

# Freshwater Ecology of Kenyan Highlands and Lowlands

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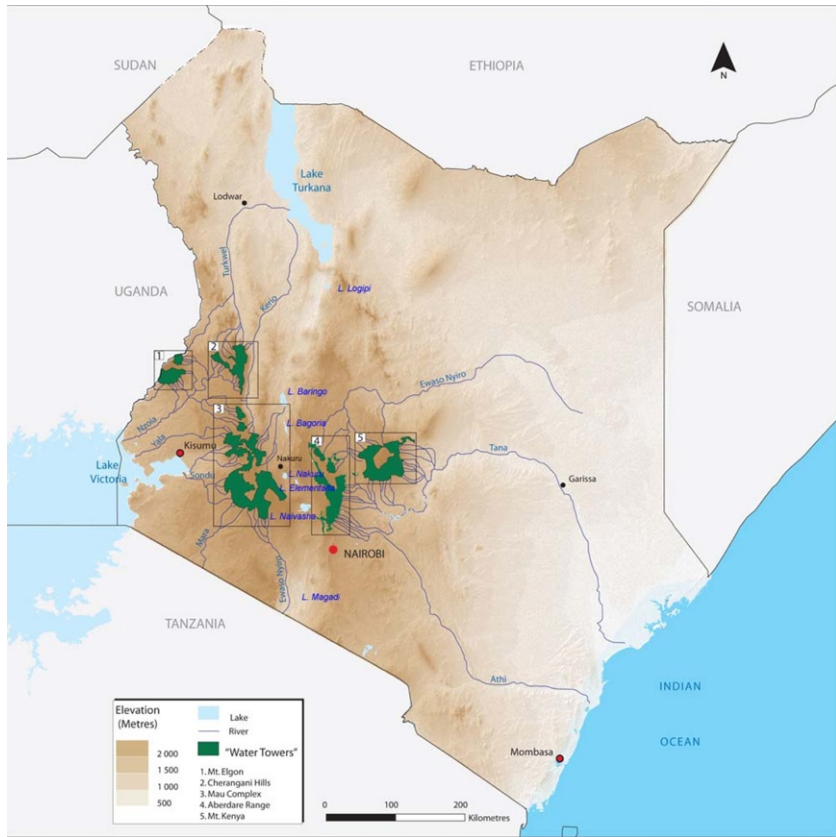
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## 1 INTRODUCTION

Kenya lies astride the equator, but the country experiences wide variations in climate. Freshwater ecosystems occur mainly in the narrow coastal plain, the central highlands and western parts of Kenya. These cover about 25%, while the rest of the country (75%) experiences arid or semiarid climate. The annual rainfall in the country averages 621 mm per year, but it varies seasonally and spatially. The amount of annual rainfall available to maintain freshwater ecosystems varies from a maximum of 750 mm in the dry areas to a maximum of 1700 mm in the coastal plain, the central highlands and Lake Victoria basin. Surface runoff and natural river flows as well as the rate of seepage of rainwater are influenced by variations in intensity of rainfall, density of vegetation, type of soil and the presence or absence of wetlands.

The headwaters of Kenya's five primary catchment areas all arise in five indigenous montane forest areas commonly referred to as Kenya's 'water towers' (Figure 1). The water towers, namely, Aberdare Range, Mount Kenya, Mount Elgon, Mau Complex and Cherangani Hills, have an average annual rainfall of 2300 mm and a potential rainfall–runoff ratio of 65%, which is more than 75% of the renewable surface water resources of Kenya (19,691 million m<sup>3</sup> per year). They occur in a wide range of rainfall regimes and at varying levels of altitudes, mainly between 1500 and 2500 m above sea level. These towers provide water for domestic uses, industrial and irrigation developments, hydropower generation and other needs.

The five drainage systems in Kenya are determined mainly by the Great Rift Valley, which runs in an almost north–south direction, and the Lake Victoria system that drains the western flanks and eastwards-flowing rivers to Indian Ocean. These drainage basins are Lake Victoria, covering 8.0% of the country; Rift Valley



**FIGURE 1** Map of Kenya highlighting the five water towers or headwaters of the main river catchments.

and inland lakes, covering 22.5% of the country; Athi River and coast, covering 11.5% of the country; Tana River, covering 21.7% of the country and Ewaso Ng’iro, covering 36.3% of the country (Seeegers et al., 2003). All drainage or river basins are defined by the watershed, which begins in the high-altitude areas or highlands from which snowmelt and precipitation feed into streams and rivers. These rivers in turn feed into a middle reach that is the mainstream of the river and then flow to the lowlands, which empty into the ocean or into swamps or lakes; in some cases, it may dry out. This chapter describes the present status, threats and management challenges of Kenya water towers and the main drainage systems.

## 2 KENYA WATER TOWERS

### 2.1 Mount Kenya

Mount Kenya is the highest mountain in Kenya and the second highest in Africa, after Kilimanjaro. The highest peaks of the mountain are Batian

(5199 m (17,057 ft.)), Nelion (5188 m (17,021 ft.)) and Point Lenana (4985 m (16,355 ft.)). Mount Kenya is located in central Kenya, just south of the equator, around 150 km (93 miles) north-northeast of the capital Nairobi. Mount Kenya is a stratovolcano created approximately 3 million years after the opening of the East African rift. Before glaciation, it was 7000 m (23,000 ft.) high. It was covered by an ice cap for thousands of years. The erosion from the gradual ice melt has resulted in numerous valleys radiating from the centre, which form the sources of several streams and tributaries that join to and from major rivers further downstream.

