Morphological Structure and the Anthropogenic Dynamics in the Lake Naivasha Drainage Basin and its Implications to Water Flows

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Abstract

Throughout its length, the Kenyan Rift Valley is characterized by Quaternary volcanoes. At Lake Naivasha drainage basin, the Eburru (2830m) and Olkaria (2434m) volcanic complexes and Kipipiri (3349m), Il Kinangop (3906m) and Longonot (2777m) volcanoes mark the terrain. Remote sensing data and field survey were used to make morphostructural maps and to determine the structural control and the land use impacts on the drainage systems in the basin. Lake Naivasha is located at the southern part of the highest part of Kenya's Rift Valley floor in a trough marked to the south and north by Quaternary normal faults and extensional fractures striking in a N18°W direction. The structure of the rift floor influences the axial geometry and the surface process. Simiyu and Keller (2001) interpret the rift floor structure as due to thickening related to the pre-rift crustal type and modification by magmatic processes. The rift marginal escarpments of Sattima and Mau form the main watershed areas. From the marginal escarpments the Rift Valley is formed by a series of down-stepped fault scraps. These influence the nature of the soils and the rainfall regime. The drainage is also influenced by the fault trends. At the Malewa fault line for example the drainage is south-easterly influenced by the trend of the Malewa fault line (Thompson and Dodson, 1963). The morphotectonic control on the drainage has implications on ground water recharge in the Naivasha basin. This may also influence the spring water supply and geothermal reservoirs. The nature of the terrain, human development processes and their impact on the lake was visualized using Landsat TM satellite data (path 169/Raw 060) from three dates (28/1/1986 L5, 1/3/1989 L4

and March 2000 L5) and a mosaic of the data based on satellite data of various dates from 1989. The image data was compared with elevation models of the terrain and the normalized difference vegetation index (NDVI) data.

The Kenyan Rift Structure within the Lake Naivasha Basin

The Kenyan Rift system is part of the classic East Africa Rift System where volcanism preceded or in some cases has been contemporary with major faulting (Ebinger, 1989). The rift basin is asymmetric and bounded by step border faults showing 2-3 km displacements. Along the rift there is North-South variation in volcanism, structural style and crustal and upper mantle seismic velocities. The variety and differences in the volume of magma products varies from flood basalts - Miocene, phonolites - Pleistocene and trachytes - Quaternary. (Baker, 1972) and Williams, MacDonald and Chapman (1984) indicate that these magma evolutions are a key issue in understanding the rifting processes. Their observations suggest that the locus of extension and volcanic eruptions relocated to the axis of the rift valley in the Pleistocene with cinder cones becoming active 1.6 Millions of years ago (1.6Ma). Within the Kinangop and Gilgil Plateau the fault systems show an *en enchelon* pattern.

KRISP (1987) indicates that the effective elastic plate thickness varies along the Kenya Rift, thinning to 17±2km at the highest part of the rift valley floor in Kenya (the Kenya Dome). The Kenya Dome coincides with the regional Bourger gravity minimum (-200 to –240mgal.) that is related to the crustal attenuation and crustal thinning (Khan, Swain and Bishop; 1987). The gravity maxima are to be found to the east and west of the rift shoulders at the plateaus where the crustal thickness average 40km. Recent studies in the Olkaria Geothermal Field which is within the axis of the rift valley floor (Simiyu and Keller, 2001) show that comendites, rhyolites and obsidian lavas were erupted mainly after the emplacement of Lake Naivasha sediments and concurrent with the initiation of the Olkaria Volcanic eruptions. Geothermal drilling show temperatures of 350°C at a depth of 2km with a rapid decrease from the prospect areas of Olkaria and Eburru towards the rift shoulders. This is indicative of the effect of crustal thinning.

The volcanic centres of Olkaria are associated with a belt of volcanism on the rift floor which includes Longonot, Eburru, Lake Elmenteita volcanoes and Menengai (Figure 1).

