Sediment dynamics and improvised control technologies in the Athi River drainage basin, Kenya

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Abstract In Kenya, the changing of land-use systems from the more traditional systems of the 1960s to the present mechanized status, contributes enormous amounts of sediments due to water inundations. The Athi River drains areas that are subject to intense agricultural, industrial, commercial and population settlement activities. These activities contribute immensely to the processes of soil erosion and sediment transport, a phenomenon more pronounced in the middle and lower reaches of the river where the soils are much more fragile and the river tributaries are seasonal in nature. Total Suspended Sediments (TSS) equivalent to sediment fluxes of 13 457, 131 089 and 2 057 487 t year^{-1} were recorded in the headwater areas, middle and lower reaches of the river, respectively. These varying trends in sediment transport and amount are mainly due to the chemical composition of the soil coupled with the land-soil conservation measures already in practice, and which started in the 1930s and reached their peak in the early 1980s. This paper examines trends in soil erosion and sediment transport dynamics progressively downstream. The land-use activities and soil conservation, control and management technologies, which focus on minimizing the impacts of overland flow, are examined to assess the economic and environmental sustainability of these areas, communal societal benefits and the country in general.

Key words land-use systems; soil erosion; sediment dynamics; improvised control technologies

INTRODUCTION

The change of land-use systems in Kenya from the more traditional systems used in the 1960s to the present mechanized systems contributes to increased sediments yields. This is due to the increasing susceptibility of the more fragile soils in the Arid and Semi-arid lands (ASALs) of Kenya to water inundation. The Athi River drainage basin drains diverse land-use systems ranging from intensive agriculture, industrial and commercial, to population settlement activities. The use of land by these activities contributes immensely to the processes of soil erosion and sediment fluxes to rivers. This phenomenon is more pronounced in the middle and lower reaches of the river where the soils are more fragile and most of the river tributaries are seasonal in nature. In addition, the land-use systems (mainly subsistence agriculture and livestock keeping) do not allow the soils to recuperate and only limited soil-conservation measures are in place.

The basin's climatic conditions make it more prone to land degradation with far reaching implications on the sediment fluxes and loads in the lower parts (mouth of the river). The soil types play a significant role in the generation of increased sediment loads in the river system. The upper parts (headwater areas) exhibit low soil erosion and sediment levels, while the middle and lower areas indicate increasing trends in sediment fluxes and amounts due to the chemical composition of the soils coupled with the land and soil conservation and control strategies in use.

This paper presents findings from two research projects carried out in the basin between 1990 and 2003, and details the trends in sediment fluxes and loads progressively down the river. General soil erosion trends indicate the sediment dynamics over the years. Land-use activities and soil conservation and control strategies which focus on minimizing the impacts of overland flow and conveyance are examined in order to reduce the increase in sediment deposition at the mouth of the river and minimize water pollution levels. This will effectively reduce the danger of polluting the coastline near Malindi town and so protect the marine life and has communal benefits.

STUDY AREA

The focal point of the investigation was the main Athi River and its various tributaries from the headwater areas downstream to the river outlet near Malindi town. The major perennial stream in