There are currently 11 small glaciers and the forested slopes are an important source of water for part of the Ewaso Ng'iro basin and the Tana River basin. The Mount Kenya ecosystem and unique natural resources, however, are being degraded and in many cases destroyed by uncontrolled use and exploitation. The forests especially are under extreme threat from human-induced illegal activities. In 1999, an aerial survey of the then forest reserve conducted by the Kenya Wildlife Service highlighted the ongoing destruction of the forest, leading to the decision to regazette the forest reserve as a natural reserve (KWS, 2003). The report gives an excellent summary of the threats on Mount Kenya's forests. Since the 1999 report and following the subsequent regazettment of the reserve and the formation of the Mount Kenya Trust, a follow-up report was released. This report was compiled by the Kenya Wildlife Service, UNEP, the Kenya Forest Working Group and the Durrell Institute of Conservation and Ecology, University of Kent. The report shows encouraging improvements; however, extensive destruction still continues to threaten the future of Mount Kenya's precious resources.

The major threats to Mount Kenya's ecosystems currently include the following: illegal logging—the KWS survey recorded fresh and old logging of indigenous trees in natural forest. Some of the most targeted species were identified separately. They include camphor (*Ocotea usambarensis*), cedar (*Juniperus procera*), wild olive (*Olea europaea*) and E.A. rosewood (*Hagenia abyssinica*). The major drivers of this activity are the widespread use of woodfuel in the lowland areas and the demand for cedar fencing posts in the farms and ranches of the Laikipia plateau. Intensive charcoal making, in various stages of production, was also observed in the lower parts of the Upper Imenti Forest Reserve, whereby significant areas of indigenous forests have been destroyed.

Secondly, there is the grazing of livestock. In total, 4258 heads of livestock were counted in the reserved forests during the survey. This number rises to over 10,000 during the periodical droughts in northern Kenya when pastoralist communities drive their livestock into the forest in search of pasture. In the rainy seasons, goats are a particularly acute problem because their browsing has a significant negative impact on the growth of seedlings and tree recruitment. The third major threat to this forest is fire. Fires occur in the forest as a result of illegal charcoal-burning activities, honey gatherers, and carelessness on the part of guides and tourists climbing the mountain and camping in the forest. In March–April 2012, over 60,000 ha of the forest was destroyed

in a fire that was estimated to have cost the country over Ksh. Eight billion (US \$95,000,000). The risk level is particularly high in the dry season when the deep peat layer in the moorlands is easily combustible and very difficult to extinguish without the use of heavy equipment.

Significant policy weaknesses underlie several of the threats to Mount Kenya and other forests in Kenya, notably the plantation establishment livelihood improvement scheme. This was established by the Kenya Forest Service (KFS) to engage communities in establishing plantation forests as they practise agriculture in the forests.

## 2.2 Mount Elgon

Mount Elgon is an extinct shield volcano on the border of Uganda and Kenya, north of Kisumu and west of Kitale. The mountain's highest point, named 'Wagagai', is located within the country of Uganda. Notable physical features on Mount Elgon include the caldera, which is one of the largest intact calderas in the world. It also has a large network of caves including Ngwarisha, Makingeny, Chepnyalil and Kitum. Kitum Cave is over 60 m wide and penetrates 200 m into the mountain. It was formed over the centuries by the activities of wild elephants that lick the salt exposed by gouging the walls with their tusks. The mountain soils are fertile red laterite, which have resulted in intensive cultivation on the slopes. The mountain is the catchment for the several rivers such as the Suam River, which becomes the Turkwel downstream and which drains into Lake Turkana, the Nzoia River and the Lwakhakha, which flow to Lake Victoria. The town of Kitale is on the foothills of the mountain. The forest around the mountain is protected by two Mount Elgon National Parks, one on each side of the international border. However, the effect of the protection is limited by the small size of these national parks. They have been effective in protecting the rare flora found on the mountain, including *Ardisiandra wettsteinii*, *Carduus afroreanensis*, *Echinops hoehnelii*, *Ranunculus keniensis* and *Romulea keniensis*, but there is not enough ground cover to prevent siltation of the rivers.

Policy weaknesses are a challenge to the conservation of Mount Elgon forest, and this is further complicated by its situation on an international border. The reserve on the Ugandan side was upgraded to a 'national park' in 1993, and its boundaries were expanded from the reserve's previous *de facto* endowment—a process that entailed, by some estimates, the eviction of more than one hundred thousand people from within the new boundaries. The people were forcibly evicted from their homes by the Uganda Wildlife Authority (UWA) and the Uganda People's Defence Forces (UPDF, the Ugandan military). Incidences of displaced villagers confronting rangers have become commonplace as they fight to reclaim their lost land. In Kenya, the forest has also been the scene of fighting between security forces and local militias. This social instability has compromised environmental conservation efforts in Mount Elgon over the years.

Further pressure on forest and land resources results from population explosion of approximately 2 million people living on the slopes of Mount Elgon and growing at a rate of 2.3–4.3% per annum. Limited livelihood options pose a threat to the environmental integrity in the Mount Elgon ecosystem because a large proportion of the population survive on resources obtained directly from the forest, including mushrooms, bamboo shoots, vegetables, firewood and timber. Predominant subsistence farming on the slopes where the rivers flow from has resulted in poor farming practices, for example, cultivation of riparian zones. Illegal settlements in the forest have led to the felling of trees in order to create space for construction and cultivation. This has also compromised the quality of wildlife and biodiversity habitats in the area. Poaching has substantially reduced the biodiversity as animals are hunted down for game meat. Records at the Kenya Wildlife Service and UWA show that the targeted species include duikers, buffaloes, leopards, red-tailed monkeys, various antelopes and birds. Hitherto, potential tourist attractions have all escaped to the Kenya side of the mountain and many of the species are now at the brink of local extinction. Perhaps the most robust challenge to law enforcement in this particular water catchment is the ‘no man’s land’ that exists between international boundaries. Perpetrators of environmental crimes in Kenya regularly escape across the border to Uganda and vice versa.