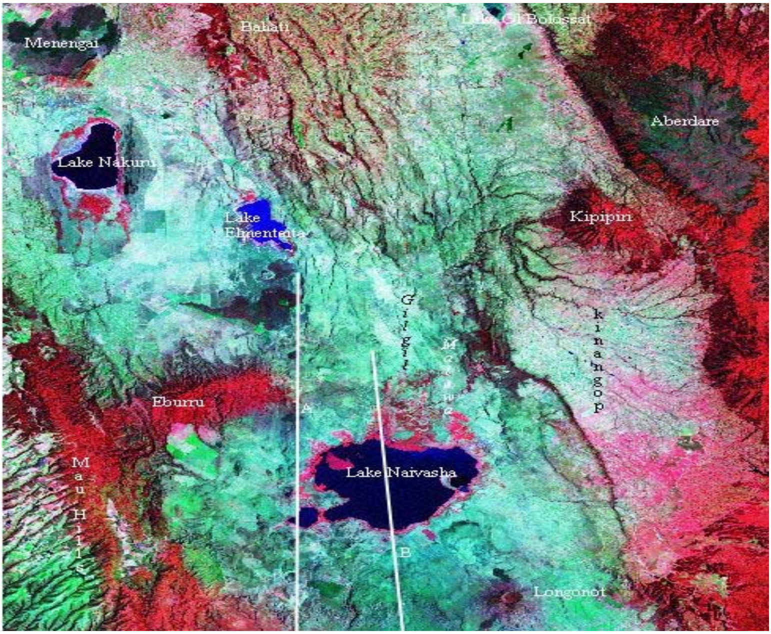

Figure 1: Landsat satellite image mosaic of Lake Naivasha drainage basin. The positions of Gilgil-Ol Obonge-Olenguruoni-Lolonita-Loirogwe major fault structure and Muruandati-Baxia-Ololbutot fault line are indicated by lines “A” and “B” respectively. Note the agricultural activities on Kinangop plateau and depletion of forest in Mau hills

The composition of the volcanic centres is characterized by volcanic ashes and acid lava piles of predominantly alkalirhyolite (comendite) and ash/tuff. The volcanisms are of Pleistocene to Recent and show some peralkaline and intermediate rock occurrences (Clarke, 1990). The lavas and ashes are well exposed in the Ol Njorowa Gorge (Figure 2a), which form cliffs between 60 to 120m high. The gorge was created by discharge of Lake Naivasha, subsequent to its damming by Longonot and Olkaria Volcanics (Nyamweru, 1977). The drained water flowed towards the Kedong valley through north and east of mount Suswa creating the gorge in which Ewaso Kedong River presently flows. Sections created by the water channels (Figure 2b) and located in the area east of Longonot, and south of Longonot at the Akira plains are evidence of this. In these sections pyroclastic are underlain by lacustrine sediments which in turn are overlain by the latest eruption from the Longonot.

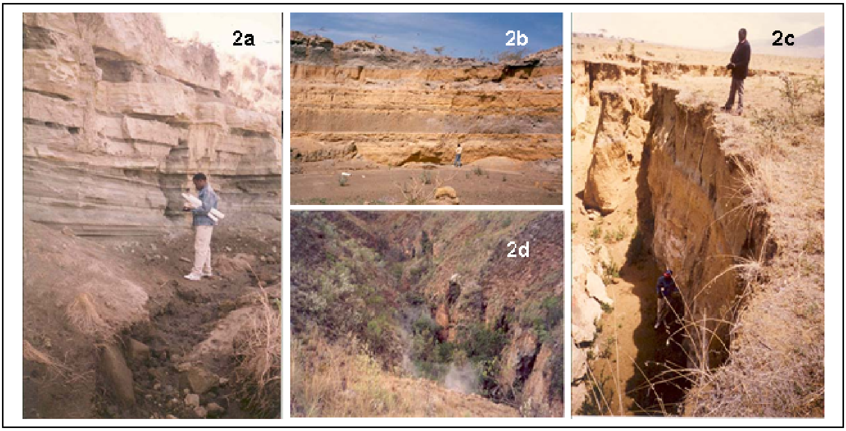

Figure 2: Morphotectonic structures in the Lake Naivasha drainage basin area. (2a) - Ol Njorowa Gorge (note the thin lake deposit at the bottom of the layers and the thicker layers above that are a contribution from the Longonot eruption; (2b) - a typical section at the Ewaso Kedong Valley; (2c) - rejuvenated fault gush at the Akira plains; (2d) - a fissure structure in the Olkaria area. Also note the steam from the geothermal sources (*field survey).*

In most parts the water channels are buried under the pyroclastics, and other than at the few river sections, are not traceable after the exit from the gorge. Scott (1980) has shown that most of the pyroclastics from Longonot predate the draining of Lake Naivasha through the Ol-Njorowa gorge dated 12000-5600 B.p. Richardson and Richardson (1972) and Kamau (1974) also give the same date and suggest that after the creation of the gorge, it was refilled by tephra from eruptions of Longonot and perhaps Suswa after 5600 B.p.

