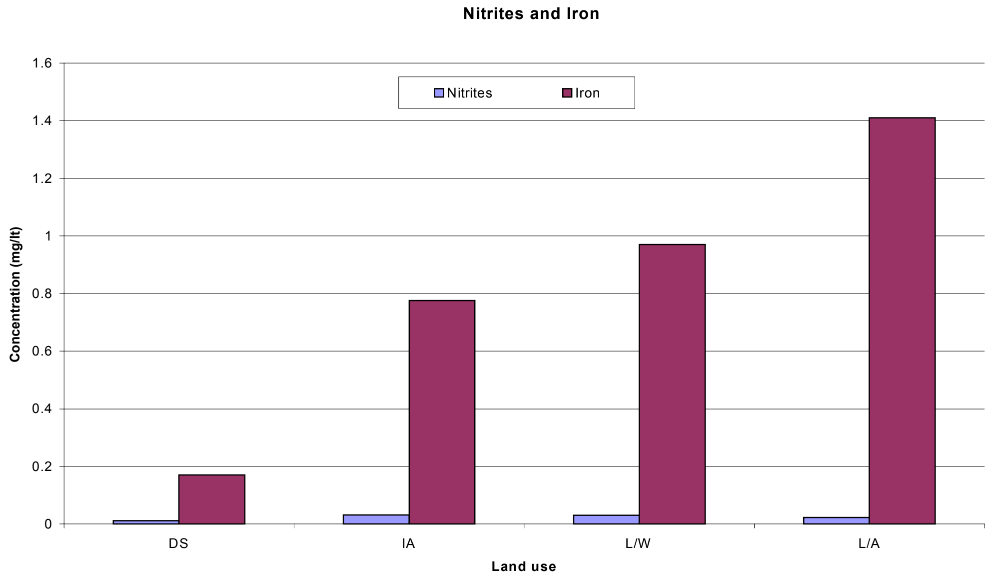

Figure 4f. Nitrites and iron concentrations in water samples obtained from sources under different land use types

Declines in concentrations were detected when discharge from the irrigated farm canals at 4.6 mg/lt. were compared to the spring sources. These declines could have arisen from the phosphorous binding to soil particles within the irrigated fields and uptake by phytoplankton, sedges and macrophytes that were common in the canals. The total phosphate concentration (5.7 mg/lt.) in areas where land use comprised of livestock and wildlife was comparable to that at the spring's sources. The highest concentrations of phosphates were found where upstream land use consisted of irrigated agriculture and livestock at 10.14 mg/lt. The sample collection points for these samples were at flow termination or points with long-term downstream deposition and accumulation, through evaporation and deposition of particulate matter. The high phosphorus loading at these points portrays the long-term impacts of anthropogenic nutrient enrichment of the water bodies in study area. The low concentrations in the discharge canals from the irrigated farms are due to dilution and higher discharge rates through irrigation water flushing. Orthophosphate concentrations more effectively indicated cultural phosphorous loading inputs with their highest concentrations (3.34 mg/lt.) being found in the discharge in irrigation canals. The removal by aquatic floating and rooted macrophytes could have lowered the concentration of this reactive form of phosphorus at flow termination points under agriculture livestock (1.9 mg/lt.), to less than that at the spring sources (2.9 mg/lt.). Nitrite concentration in the water samples from the study area was low, although the highest concentrations were found in the irrigation discharge water at 0.031 mg/lt. compared to 0.012 mg/lt. at the spring sources (Figure 3d). Nitrite is a reduction derivative of nitrates, and the high concentration in the irrigation discharge corresponds to that of the high nitrate concentration at these sampling points.

Iron concentration in the water samples increased with land use, attaining levels of 0.766 mg/lt., in the irrigation discharge samples, before peaking at 1.41 mg/lt. at areas where land use upstream was designated as livestock/agriculture (fig. 4f). Manganese was the only other heavy metal detected in the study area, being found in two samples from Leinkati, at the middle and end with concentrations of 0.011 mg/lt. and 0.032 mg/lt.

Table 2. Comparison of water quality parameters with WHO and KEBS standards levels.