### 2.3 Aberdare Range

The Aberdare Range is located in central Kenya and straddles the equator. The Range stretches over 125 km from Nyahururu in the north to Limuru in the south. It is the third highest mountain in Kenya, with two main peaks, Oldonyo Lesatima (also known as Sattima) and Kinangop, which reach, respectively, altitudes of 4001 and 3906 m. The Range presents a deeply dissected topography sloping gradually to the east. In contrast, the western side drops along impressive fault escarpments towards the Rift Valley. The climate of the Aberdare Range is generally characterized by two rainy seasons—from April to May and October to November. Rainfall varies with altitude and exposure to the dominant wind from the Indian Ocean but reaches a maximum of around 2600 mm annually on the southeastern slopes and drops to less than 900 mm a year on the northern and southwestern lee slopes. Various vegetation zones can be distinguished on the Aberdare Range, including the closed-canopy forest belt, the bamboo zone and the subalpine and alpine vegetation. The forest belt covers a major part of the Range. Most of the forest is gazetted as forest reserves. However, parts of the upper forest zone fall within the Aberdare National Park. The forest belt of the Aberdare Range is characterized by a high diversity of forest types, because of the wide altitudinal range (from 1800 to 3600 m) and the climatic differences between the slopes.

The Aberdare highlands form one of the most economically important water catchments in Kenya, supplying over 70% of the water needs for Nairobi city, which in turn produces approximately 40% of Kenya's GDP. It is also the source of the Ewaso Ng'iro River, which is the lifeline of the northern Kenya rangelands, including the Laikipia plateau.

The major threat to the ecological integrity of the Aberdare mountains is human population growth and related habitat transformation. It is estimated that 6100 ha has already been largely converted to agriculture. This destruction and conversion into settlements includes 4475 ha around Kipipiri and 1104 ha in Ragia forest. Unattended charcoal kilns and illegal logging of indigenous trees occurs extensively in the northern, western and southern slopes. In the southern slope for example the Rhino Ark, a charitable trust supporting conservation in Kenya, counted over 10,000 charcoal kilns in a recent aerial survey. The latter is an important refuge for the endangered mountain bongo (*Tragelaphus eurycerus*) in Kenya. In addition to the common threats posed by livestock grazing, quarrying is a major threat that is particular to this forest complex. Some 23 quarries were recorded in the Aberdare Range forests. Most of them were located in Nyeri Forest Reserve and Kiganjo Forest Reserve on the eastern slopes and on the northern part of the Aberdare Forest Reserve. All the quarries were outside fenced forest areas. This threat is largely driven by the construction industry in Nyeri town and its demand for the murrum and rock that lies at an average depth of 4 m below the forest floor. This pressure from quarrying activities in the lower Aberdare forest underscores the importance of the fence erected around the protected area.

## 2.4 Cherangani Hills

The Cherangani Hills is an expansive area traversing three districts. It is situated in parts of Trans-Nzoia, Elgeyo-Marakwet and West Pokot districts. Of the water towers in Kenya, it is arguably the most heavily impacted by human activity and agriculture, since it occurs in Trans-Nzoia County, which is part of the country's 'bread basket' or the most productive maize-growing area. The destruction was largely driven by the politically based forest excisions that occurred in Kenya during the 1980s and 1990s. The actual forest cover is diminished to a level where it is not listed as a forest area in the current KFS strategic plan other than the Embobut area. The Cherangani Hills still functions as a catchment, drawing relief rainfall, but the poor condition of the forest is evident in the silt load carried by the Nzoia and Birbiriet rivers.

Increasing density of settlements and intensification of land-use activities driven by rapid population growth and increasing poverty continue

to exert pressure on the Cherangani Hills forests. Absolute poverty in the area stands at 54%, largely driven by the weaknesses in agricultural policy and the resultant instability of maize prices in local markets. This circumstance has triggered community encroachment into the forests for timber, firewood and charcoal or in an effort to increase the land area under maize.

Cherangani Hills forest has witnessed conflicts between downstream and upstream communities over the dwindling water resources because of watershed degradation by upstream communities. This conflict often manifests as cattle rustling and ethnic hostilities. In addition, a declining natural resource base especially pastures and water has seen pastoralist communities venture into crop farming on the hillsides to diversify their livelihoods. As a result, the fertile but steep forestland has suffered serious degradation. Occasional fires are a threat to the Cherangani Hills. This is caused by immigrant labourers engaged in charcoal burning to supplement their dwindling seasonal incomes from the maize farms and clearing forest to access land, which they can occupy as squatters.

### 3 FRESHWATER ECOSYSTEMS OF ATHI RIVER BASIN

The Athi River Basin has three names at different parts of its flow and is thus named Athi–Galana–Sabaki river system. It is the second largest of the eastwards-flowing rivers of Kenya and drains a comparatively small catchment of 66,837 km<sup>2</sup> flowing across southeast Kenya into the Indian Ocean. The river provides water for urban and rural areas including Nairobi, Mombasa and Malindi towns. The Athi River flows through semiarid land with an average annual rainfall of 739 mm and a low groundwater recharge rate of 296 million m<sup>3</sup> per year. When compared with the other four drainage basins, Athi River Basin has the largest number of small dams (90), shallow wells (6720) and boreholes. That information clearly points to an area with limited surface water and consequentially limited freshwater ecosystems.

In the upper catchment, Athi River is fed by numerous streams originating on the densely populated Kikuyu Highland and Ngong Hills. The main permanent streams are Gatharaini, Mathare, Nairobi, Mpakasi and Kiserian. These streams originate from springs and small wetlands in the upper catchment area. There are also numerous water storage dams, such as Tigoni, Nairobi, Jamuhuri and Ngong forest dams, that were constructed across some of the streams to enhance water supply for domestic and farm use. In many places, however, the dams have become polluted with domestic or farm waste and their water is no longer suitable for human use.