The Tectonic Setting and Land Use in the Lake Naivasha Drainage Basin

Lake Naivasha (1889: 3m above sea level a.s.l; 1983 level (Ase, Sernbo and Per, 1986) - and 1886m a.s.l. 2002 level (www.wetlands.org/RDB/Ramsar_Dir/Kenya/ke002D02.htm), accessed 13/3/2005)) is located in a trough between Eburru and Olkaria/Longonot volcanic massifs centred at 00°45'S 036°21'E. The lake is at the highest part of the Rift Valley floor, from where the floor slopes to the south and north, attaining low altitudes at lakes Magadi (600m a.s.l) to the south, and Bogoria (985m a.s.l) to the north. The lake is a Ramser site of wetlands of international importance (Kenya 1KE002, 1995) and is a fluctuating tropical lake ecosystem whose sustainable management remains a pressing priority on account of both intensive and subsistence farming. The lake is the only freshwater lake (mean conductivity 294 ± 24µscm^{-1}) in an otherwise series of saline lakes located at the rift floor. The lake is characteristic of its bio-geographical region at the floor of the East Africa Rift Valley in the volcano-tectonic terrain. It is the largest freshwater reservoir in the Kenyan Rift Valley, and a refuge for many species of wildlife (Hell's Gate National Park is located here).

The Naivasha basin is separated from Nakuru and Elmenteita basin by Eburru Volcanics and a very low divide (2000m a.s.l) formed by the Gilgil escarpment. The lake is flanked by the high escarpments of Mau and Kinangop (see Figure 1). These escarpments, together with Eburru, receive ample rainfall and form the main catchment areas considered by Clarke (1990) as groundwater highs. The principal surface influx to the lake is from the north, down Bahati and Kinangop escarpments, and covers a watershed area of 3320km². The runoff from Bahati escarpment is channelled through several tributaries of the Gilgil; whereas that from Kinangop escarpment is channelled through tributaries of the Malewa. Malewa is the only perennial river reaching the lake by means of surface runoff The Gilgil River also reaches the lake by means of surface discharge, but in periods of prolonged drought it becomes ephemeral at its approach to the lake. The rest of the drainage from Bahati, Kinangop and Mau escarpments, and Eburru, Longonot, and Olkaria volcanic centres do not reach the lake by means of surface runoff. The Marmonet, for example, with its main drainage sourced at the Mau escarpment, is a tapering stream that loses itself in the featureless Ndabibi plain, never reaching the lake by means of surface discharge.

Structurally, and with the exception of Lake Naivasha, all he Rift Valley lakes are elongate in the direction of the Rift Valley fault structures. Lake Naivasha forms a near circular trough (see Figure 1) with two half buried craters forming the Small Lake (Lake Oloidien) and the Crescent Island, and another satellite basin forming the Crater Lake. Crescent Island crater is a small-submerged crater basin within the main lake and occurring along the eastern shore of Lake Naivasha. Lake Naivasha is hydrologically open, with river and groundwater inflow from the north and from western rift border escarpments. The lake is maintained by river input primarily from the Malewa River, which drains the Kinangop Plateau and part of the Aberdare ranges. The lake with no modern surface outlet maintains its low salinity, through underground seepage probably into Olkaria geothermal field through buried structures and pyroclastics that dam it to the south. Baker (1986) observes that the lake is a water table lake, which maintains its freshness by sub-surface discharge into permeable pyroclastics of Longonot, and Olkaria Volcanic. According to Gaudet and Melack (1981), the lake discharges through groundwater seepage to the south and southeast. It is possibly maintaining its freshness this way and through geochemical and biogeochemical sedimentation.