Parameter	Springs	IR/A	Exits	WHO	KEBS
COD (mgO_2/lt)	124**	325**	244**	10	10
BOD (mgO_2/lt)	129**	169**	110.4**	6	6
TDS	129.6	253.5	230.4	1500	1000
SS	369.6**	283**	523**	Nil	Nil
NO_3-N	4.8*	14.5**	8.68*	1.0	10
NO_2-N	0.012	0.031	0.022		
PO_4-P	5.44**	4.6**	8.8**	0.1	0.1
pH	7.2	7.82	7.48	5.5-9	
EC (S/cm)					
Fe	0.17	0.766**	1.1**	0.3	0.3
Mn	-	0.011	0.03	0.1	0.05

** values beyond both WHO and KEBS limits,
* values beyond WHO safe limits.

5.0 Discussion

The water resources including rivers and wetlands in the Loitokitok area were simultaneously subjected to multiple and competing uses. They served as domestic water sources, agricultural land and irrigation water sources as well as watering points for livestock and wildlife. The rivers and associated wetland ecosystems constituted dry season livestock grazing areas and wildlife refuge. They were also used as sources of wetland products such as *Typha sp.* for dwellings and shelters construction and energy through firewood collection as well as charcoal burning. These varied uses of the rivers, swamps and wetlands have varying and far reaching impacts on the water quality in the Loitokitok area. The scarcity and distribution of the water resource, the arid climate, and utilization regimes as well as a lack of a sustainable utilization system exacerbate the impacts. Like other wetlands in the country, wetlands in the Loitokitok area are facing an array of threats to their continued existence from encroaching human activities (Kareri, 1991). They are at risk as several communities with different socio-economic backgrounds utilize them and the economic activities undertaken in the wetlands is a reflection of the mode of life of these different ethnic groups.

Amongst activities undertaken in the rivers and wetlands in the Loitokitok area, the expanding irrigated agriculture had the most profound negative impacts on the water quality and quantity. Agricultural activities have the potential to profoundly and irreversibly impact river systems and wetlands in the Loitokitok area. Agriculture has two fold impacts. First is the competition between agricultural land and other land uses including wetlands. Agriculture involves diversion and consumptive use of water, which would otherwise have flowed downstream. The diversion of water from to feed irrigation schemes depletes downstream water supplies, impacting wetlands that depend on it. The second impact revolves around the contamination of water supplies by the vast range of chemicals used in agriculture (Anonymous, 1993). Human activities within the wetlands have far reaching impacts on soils, wetland size, ecological functioning and integrity.

In the Loitokitok area, all these impacts of agriculture on water quality, wetlands and water resources availability were evident in this study. Water quality downstream deteriorated with use and most of the parameters indicated cumulative deterioration of water quality with use especially where agriculture was practiced. Irrigated agriculture impacts water quality through the use of agro-chemicals, excessive water abstraction and evaporative loss. The COD, BOD, suspend and dissolved solids, electrical conductivity and pH were found to be highest in water draining irrigated fields. Nutrients in samples obtained from such sources were several folds higher than those contained from the spring sources that served as baseline samples. The samples from Leinkati portrayed the downstream parameter amplification most vividly, with the highest proportional increment in nutrients, iron and other water physical characteristics. Similar trends were also observed in Namalok swamp as well as Rombo and to some extent in Nolturesh. High conductivity, increased turbidity, growth of filamentous alga and alga scum, vigorous establishment of aquatic plants including floating macrophytes signify significant levels of eutrophication (Rast, 1989). These were clearly manifest in Namalok and Leinkati swamps.

The irrigation system used in the study area can be described as informal as small-scale farmers or groups in accordance with their needs, using simple technology manage it (Roggeri, 1995). The micro-scale schemes allow farmers to take individual decisions on crop choice and marketing decisions leading to a varied production system and intra-scheme scheme variation. The irrigation system used in the study area is furrow irrigation, where water flows into the furrows in the irrigated parcel. This system is cheap, inexpensive to operate as it relies on gravity flow and does not lead to long periods of field inundation (plates 6 and 7). The furrows are liable to erosion, requiring regular maintenance. The field irrigation efficiency is poor and soil water logging and salinization risks are high. The soils in swamps are poorly drained, strongly calcareous, saline and sodic clays (Jaetzold & Schimdt, 1983). Water logging under arid conditions leads to salinization of soils as water evaporates as it nears the surface and leaves a salt residue. Soil degradation resulting from water logging and salinization leads to lower agricultural production, decline in agricultural yields and decrease in agricultural area since salt residues are damaging top crops and often preclude cultivation. This was evident in most of the areas under irrigation especially in Leinkati where numerous plots adjacent to the irrigation canals have been abandoned. The salts require more water to be applied to flush them from the soils, which was not successful as observed from the numerous patches salt encrusted salts in the irrigated fields. Leaching of salts from these fields elevates the electrical conductivity of irrigation water as observed from the various flow termination and irrigation water discharge samples where the electrical conductivity was beyond the 300 µS/cm range compared to source springs at below 150 µS/cm. The abandoned fields were severely overgrazed, aggravating the impacts on the soil characteristics.