Athi–Galana–Sabaki river system: Athi River at 14 falls, Ol Donyo Sabuk—Thika.

The middle part of Athi Basin is largely semiarid and most of the freshwater ecosystems are closely linked with seasonal rainfall. Most rivers, marshes, ponds and water pans are seasonal. The main rivers that supply water to Athi River for most of the year are the rivers Kiboko, Tsavo and Voi. The hydrology of the middle Athi Basin permits formation of numerous springs, water pools and shallow lakes. Rain and mist water seeps on Chyulu Hills and appears at Mzima Springs in Tsavo West National Park and at Umani Springs near Kibwezi. These water systems are extremely important because they support the water needs of the people, agriculture, livestock and wildlife.

The Kiboko wetland system has been formed by surface runoff and springs arising from seepage of rain and mist on the surrounding hills. Water seeping on Mount Kilimanjaro has permitted the formation of permanent swamps and a lake in Amboseli. The lake basin is flat and has fine alkaline sediments deposited over the years by seasonal runoff from the watershed, including sediments transported downstream by Namanga River. The basin holds shallow water during periods of heavy rainfall, but for most of the year, it remains an unfriendly dust bowl. Evaporation rate is high and soda ash is deposited on the soil surface as the water evaporates.

*14 falls* Below the Lugard Falls (near the R. Tsavo), the river is called Galana, while the lowermost course is the Sabaki, which flows to its mouth 11.3 km north of Malindi town. Flood plain lakes exist towards the mouth of the river and are often maintained by rainfall and runoff. These lakes include: Chem Chem, Jilore, Merikano, Mbirikano and Mekimba (Okeyo, 1998).





Athi River at Lugard Falls after which the river becomes Galana River.

Nairobi is the principal urban centre but there are other rapidly growing municipalities in the upper catchment of Athi River. These emerging municipalities include Kikuyu, Ngong, Kiserian, Athi River and Kitengela. Pollution with municipal, industrial and farm waste is a fundamental problem affecting freshwater ecosystems. Natural wetlands have also been under pressure from excessive water abstraction for domestic and farm use, encroachment by subsistence farmers and dumping of waste material. The available surface water is inadequate to meet the growing demand for water. Therefore, there is increasing abstraction of water from underground resources through wells and boreholes throughout the upper Athi catchment.

Malindi District as the most downstream riparian district of the Athi–Galana–Sabaki river system is, due to its hydrological position, dependent on any modification in water flow occurring further upstream. During the last severe drought in 1998–2000, there was inadequate quantity of water to meet the requirements of all the water users in Malindi District. Upstream water users overabstracted water, leaving none for users downstream. In the context of such water use competitions, Malindi District is vulnerable to every additional water abstraction further upstream. In the last decades, protection of river water users in Malindi District against overexploitation by co-riparians further upstream was not necessary, since most of the time, there has been enough water for all. Although Athi River as the main tributary to the Sabaki River tends to dry up in times of drought, Sabaki River in Malindi District has never dried up due to permanent flow of the Mzima Springs,

which drains its water into Sabaki. A certain part of the clear Mzima Springs water is transferred by the so-called 1 pipeline to the urban region Mombasa. This water transfer (within the Athi River Basin) reduces water levels in Sabaki River. Due to sufficient amounts of Mzima Springs water, water use conflicts between water users in Mombasa and Malindi District arise only in times of drought, which occurs every 3–4 years.

#### 4 FRESHWATER ECOSYSTEMS OF TANA RIVER BASIN

Tana River is the largest river in Kenya and flows for nearly 1000 km to the Indian Ocean. The river drains a catchment of 126,026 km<sup>2</sup>, which encompasses the southern and eastern slopes of Mount Kenya (5100 m asl) and the eastern slopes of the Aberdare Mountain Range (4030 m asl). The upper catchment of the river receives 1000–1500 mm of annual rainfall, but the whole of Tana River Basin receives an average of 697 mm of rainfall per year. Most of the river flows through a semiarid region and its basin varies from 6 km wide in the upper part to 42 km wide in the lower part.

The upper catchment of Tana River has a large network of primary and secondary streams. Among the major secondary rivers feeding into Tana River are Sagana from the Aberdare catchment and Nyamindi and Thiba from the massive Mount Kenya catchment. Because of the high gradient of the land, most of the rivers are fast-flowing and their valleys have little marginal vegetation. However, where the land gradient in the valley is low, there are patches of riverine forest, marshes and swamps. Remnants of valley bottom wetlands occur widely in Nyeri, Kirinyaga, Embu and Meru Counties. The wetlands play an important hydrological role as they trap silt, store floodwater and regulate water flow in the valleys.

Apart from the natural freshwater ecosystems associated with streams and rivers, the upper catchment of Tana River has numerous artificial water ecosystems. These include stream impoundments for water storage, aquaculture ponds for fisheries research and production and irrigated small-scale and large crop fields. There are small fish farms at Kiganjo and Sagana, which are dedicated to cold stream fisheries research and fish fry production. These facilities produce and supply fish fingerlings to small-scale fish farmers in central and eastern Kenya. The waters of the permanent rivers Thiba and Nyamindi support 4000 ha of paddy fields at Mwea in Kirinyaga County. A few of the tributaries supplying water to the Tana, such as Sagana River, have been dammed to generate hydroelectricity, which is used locally or transmitted to the national power grid. Overall, the rivers of the Upper Tana Basin are a valuable source of water for human use, crops, livestock and wildlife, not only within the vicinity of the mountains but also further downstream.

The low-elevation sections of Tana River Basin cover at least 30% of the basin and fall in a semiarid environment. The dominant economic activities are dry land agriculture and livestock production in the semiarid rangelands.