Lake Oloidien (Small Lake - 5.1km^2) is located at altitude1886m a.s.l. and separated from the Main Lake by a permeable volcanic sill. Within both the Main and Small lakes, rainfall and evaporation average 646mm and 1903mm per year respectively with considerable inter-annual variation KMD (2001). There are therefore water loses due to evaporation. Without river inflow directly into Lake Oloidien nor significant surface runoff from the surrounding areas, the level of Lake Oloidien must therefore be maintained by direct rainfall on the lake’s surface and a considerable contribution from subsurface inflow through the permeable sill between the Main and Small lakes. The Small Lake is formed in a *graben* between fault blocks. The fault lines are pointers to possible tectonic involvement through the fault structures, and to connection of discharge of the Small Lake and Lake Naivasha into Olkaria reservoir. Presently, the Small Lake is completely cut off from the Main Lake.

The precipitation pattern is diverse showing a range from 630mm at the lakeshore area to 1380mm at the Aberdare (Table 1) and is reflected in the vegetation cover. The variation in rainfall results in differences in erosion and sedimentation patterns with wind and gully erosion dominating. The volcano morphology of the area has an influence on the catchment's rivers and the vegetal cover which include dry land savannah at river channels, open savannah grassland at the rift floor plains, grass and scrub savannah and wooded savannah at the escarpment faces.

Table 1 : Monthly and annual rainfall averages (in mm) measured in a standard rain gauge (12.7 cm diameter and set 30 mm above the ground) (*courtesy of the Kenya Meteorological Department)*

Station Name	Kwetu Farm	Gilgil r.s.	Kinango p f.s.	Naivasha KCC	Naivasha DO	Kerita f.s.
No.	9036029	9036034	9036025	9036073	9036002	9036061
Alt m	2348	2008	2631	1936	1900	2439
Jan	35.3	29.7	49.0	33.1	32.7	72.0
Feb	34.8	31.1	53.3	38.3	38.0	73.8
Mar	57.5	49.3	85.1	56.9	58.7	126.3
Apr	154.0	96.7	172.6	105.8	124.0	325.2
May	118.9	67.3	154.9	82.7	81.8	234.3
Jun	82.5	46.8	95.9	50.8	40.0	65.2
Jul	105.0	57.4	73.8	39.5	35.6	49.1
Aug	18.7	51.6	95.7	49.3	45.3	38.2
Sept	80.1	44.2	100.7	29.7	40.1	40.2
Oct	88.1	56.8	103.7	44.2	55.2	108.6
Nov	86.4	66.7	104.0	52.5	61.7	164.6
Dec	49.7	43.3	67.8	40.1	45.4	93.8
Total	1020.9	635.5	1154.6	631.2	670.9	1382.1

Table 2: The latitudes and longitudes of the various stations

Station	Latitude	Longitude
Kwetu Farm	0°21'S	36°18'E
Gilgil RS	0°30'S	36°20'E
Kinangop FS	0°35'S	36°38'E
Naivasha KCC	0°40'S	36°23'E
Naivasha D.O.	0°43'S	36°26'E
Kerita FS	0°59'S	36°38'E

Lake Naivasha supports a high diversity of fauna and flora offering a rare opportunity for scientists to simultaneously study geological, climatological, hydrological, paleolimnological, evolutionary, and ecological phenomena. The lake has a fringing swamp and submerged vegetation, and a riverine floodplain at the mouth of Malewa and Gilgil Rivers that show a deltaic structure. The shoreline vegetation consists of emergent plants, and floating and submerged species which are home to hundreds of bird species. The entire wetland system has over the years been surrounded by woodland of *Acacia xanthophloea* and papyrus that protected it from losses due to evaporation and filter the water entering the lake. This vegetation cover now consists of isolated groves of *Acacia xanthophloea*, and patches of papyrus at the lakeshore as a consequence of unsustainable human settlement.

The human impact upon the hydrology of the lake is reflected in the physio-chemical properties of its water, sedimentation and decreased water levels. The diverse consequences of the unsustainable practices are significant for the basin’s ecosystem. The lake’s watershed has been experiencing large temporal and spatial variation in population size as a result of improved transportation system and opening up of the area to agricultural development. This has led to influx of labour forces into the area. There was for example temporary increment of labour forces at the time of construction of the Geothermal Stations. Large abstraction of water from the lake and the Malewa River for domestic use in Naivasha town, for preparation of power generation wells and for intensive horticultural irrigation is further stressing the lake ecosystem. In the preparation of the geothermal generation wells for example, water is required for drilling, for compaction during construction, for re-injection well testing and as cooling water in the power station. Kubo (2003) indicates that a typical production well at Olkaria drilled to a depth of 2200m can utilize up to 100,000m³ of water, all of which is abstracted from the lake but lost into the geothermal formations.