The tenancy arrangement in the irrigated land parcels demands that agricultural yields are high to recover costs and implies the intensive use of fertilizers and pesticides. This type of tenancy arrangement leads to poor land husbandry, as the farmers are interested in reaping maximum benefits from the rented land parcels. Maintenance of the soil fertility is not their primary concern leading to heavy application of agro-chemicals to boost production from the fields (Campbell, ***et. al.,*** 2003). The communal ownership of the land through group ranches further militates against sustainable use. Artificial fertilizers alter the trophic status of a water body with resultant changes in biodiversity and lower the water quality for other uses (Rast, 1989). The large extent of eutrophication was very evident in Namalok and Leinkati swamps where the water bodies downstream of the irrigated fields were choked with aquatic weeds such as *Azolla,* vigorous growth of sedges, filamentous algae and algal scum, which are considered indicators of hyper eutrophication. The water was also very turbid and other water quality indicators were diagnostic of water quality deterioration. Artificial fertilizers are the most immediate cause of concern in the study area and eutrophication of the water bodies has progressed substantively, especially in Namalok and Leinkati. The vigorous growth of floating aquatic weeds, the establishment of filamentous algae mats is an indication of extreme hyper eutrophication. Under the arid climatic conditions, the explosive growth of toxic algae species can be expected with mortalities for livestock and wildlife (Bowling & Baker, 1996).

Plate 6. Maize grown under the furrow irrigation system in Namalog swamp.
Note the soil deposits in the furrows indicating salinization.

Plate 7. Tomatoes growing in a subsidiary spring at Namalog.

In irrigation schemes, the need to protect crops using pesticides increases, as permanent water bodies tend to favour the proliferation of pests such as insects, snails and birds. In the study area, there was liberal application of pesticides with farmers blending several pesticide brands in the hope of maximizing protection for the crops. Several instances of pesticide application were encountered during the study and captured on film and farmers were not observed to have any protective gear during the application. The applied chemicals are finally washed into the water bodies after water application in the fields, contaminating downstream water bodies and ecosystems. Containers for malathion and adrin pesticides were collected in the fields. There is no education on safe use of the pesticides and most of them are purchased from agro-vet stores. An investigation of pesticides use and their fate in the ecosystem need to be urgently undertaken.

Inter-basin water diversion and abstraction for irrigation has serious implications on downstream ecosystems as water inflows into them declines. Salinity increases downstream, parts of the wetland ecosystems are desiccated as water levels decline, leading to changes in community structure, loss of communities dependent on a particular level of inflows favouring the establishment of salinity tolerant plant species. Water diversion and abstraction are already impacting water availability and plant community structure in the study area. The diversion of virtually the entire Nolturesh River flow to Kitengela has destroyed downstream riverine ecosystems and displaced the local people from their traditional home area at Ol Laika. Water is scarce in this area and residents were observed digging hole in the dry riverbed to draw water for domestic purposes from pools that formed. Large numbers of *Ficus sycomorous* trees and Acacia had dried due to the water diversion. The residents said a large number of people formerly living in the area moved to the Leinkati area, compounding the ecological problems in this later site. Desiccation through water diversion may explain the reduction in extent of the Leinkati swamp and accessibility to virtually the entire swamp by livestock for grazing.

Over utilization of water resources within the water bodies studied has already led to a shortage leading to implementation of water rationing regimes. The amount of water available is not adequate to sustain the current level of use within Leinkati, Namalok and Kimana and there were several abandoned fields in Namalok as well as in Leinkati. The situation will be compounded by the new expansions observed at Namalok and Isinet. The latter has potentially devastating effects on Leinkati as well as wildlife and livestock use. The spike observed in Leinkati in all parameters compared to the Isinet bridge and Kimana bridge samples are attributable to the activities downstream of these two bridges. The shortage of water is aggravated by the wasteful furrow application, which has its own negative consequences on water availability, quality and soil characteristics.

Most of the irrigation in the Loitokitok area is practiced on land reclaimed from the swamps. Swamp soils once exposed undergoes changes that affect their structure and fertility. They undergo oxidation; lose their organic matter content, leaching of nutrients and accumulation of salts (Roggeri, 1993). To compensate for the loss in fertility, other areas in the swamps are cleared to increase crop production and compensate for the loss in productivity of exhausted and unproductive fields. This was evident at Isinet, Leinkati and Namalok where new areas were being opened for agriculture and other apparently abandoned.

Consumption of water for domestic purposes was observed at various points throughout the water bodies. Most of the chemical parameters such as COD, BODand TSS, and concentration of iron, nitrates and phosphates are beyond the World Health Organization and Kenya Bureau of Standards safe limits. This in combination with pesticides application renders the water unsafe for human consumption and raises concerns on human, livestock and wildlife health issues.