Apart from Tana River and its numerous seasonal tributaries, the principal freshwater ecosystems in this part of the basin are the seven major impoundments constructed for water storage and generation of hydropower. These hydropower dams are Masinga, Kamburu, Gitaru, Kiambere, Kindaruma, Sasumaru and Bathi. Masinga dam is large (150 km<sup>2</sup>), with 1560 million m<sup>3</sup> of water storage capacity. Most of the other dams are relatively small with storage capacities ranging from 2 to 10 million m<sup>3</sup> of water. The power generation capacities of these dams are gradually diminishing because of siltation and fluctuations in water supply from the Aberdare and Mount Kenya catchments.

Apart from hydropower generation, the dams store water, which is used by local people, livestock and wildlife. They support economically important fisheries resources, especially of tilapia, catfish and common carp. These resources have immense potential for sport fishing and other tourism activities. Availability of adequate water of high quality is fundamental to the development of hydropower and fisheries in the Tana Basin. Wildlife conservation and tourism as well as livestock production are currently high-value uses of the rangelands and natural wetlands in the middle and lower Tana Basin. However, expansion of cultivation in the highlands and increased levels of urbanization is contributing to diminishing water supply and increasing water pollution levels.

## 5 FRESHWATER ECOSYSTEMS OF EWASO NG'IRO BASIN

Ewaso Ng'iro is the largest drainage basin covering 210,226 km<sup>2</sup> or 36% of the total area of Kenya. However, the basin has low mean annual rainfall (411 mm), high evaporation rate and the low mean annual runoff. Nevertheless, because of its large surface area and highly permeable geologic formations, the basin has a high groundwater recharge rate and a huge groundwater reserve. Surface water is scarce and hence most freshwater ecosystems are small and largely seasonal or periodic.

The major freshwater ecosystems comprise Ewaso Ng'iro River and its tributaries, and the Lorian Marula, Rumuruti and Pesi swamps. There are also natural springs, numerous man-made dams and pans and seasonal marshes. These wetlands serve as sources of water for people, livestock and wildlife. The swamps and seasonal marshes provide valuable dry season grazing areas for livestock and wildlife. The occurrence and distribution of freshwater ecosystems in Ewaso Ng'iro Basin are influenced by a number of factors. These include the amounts of rainfall and prevailing evaporation rate as well as local topography.

The ultimate effect of the variable structure and distribution of freshwater ecosystems are consequences of changes in biotic communities.

Freshwater ecosystems cover approximately 1% of Kenya's rangelands. However, the structural and functional dynamics of the ecosystems have had profound implications on the availability of water, pasture and fisheries

resources and sustainable livestock production and wildlife conservation. The freshwater ecosystems in these dry lands have served like ‘magnets’ that attract concentrations of people, livestock and wildlife. They are therefore highly vulnerable to disturbance and degradation through overexploitation of natural resources, such as water extraction, overgrazing by livestock, and drainage of wetlands for agriculture, settlements and development of infrastructure.

## 6 FRESHWATER ECOSYSTEMS OF LAKE VICTORIA BASIN

Lake Victoria is the largest freshwater body in Africa. It has a catchment area of 180,950 km<sup>2</sup>, 21.5% of which lies in Kenya. The lake is a vital water reservoir with an average depth of 40 m and an expansive surface area of 68,870 km<sup>2</sup>. Only a small portion (6%) of the water surface occurs in Kenya. The lake’s shore line is 3450 km long, 17% of which is in Kenya. Lake Victoria receives 85% of its water from direct precipitation, which averages 1350 mm per year and the balance of 15% derives from rivers, which drain the surrounding catchment. Most of the water leaving the lake (85%) is through direct evaporation from the surface, while 15% is lost via Nile River outflow.

The eastern catchment is wholly in Kenya and comprises Mount Elgon, Cherangani, Mau Mountain ranges and other highlands in western and south-western Kenya. The average annual rainfall in the catchment ranges from 1300 mm in the Nzoia–Yala Basin in the north through 1415 mm in the Sondu Miriu Basin in the Kisii highlands to 1040 mm in the Mara River basin southern segment of Mau ranges. The eastern catchment is drained by six main rivers: Nzoia, Yala, Nyando, Sondu Miriu, Gucha and Mara. Rivers Nzoia and Yala have the largest subbasin of 15,143 km<sup>2</sup> followed by Mara River (13,915 km<sup>2</sup>) and Gucha River (6612 km<sup>2</sup>). The other two rivers, Nyando and Sondu Miriu, have relatively small subbasins of about 3600 km<sup>2</sup>. There are also numerous other streams and springs that originate in the lake basin and drain into the shores of Lake Victoria.

Most of the Kenyan portion of Lake Victoria lies in Winam Gulf, which lies in a 46,230 km<sup>2</sup> drainage basin. Apart from the gulf, there are other freshwater ecosystems, such as small lakes, dams, marshes and swamps, fish farms, sewage ponds and rice paddies, that occur on the surrounding land. The main satellite lakes are Kanyaboli, Sare and Namboyo, which occur on the Nzoia–Yala flood plain in the northern basin of Lake Victoria. In the southern basin, there is a small crater lake, known as Simbi Nyaima. The lake has saline water, though it is only about 100 m from the lake. There are also numerous water storage dams and fish ponds found in all parts of the eastern catchment.

The rivers draining the eastern catchment are short and tend to flow rapidly, transporting large loads of sediment and other pollutants from their catchment. They tend to have little aquatic vegetation, but they have linear blocks of woodland along their valleys. Their flood plains are flooded during

periods of high rainfall in the catchment. The affluent rivers enter the lake through extensive swampy deltas, dominated by herbaceous vegetation, especially papyrus (*Cyperus papyrus*) and elephant grass (*Vossia pyramidalis*). The northern basin is covered by the extensive Yala Swamp with numerous open channels that drain the river and surface runoff slowly into the lake. There are also extensive delta wetlands at the mouths of Nyando River and Sondu Miriu.