Increased land use in the catchment areas, the significant direct water consumption from the lake for irrigation, and damming of Turasha River to supply water to Nakuru Town, are significantly contributing to the overall water balance in the lake with a net deficit due to the various uses and due to the impacts of drought. The activities also release mineral rich leachates from fertilizer and agro-chemical applications. Among other human induced threats, domestic or industrial pollution from Naivasha town, illegal hunting (fishing), and excessive cutting of wetland vegetation such as the *Acacia xanthophloea*. In 2001 the government itself excised the Eastern Mau Forest (35,301.01ha), and forests in Nakuru District (270.5ha). Deforestation in the escarpments touches on the catchment and is reducing river flows. Cultivation of steep slopes down to the riverbanks, overgrazing, and water extraction are lowering the Malewa's levels and increasing its silt and nutrient loads. The short-term economic gains of clearing woodlands for timber or agriculture must be seen against the even bigger, long term, losses as a result of uncontrolled and unsustainable deforestation.

Present demands on Lake Naivasha watershed resources therefore dictate that concerns for its sustainable management take an environmental approach. This demand critical analysis and proper management of agricultural, urban and other developments within the watershed. Naivasha town, for example, epitomizes the pressure placed on Lake Naivasha by the burgeoning human population - people living in crowded, uncoordinated developments with often unsanitary conditions and a malfunctioning urban sewage system - extractions from the lake’s main feeder river, the Malewa, and the continuing destruction of the forests that provide vital catchment for groundwater, to see the lake through drier periods. At the plains to the east of Longonot on the other hand, is an epitome of the impacts of land degradation and unsustainable land management practices that is reflected in the wind erosion deposits (Figure 3a) Adequate water supply in Lake Naivasha drainage basin is one of the limiting factors necessary for advanced economic development for the local communities.

Figure 3: Land degradation in the Lake Naivasha drainage basin.
(3a) wind eroded soil deposit at the plain to the east of Longonot;
(3b) deforestation and land degradation in the Mau hills;
(3c) proliferation of water hyacinth in lake Naivasha
(Source: field survey)

The depletion of the forests on the Kinangop, Mau (Figure 3b) and Eburru escarpments is the cause of severe erosion damage with no lasting water during periods of rainfall. Natural potential threats to the lake are siltation and infestation by floating aquatic weeds. Hubble and Harper (2002) indicate that the lake shows a seasonal shift between diatom and cyanobacterial dominance, which are indicators of nutrient conditions in the lake. On the lake surface and at the shores, this has lead to proliferation of hydrophytic species succession - *Salvinia molesta* (water fern), *Eichhornia crassipes* (water hyacinth) papyrus, *acacia dreponalopium* (yellow fiver acacia) (Adams, , 2002). The lake currently is infested by a thriving water hyacinth as a result of the nutrient rich waters (3c). *Salvinia molesta* is also seen floating on the lake, occurring in large concentrations at the lakeshores along with the water hyacinth, both of which increase evapotranspiration from the lake.

In addition to land use/land cover changes affecting the Lake's watershed, the cause of the water level changes in the lake is also of geological interest. Percolation of runoff from Eburru volcanic complex, and the Mau escarpment are the recharge waters for the underlying thermal sources at Eburru. Meteoric waters from Mau escarpment may however, not be crossing into Lake Naivasha or

Olkaria reservoir beyond the west downthrown Gilgil-Ol Obonge-Olenguruoni-Lolonita-Loirogwe major fault structure (see Figure 1), along which are aligned recent volcanic centres. The other fault of significance is the Muruandati-Baxia-Ololbutot fault (see Figure 2d), which cuts cross the lake. These structures are visible on satellite imagery. There are probably other buried fault structures underlying the lake basin that are connected to the Olkaria geothermal reservoir and are inferred to control the discharge from the lake. The aligned sinkholes in the Ndabibi plain, west of this major fault structure, also point to buried faults that are structural barriers to groundwater that could be crossing in to Lake Naivasha.