In arid and semi-arid regions, the survival of many wildlife species depends on availability of water in the dry season. The fencing of several swamps converted to agriculture excludes wildlife from these water resources, concentrating them in watering points where no fences have been erected. Nearly all the swamps other those within Amboseli National Park has some level of cultivation and the congregation of wildlife at these unfenced swamps is aggravating the human wildlife conflict. This is rampant in Leinkati, where extensive damage to maize and other crops by elephants was observed. Declines in wildlife number risks the only other viable land use in the area, through eco-tourism and other wildlife-based economic activities (Western, 1982). The wildlife-based diversification of the local economy is highly desirable in view of the fact that livestock grazing possibilities are already fully exploited and in some places overused (Jaetzold & Shmidt, 1983; Mworia, 2003).

6.0 Conclusions

The changes in water quality through precipitated by land use changes in the study area have potentially devastating ecological, cultural and socio-economic long-term implications if current trends are not halted and reversed. The continued application of fertilizers and pesticides is contaminating the water bodies with pollutants with possible accumulation and bio-magnification in the food chains. Eutrophication under the hot and arid climate can lead to algal bolls in the water bodies, altering their biodiversity content and formation of toxic blooms. Further expansion of the area under irrigation will increase water demand and extraction levels irreversibly affecting the community structure of the wetland ecosystems, further reducing the value of these areas as dry season livestock and wildlife grazing. The expansion of agriculture will aggravate the human-wildlife conflict witnessed at Leinkati that in lead to erection of expensive electric fences at Namalok and Kimana. The conflicts will potentially reduce the wildlife population, eradicating the only other viable land use alternative through ecotourism in the area. As currently practiced, irrigated agriculture in the area is unsustainable due to the attendant salinization of the soils, loss of fertility and destruction of the soil structure. The land use practices especially agriculture are depriving the wetlands of all the elements from which they derive their value in this arid region with a scarcity of other viable resources.

Freshwater is a vital but scarce resource in the dry lowlands of Loitoktok for socio-economic development, wildlife, and the maintenance of the valuable biodiversity and wetland ecosystems in the area. The quantity and quality of the water resource are both important for it to continue providing benefits to horticultural farmers and pastoralists, while maintaining biodiversity. Efficient irrigation methods and agricultural practices that reduce the unnecessary wastage of water, prevent soil degradation and pollution of water resources need to be adopted.

The drip irrigation method supplies water directly to the plant roots where it is needed without inundating adjacent areas. This irrigation method minimizes the amount of water needed in a growing season and reduces water loss through evaporation and prevents soil degradation. Simple and inexpensive plastic piping can be used to deliver water to the crops, while keeping the costs minimal. The reduction in the surface area inundated will ensure more efficient utilization of nutrients, through retention in the rooting area, and minimize the eutrophication of rivers and wetlands. There is a need to substitute expensive artificial fertilizers with manure to reduce the costs of crop production. The area has a large livestock population ensuring an adequate and continuously available supply of organic manure. The manure will increase soil water retention properties, improve soil texture and improve the profit margins for the farmers and open a new economic avenue to the livestock keepers. Large proportions of the cropped areas are exposed to direct insolation, raising soil temperatures and enhancing water evaporation. The use of mulch in the fields will reduce evaporative water loss, and on decomposition add humus to the soil and further improving its organic carbon content and water retention capacity.

Eutrophication of the water channels, rivers and wetlands can be controlled to a large extent by the use of grass strips along the edges of irrigated fields. The grass and reeds strip nutrient from the waste irrigation water and they can be sued as livestock fodder and mulch on the farms, preventing eutrophication and the attendant reduction in water quality and alteration of wetland community species composition. The farmers in the area mix several pesticide brands in a cocktail aimed at maximizing efficacy without expert advice. Education on safe handling of pesticides and application procedures is urgently needed to reduce environmental contamination and safeguard the farmers' health. Synchronized application of pesticides by the farmers is desirable to prevent re-infestation from adjacent fields further reducing the amount and frequency of pesticide application. The fields in the area appear to be continuously under cultivation and a fallow system needs to be instituted to facilitate soil fertility recovery. The piecemeal irrigation schemes within the Loitoktok area need to be harmonized and managed as unit. The establishment of piecemeal irrigation farms is more threatening to the ecosystem integrity, as the impacts are subtle resulting in incremental effects. Individually they schemes represent insignificant activities but when combined with others they can produce major changes in the wetlands which are already evident.

7.0 Recommendations

From this study it is recommended that:

- A long-term study be initiated on water balance in the area.
- An urgent analysis of the extent of pesticide contamination in the area.
- More systematic and detailed studies in individual water bodies especially where there is an agriculture-livestock-wildlife continuum.

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