The main freshwater issues in Lake Victoria basin are exploitation of the fishery, water quality and supply, rampant waterborne diseases and introduction of invasive species. The lake and marginal wetlands receive factory effluent, oil and grease, and sewage and storm water from the 18 towns in the basin and catchment area. The loading of untreated effluent discharge from urban centres has contributed to loss of oxygen and build-up of total phosphorus and nitrogen content in the lake. Much of the water in Winam Gulf is therefore murky, smelly and choking with algae and water hyacinth. This deteriorating water quality has serious implication on the shrinking aquatic biodiversity, the diminishing fisheries resources and limited access to clean and potable water, which is a fundamental livelihood and public health issue for the residents of Lake Victoria basin.

## 7 FRESHWATER ECOSYSTEMS OF THE RIFT VALLEY BASIN

Kenya's Rift Valley extends for 900 km from north to south and its altitude ranges from 400 m in the north to 1880 m in the central part and 600 m in the southern part. Except for the elevated central part of the valley, this internal drainage basin has semiarid to arid climate. Annual rainfall varies from 250 mm in Lake Turkana Basin through 900 mm around Lake Nakuru to 400 mm around Lake Magadi in the south. As a result of the low rainfall received in the basin, surface water is relatively scarce. The basin contributes 1% of national surface water yield but a significant proportion (20.3%) of the national groundwater yield. The uplands flanking the Rift Valley receive 1000–2000 mm of rainfall per year and serve as the main rainfall catchment for numerous springs, streams and rivers that drain into the valley.

The rivers and streams flowing into the Rift Valley are short and flow rapidly, especially as they flow down the escarpments. The main rivers are Turkwel, Kerio, Suam and Suguta, which flow into Lake Turkana; Molo, Ol Arabel and Perkerra, which flow into Lake Baringo; Subukia, which flows into Lake Bogoria; Malewa and Gilgil, which flow into Lake Naivasha; Njoro and Nderit, which flow into Lake Nakuru; and Mara and Ewaso Ng'iro (South), which flow into Lake Victoria and Lake Natron, respectively. There are also many seasonal streams that supply water to the Rift Valley lakes and wetlands. The rivers valleys and other areas with shallow underground water table support characteristic woodland vegetation dominated by *Acacia xanthophloea* and fig trees, such as *Ficus natalensis*. The rivers enter the lakes

via small deltas with characteristic wetland reeds and sedges. The riverine woodlands provide vital habitat corridors for movement of birds and primates between the valley floor and the adjacent forested escarpments. The rivers are important for water supply and fishes, which support subsistence fishing, sport fishing and camping sites.

The Rift Valley basin contains a chain of freshwater and saline lakes, which occupy closed basins with no surface outflows. There are also permanent swamps and seasonal marshes as well as numerous streams that drain into the valley from the adjoining highlands. The Kenya Rift Valley contains seven major lakes, one of which is fresh (Naivasha), two are moderately saline (Turkana and Baringo), three are saline (Bogoria, Nakuru and Elementaita) and one is hypersaline (Magadi). Most of the Rift Valley lakes tend to be shallow, long and narrow. The saline and hypersaline lakes have narrow shores with large boulders, gravel, sand or expansive fine silt and crystalline salt. There are also seven minor lakes that are scattered along the valley floor from the north to the south. These minor lakes are Logipi, Kamnarok, Kijiritit, Solai, Ol Bolossat, Kwenia and Kabogo. The basins of the lakes are under semiarid climatic conditions, where the evaporation rate far exceeds the prevailing rainfall. In the short term, lake water levels fluctuate with surface water flow and supply from seepage in the watershed.

The water chemistry and associated sediment types influence the community structure of microorganisms, animals and plants found in each lake.

Freshwater ecosystems associated with the Rift Valley support a wide range of aquatic and terrestrial organisms. Most of the primary productivity in the saline lakes can be attributed to the floating photosynthetic algae (*Spirulina platensis*) and the variety of phytoplankton community. The freshwater lakes, especially Lakes Naivasha and Baringo, have abundant floating, submerged and marginal vegetation and freshwater algae and phytoplankton communities. All these primary producers contribute the organic energy needed to maintain short animal food chains and food webs in the lakes. The freshwater Lake Naivasha and the moderately saline Lakes Baringo and Turkana support moderate diversity of fishes and regionally important fisheries resources.

Lake Turkana occupies an area of 7560 km<sup>2</sup> and it is the largest single lake in Kenya. This long but narrow lake has three volcanic islands: north, central and south islands. The lake is located in a hot desert environment, but receives 90% of its water from the Omo River which drains the humid central highlands of Ethiopia. The river enters the lake via a swampy delta at the northern end. Rivers Turkwel and Kerio have increasingly become seasonal, reaching the lake during the extremely wet seasons via a sandy and gravel delta on the southwestern shores. The lake supports 48 known fish species, seven of which are endemic to the lake. The central island has three saline crater lakes, which support some endemic cichlids (*Tilapia* spp.). There are 12 commercially exploited fish species with littoral tilapia fishery, which is dominated

by *Oreochromis niloticus*, comprising 52% of the fishery. The demersal fishery, which is dominated by *Labeo horie* and *Bagrus bayad*, contributes 21%, while the pelagic fishery consists of seven species dominated by the Nile perch (*Lates niloticus*, 10% and *Alestes*, 7%). This fishery is characterized by 10 year boom and bust cycles, which are associated with water fluctuations arising from climatic variability in the catchment of Omo River.