Geologically the lake ecosystem is far less understood and appears to be undergoing ecological changes in a much shorter time frame. The lake has had a history of fluctuations, which have been recorded since 1860 (Richardson, 1966). In general, as indicated by Richardson and Richardson (1972), there has been an overall fall in the water level since 1917. The lake's Pleistocene high level is recorded at about 120m above its present lake level (Thompson and Dodson, 1963). The annual rainfall and evaporation figures from meteorological station around the lake, although fluctuating over the years and showing significantly low volumes in the ten-year drought cycle, reveal no overall decrease or increase in precipitation. Becht and Harper (2002) have calculated the water balance of Lake Naivasha based upon the long-term meteorological data of rainfall, evaporation and river flow. Their lake level prediction model estimates the current extraction at 60 x $10^6 m^3$ per annum.

In recent years the lake has shown significant drops during prolonged droughts, especially in the year immediately following the ten-year drought cycle of 1965, 1976, 1984 and 1993, when most rainfall stations in the study area recorded less than 700mm of total annual rainfall. In 1994, for example, following the drought of 1993, there was a significant drop in the lake levels of all central rift valley lakes in general (Onywere, 1997). In this period, large sections of the Lake Naivasha lake-bed were exposed, with the resulting changes causing significant ecological imbalance in the lake and affecting the fishing industry. The entire crater rim of the Crescent Island, whose eastern section is always submerged, was exposed.

The Tectonic Environment of the Crater Lake Area

The Crater Lake is a small water-filled crater located just 15m above the level of Lake Naivasha. Being confined in a crater, the lake has no surface recharge, and is directly recharged by rainfall. Its waters are green being infested by blue-green algae. The soda tolerant *Cyperus laevigatus* is found around the shores of the lake. The lake's volume slightly fluctuates with the seasons. The water is relatively deep and confined by underlying non-porous agglomeratics rock. The main mass of the crater is agglomeratic, composed of welded pyroclastic with large clasts of comendite, basalt, and obsidian, probably broken from a plug that initially blocked the vent. The crater is faulted on its eastern side with the down-throw to the east. On the satellite imagery, a fault line forms a linear feature, traced south to the escarpment at Kongoni and into Olenguruoni hills, just north of Olkaria hill (the Muruandati-Baxia-Ololbutot fault). To the north, the fault line falls in a line of a fissure (see Figure 2d) that passes through the youngest volcanic vents on the eastern part of Eburru. To the east of the Crater Lake and close to the shores of lake Naivasha, are other fault scarps forming a couple of low raised blocks.

The rest of the cinder cones within the Crater Lake area, are of *rhyolite* and layered *pyroclastics* of dark ashes and pumice. Since the Eburru lava flows lean against these *pyroclastics* and the cinder cones, the Eburru flows are of later extrusion. To the north of Eburru and along the low Gilgil escarpment, are the cinder cones of Elmenteita 'Badlands'.

Spatial techniques were used to reconcile the competing interests in land use. The national base topographic mapping at 1:50,000 scale was used to compile the digital elevation model (DEM) of the area and to drape the extracted information on the image for interpretation (Figure 4).