The Naivasha basin contains the freshwater Lake Naivasha (160 km<sup>2</sup>) and two saline lakes Oloidien and Sonachi. Lake Naivasha is one of the most studied tropical lakes and has been shown to support a high diversity of aquatic plants, birds and invertebrates. Following the extinction of its only native fish species, *Aplocheilichthys antinori*, in the early 1970s, Lake Naivasha has no native fish species but has had 10 fish introductions since 1925. Out of the 10 species introduced, only three successfully established in the lake: blue spotted tilapia (*Oreochromis leucostictus*), redbelly tilapia (*Tilapia zilli*) and black bass (*Micropterus salmoides*). In the late 1990s, the common carp (*Cyprinus carpio*) invaded the lake from fish ponds in Kinangop Plateau and Dundori Hills. By the year 2010, the common carp was contributing nearly 70% of the total fishery of Lake Naivasha. The occurrence of abundant food in the form of fish, invertebrates and aquatic vegetation has supported nearly 420 species of birds in the lake and the surrounding littoral zones and woodlands. Lake Naivasha is a wetland of international importance (Ramsar Site) because of the high diversity and large concentrations of resident and migratory species of birds.

The most conspicuous wildlife is birds, which occur in large concentrations in both the saline and freshwater lakes. The saline lakes and the associated hot springs support rich communities of microorganisms, especially algae and bacteria. They also support large concentrations of birds, especially the lesser flamingos, greater flamingos, pink-backed pelicans and aggregations of migrant and resident ducks and shore birds. The birds inhabiting the lakes and wetlands move periodically among the lakes of the Rift Valley, including Rift Valley lakes in Ethiopia and Tanzania. The freshwater lakes also support significant groups of hippopotami, crocodiles, terrapins and other wildlife, such as water-buck, giraffe, buffalo and eland on the surrounding terrestrial habitats.



Lesser flamingos form large concentrations in the alkaline Rift Valley lakes of Kenya.



The scenic beauty of the Rift Valley and the large concentrations of birds associated with the lakes, wetlands and woodlands in the valley constitute an important tourist attraction. The freshwater ecosystems in the Rift Valley basin, such as Lake Naivasha, Nakuru, Bogoria and Baringo, are major destinations of international tourists in Kenya. The rivers and freshwater wetlands and the freshwater lakes, such as Lake Naivasha, are important sources of water needed to support agriculture, horticulture and livestock, industrial and household needs. Fertile soil in the wetlands is attractive to farmers, while abundant foliage in the permanent wetlands is attractive to livestock herders. The principal threats to the freshwater ecosystems in the Rift Valley basin are high rates of siltation and pollution from catchments of affluent streams, excessive abstraction of water from affluent rivers and from the lake itself, drainage of wetlands for farming and settlement and overexploitation of fisheries and plant resources.

Human settlements and human impacts are the greatest threat to freshwater ecosystems in the Rift Valley basin. Effective and sustainable management of these ecosystems and their globally important bird populations and endemic fish species is necessary. The first priority is to ensure that the water catchment areas of streams supplying water to the lakes and wetlands on the valley floor are protected and, where necessary, rehabilitated. Thus, soil erosion and water abstraction from affluent streams are strictly controlled. This will ensure reduced sediment load entering into the lakes and continuous water supply. Land and water pollution in the lake's watershed should be controlled and exploitation of fish and plant resources from the lakes and wetlands regulated. In addition, concerted efforts should be made to minimize negative impacts of climate change on the lakes and the biodiversity that they support.

## 8 DISCUSSION

The Green Revolution in the 1940s aimed at increasing cultivated areas and water use for irrigation of high-yielding plants has in the global context been the cause for reduction in freshwater resources (Finger et al., 2011). In addition, developments in the industrial sectors have increased the economic use of water, accounting for about 20% of the global freshwater withdrawal. Water for domestic use is a very small fraction in comparison to both agricultural and industrial uses.

In Kenya, the water towers are under serious threat from population growth and poor agricultural deforestation and lack of implementation of policy decisions. The deforestation of Kenya's water towers over a 10 year period, 2000–2010, was approximately 50,000 ha, which yielded timber and fuelwood volume of 2010 cubic metres per hectare, with a cash value of 272,000 KES/ha. However, the indirect costs of deforestation are borne by sectors and households elsewhere in the economy through the reduction in value of regulating

services of the ecosystem. The negative effect of deforestation on the economy by 2010 was approximately KES 3.8 million, which outweighs the immediate cash benefit from timber and fuelwood sales by 2.8 times.

The protection of these biomes is crucial for two major reasons. Firstly, they are important water catchments, on which millions of people depend, in both urban and rural settings. The destruction of these water towers would therefore be a potential disaster affecting the quality and quantity of water available over a wide geographical area. Secondly, the threat posed by invasive species also underscores the importance of the upper reaches of rivers because they sometimes remain unreached by the invasive species due to various physicochemical barriers, and when they are invaded, it is not possible to protect the lower reaches due to the flow direction and periodical flooding. A case in point is the Louisiana red swamp crayfish *Procambarus clarkii* in Kenya. In the Ewaso Ng'iro River, this species was introduced by settlers into the lower reaches but is restricted to ambient water temperatures above 14°C, even in contiguous habitats (Ogada et al., 2009). The upper reaches of the Ewaso Ng'iro like the Burguret and Naro Moru Rivers were therefore found to be pristine habitats still inhabited by freshwater crab *Potamonautes neu-mannii*, unlike the lower reaches where these had been supplanted by the invasive crayfish. This habitat quality was reflected by the density of otters *Aonyx capensis*, with approximately 6.5 individuals per km of river is over three times that of the invaded area at 1.8 otters per km (Ogada, 2007). In another case, the steep Kinangop escarpment has protected the upper Naivasha catchment and the Aberdares from invasion by the common carp *Cyprinus carpio* from Lake Naivasha in the Rift Valley.

The importance of conservation of these biomes is further underscored in reference to point-source chemical pollution. Crustaceans cannot survive in acidic waters because the low pH interferes with their calcium uptake and shell formation (Lodge and Hill, 1994) and by this token, the negative impacts of the Athi River pollution from Nairobi are still prevalent in the apparent absence of crustaceans in the Galana River hundreds of kilometres downstream of the source in Tsavo East National Park. Kenya's water catchment areas are something of a 'confluence' of aquatic and terrestrial ecosystems, and are, therefore, crucial to our understanding of both biomes. It is well known that transfers of material and energy between ecosystems shape the ecology of entire landscapes. In the study of cross-boundary connections, much attention has been paid to linkages between aquatic and terrestrial ecosystems. It has become apparent that despite the physical differences between the two systems, they impact each other directly. Rivers in particular have been shown to be especially well linked to terrestrial systems, with significant exchange of nutrients from river to land, and vice versa either by gravity or through primary or secondary consumers. In resource-poor countries like Kenya where we are unable to protect entire rivers, there is a case for priority to be given to the catchment areas for the reasons previously mentioned.

## 8.1 Significance of Freshwater Ecosystems

Freshwater ecosystems play a fundamental ecological role and provide economically important products and services. They provide critical habitats for a large number of aquatic plants, fishes, reptiles, birds and mammals. They host many migratory and threatened species of birds, reptiles and fish. The freshwater ecosystems are areas of tourist attraction by providing recreation sites for game and bird watching.

Freshwater ecosystems, especially vegetated wetlands, play an important role in mitigation against climate variability. They do so through a number of ecosystem functions including flood control, water purification, shoreline stabilization and sequestration of carbon dioxide. At landscape level, wetlands control soil erosion and retain sediments and in so doing concentrate nutrients in the wetland soil. They also provide economic benefits such as fresh water, fisheries, fuelwood, building material, medicinal products, honey and foliage for livestock and wildlife. Wetlands provide fertile land for agricultural, mineral salts, sand and soil for making pottery and building bricks. Wetlands are central to rural subsistence economies and livelihood activities of many rural communities in Kenya. Freshwater ecosystems in general are critical to poverty alleviation and creation of employment and wealth.

Freshwater ecosystems provide water for home and farm use and for power generation and industrial development. Their biodiversity supports recreational activities and tourism. The valley bottom wetlands regulate stream flow and improve water quality through sediment filtration and absorption of heavy metals and other toxic pollutants. Wetlands absorb and store large quantities of rainwater and floodwater, thereby facilitating recharging of underground water. By recharging underground aquifers, the water table is raised, hence making groundwater available in springs and wells to support domestic, industrial and agricultural activities.

## 8.2 Threats and Management Challenges

In spite of having several freshwater sources, Kenya has been classified as a water-scarce country, which in a global context refers to a country whose renewable freshwater is between 1000 and 1700 cubic metres per capita. The Water Resources Availability in Kenya in 2010 was estimated at 1172 cubic metres per capita up from 647 cubic metres per capita estimated in 1992. The main challenge is that water in Kenya is unevenly distributed in time and space, which is a factor of the variability of rainfall patterns. In addition, extreme weather events during droughts and floods have become more frequent and affect water availability. Several other natural and anthropogenic factors affect water supply and quality.

The natural processes that threaten freshwater ecosystems and their biodiversity are variability in water supply, increasing soil erosion and sedimentation

rates, ecological succession processes and introduction of invasive species. Intensification of land use and urbanization in the catchment pose serious threats to all freshwater ecosystems in general. The rapid increase of human population and its growing demand for land, shelter and food production has led to rapid loss of wetlands due to conversion into agricultural land. Increased demand for water and other wetland resources has initiated unsustainable exploitation with serious alterations in ecosystem structure and functions.

Introduction and dispersal of alien invasive species in freshwater systems have threatened the ecosystem balance and regeneration of diverse resources. The introduction of the Nile perch (*Lates niloticus*) into Lake Victoria, for instance, had increase the economic value of the lake's fishery, but the species caused damage to the ecosystem, resulting in the loss of some native species with significant economic potential. The introduction and spread of Louisiana crayfish in freshwater ecosystems in central and eastern Kenya has had disastrous effects on fish communities and their productivity. Ornamental aquatic plants, such as water hyacinth, Nile cabbage and water fern, have invaded dams, lakes and rivers, thereby hindering fishing and transportation activities. They have contributed to unfavourable changes in native plant and animal communities. The impacts of invasive species are immense, damaging to the native species and usually irreversible.

Pollution as a result of urbanization and industrialization poses a big threat to the well-being of freshwater ecosystems. Rivers, streams and swamps are often used as receptacles of liquid effluents from municipalities and waste dumpsites for solid waste. Damming of rivers to produce hydroelectric energy helps in trapping sediments from flowing water, but they result in reduced water flow downstream, thereby affecting ecological functions and economic activities downstream. Lack of ecosystem approaches to development of hydro-power and water use, especially for irrigation and municipal supply, has serious consequences on the freshwater ecosystem and human well-being in Kenya. Concerted efforts should be made to monitor threats to the country's freshwater ecosystems and adopt ecosystem approaches to their management.

Water resource degradation was estimated to cost the country at least Ksh 3.3 billion annually (Mogaka et al., 2006). In spite of this, the government reduced spending for water resource management in Kenya from KES 4249 million in 1994 to KES 1765 million in 2001 (Mogaka et al., 2006), thus further reducing the capacity of the Ministry of Water and Irrigation to control negative anthropogenic activities in the water sector and to protect the water catchments.

Water resource assessments have deteriorated greatly in Kenya with debilitated and vandalized river gauging stations, making it impossible to carry out in-depth water resource analyses and planning. Water allocation has thus been made based on inadequate and in some cases no information on the flow patterns and quantities, leading to failure of development projects and also to frequent disruptions of water supply and rationing common in big cities such as Nairobi, Mombasa, Kisumu, Nakuru and Malindi.

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