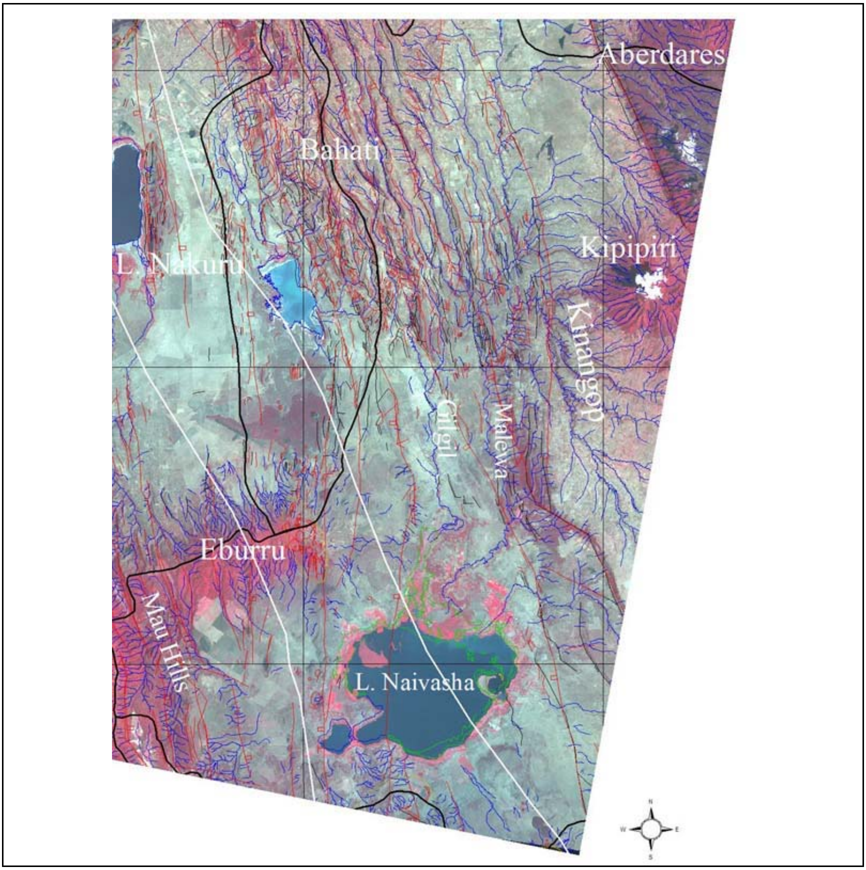

Figure 4a: Different image product and DEM used to visualize the terrain in the Lake Naivasha drainage basin. (4a) FCC with the drainage and fault systems extracted from collateral data draped on it.

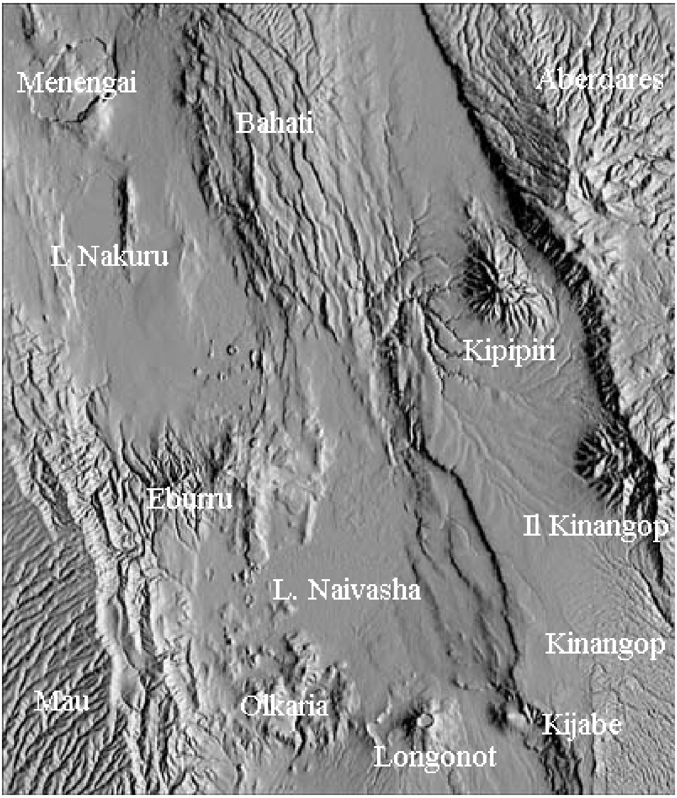

Figure 4b: SRTM data giving a DEM model sampled at 90m. (*USGS Geodata Warehouse Africa).*

On the DEMs a picturesque representation of the morphology of the area is seen. However, the base maps have received little or no updating since they were compiled in the 1970s. As such, the maps fail to reflect the explosive human settlement, the widespread expansion of subsistence agriculture and the growth of urban centres. The use of time series satellite imagery of 28/1/1986 L5, 1/3/1989 L4 and March 2000 L5 and a mosaic of the data based on satellite data of various dates in 1989 and a comparison with image classification was an excellent resource in land cover mapping and hence the determination of the land use changes that have occurred in the area.

The data was structured into geospatial data and integrated into a common GIS platform that was queried to support subsequent thematic and derivative maps (Figure 4) for a land cover classification and comprehensive land use/land cover study. Large-scale printouts of sections of the lake and its environs were generated for the land use/land cover mapping in the field that was done to assess the extent of land cover changes.

Two major approaches to analysis of digital image data, both of which benefit from digital image processing techniques, were adopted for this study. The first approach of photo interpretation or image interpretation extracted information from photographic products using spatial, spectral, and temporal elements based on Landsat subset images of the selected data sets (March 1985, 28/1/1986, 1/3/1989 and March 2000 - Path/Raw 169/060) centred at lake Naivasha. First, digital image processing was carried out to improve image quality and to georectify the images, as well as enhance useful information and deemphasize unimportant information using enhancement matrices. False-colour composite (FCC) and true colour composite images of these products (see Figure 1) were then displayed to facilitate for visual interpretation.

The second type of analysis involved quantitative analysis methods that utilized the digital numbers (DN values range 0-255) of an image. The spectral content in the Principal Component Analysis (PCA) processed digital images was used to perform classifications and derive biogeophysical parameters of the land cover classes of the study area. Digital image processing using Erdas Imagine® image processing programs utilized spectral information to group pixels with similar spectral qualities. The two methods compliment one another. The method adopted for data analysis and interpretation is dependent on the level of observation (Table 3).

The statistical treatment of Lake Naivasha using bands - average 1+2 (green), 3 (red) and 4 (infrared) images showed good contrasts in the image values. The peaks of the multimodal histograms were found to be related to specific features in the image and therefore specific land cover classes. In addition to the histogram, several standard statistical measures were calculated for the images. These include the mode, median, mean, variance and the standard deviation thus facilitating for multivariate analysis from the three bands. The image interpretation and land cover categories were verified during an extensive field research session in two periods (May 2003 - wet season and Nov. to 17^{th} – Dec 2003 relatively dry season).

Table 3: Advantages and disadvantages of image data analysis using photo interpretation and quantitative analysis techniques

Photo interpretation	Quantitative Analysis
Done on a large scale relative to pixel size	Done at the level of individual pixels
Inaccurate area estimates are made	Accurate area estimates possible
Offer only limited multispectral analysis	True multispectral (multidimensional) analysis
Can assimilate only a limited number of distinct brightness levels	Can make use quantitatively of all available brightness levels in an image.
Shape determination is easy	Shape determination involves complex software decisions
Spatial information is easy to use in a qualitative sense	Limited techniques available for making use spatial data

Discussions and Conclusions

Agricultural development in the Lake Naivasha drainage basin, removal of lakeshore vegetation for horticultural development and construction of drill pads (each occupies on average 4,100m^2) at the Olkaria Geothermal field have contributed to the increase in runoff leading to increases in sediment load to the lake. This is reflected in the turbidity of the lake waters (*schist disc transparency measure of 6m*). The surface runoff and nutrient transfer from the cultivated cropland and the open fields is significant, reflecting the degradation of the land cover. Flooding was noted in the field during the May period of 2003 at the Karati River railway crossing.

There is need, therefore, to improve vegetation cover in order to restore the riparian environment, to protect the streams and rivers and to simultaneously reduce pollutants, stream-bank erosion and sediment loads in the rivers and the lake. Improved land use management enhances the quality of adjacent water resources and reduces excessive stream flow. The degradation of the semi-arid environment can be rehabilitated by planting *tarchonantus cambhoratus* (mleleshwa), *acacia drepaolobium* (yellow fever acacia) and indigenous grasses, like star grass that are common in the area. This can improve the quality of the land cover, grass availability and the biodiversity.

The decreasing water level is attributed to increased land use cultivation in the catchment area causing decreased discharge into the lake. In the absence of sufficient recharge there is a possible deficit in the water balance of the lake. Direct evaporation from the lake is high, with significant increases in recent years due to changing climatic patterns. Increased exposure of the land due to deforestation and overgrazing has lead to increased erosion and undermining of buried fault lines in the plains around the lake. Many of these streams have cut deep; steep-walled gorges several tens of metres deep, aided by steep slopes and the loose pyroclastics and ashes. Further, accelerated erosion is due to the sudden lowering of the rift floor as a result of the rejuvenation of fault gushes (see Figure 2b), which accelerates run-off. The faults are located mainly at Ndabibi plains to the west of the lake and at Akira plains at Kedong area.

In recent years and through the intervention of the Lake Naivasha Riparian Association (LNRA) the wetland fringe is off limits to all construction or cultivation. The LNRA environmental management plan (LNRA, 2002) commits its members to monitor all activities on the riparian land, to protect the papyrus belt and to provide a 100m ‘buffer zone’ above it but below the 1906m contour - some 7m higher than today’s level of the lake. The challenge is the implementation of this intervention strategy.

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