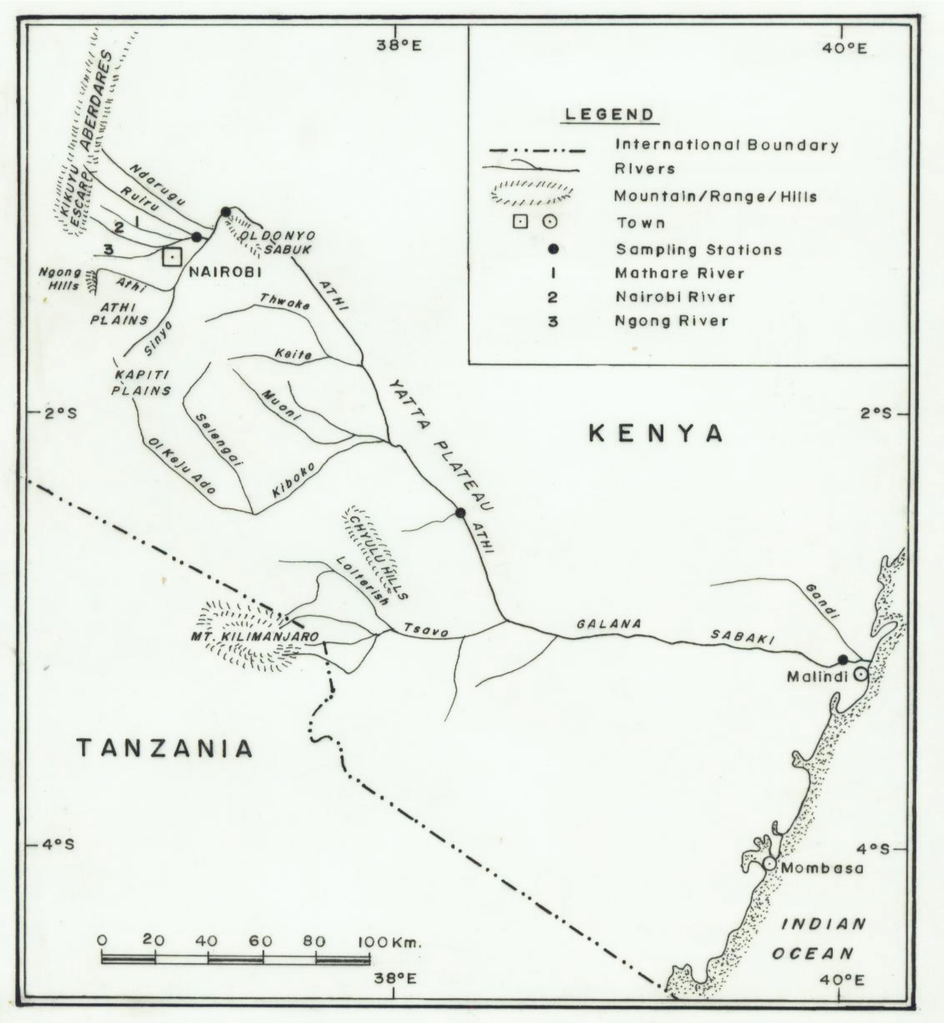

Fig. 1 Athi River drainage basin and tributaries.

the headwater area are the Mbagathi, Isinya (stony Athi), Nairobi, Ngong, Mathare, Gitathuru, Riara and Ruiru streams; in the middle areas: the various seasonal rivers of the Machakos and Makueni districts including Thwake, Kiboko and Muooni; and in the lower areas: the Tsavo and the main Athi (Galana-Sabaki) as indicated in Fig. 1.

HYDROLOGICAL CHARACTERISTICS

The rivers in the basin drain in a south-easterly direction from the flanks of the Great Rift Valley, the Aberdare ranges and the Ngong hills. The major river is the Athi River with Mbagathi, Nairobi, Ngong, Mathare, Gitathuru, Riara and Ruiru streams in the upper catchment areas, while the Thwake, Kiboko, Muooni, Kibwezi and Tsavo streams drain the middle areas with several other seasonal rivers. The lower reaches are drained by the main Athi River (Galana-Sabaki) passing through a sparsely populated areas and entering the Indian Ocean as the Sabaki River to the north of Malindi town.

The hydrological characteristics of these rivers differ in the volume of streamflow and seasonal changes in sediment fluxes. This is mainly affected by the changing rainfall and land-use patterns over the study area. The upper catchments receive reasonable annual amounts of rainfall (1200 mm), middle reaches (arid and semi-arid areas) 500–700 mm and in some parts less than 500 mm, while the lower areas receive 900–1000 mm rainfall, depending on the altitude and land–

ocean effects (Kenya Meteorological Department, KMD, 1997). This strongly correlates with the sediment dynamics (fluxes) in the basin, country and the region in general.

LAND-USE ACTIVITIES

The Athi River drainage basin is characterized by diverse land-use activities, ranging from intensive agricultural practices, industrial, commercial and settlement patterns in the upper areas to livestock and wildlife grazing in the middle and lower parts of the catchment (Kithiia, 1992, 2007a,b). These land-use activities contribute significantly to soil erosion and sediment transport with the rates of erosion surpassing the recommended values of 10 million t year^{-1} (Ongwenyi, 1985). The climatic conditions of the basin make it more prone to land degradation. Climate changes from the tropical rain forest conditions in the headwater areas to the more fragile arid and semi-arid conditions that characterize the middle and lower parts of the basin. However, there is a major contrast in the soil types over the catchment area making the rates of soil erosion and sediment transport fluxes vary significantly in the investigated parts of the basin (Kithiia, 1997). Indeed, it is the middle and lower reaches of the basin that appear to contribute significant sediment load fluxes into the river during the rain season. The high amounts of sediments are attributed to the flash floods that inundate vast areas of the basin, coupled with less soil erosion control and conservation technologies in place.

METHODS

This paper outlines results of two research projects carried within the basin in the years 1989–1992 and 1997–2006 (Kithiia, 1992, 2006). In these two investigations, the basic method of evaluating sediment load fluxes involved water sampling at various sampling points along the river profile, from the upper catchment areas through the middle and lower parts to the mouth (outlet) of the river at Sabaki Bridge. Other relevant studies are cited to indicate the magnitude of soil erosion within Kenya and the African continent as whole. Some of the sampling points are indicated in Fig. 1. The water samples were analysed using standard methods according to the American Public Health Association (APHA) and the US Water Quality Determination standards (APHA, 1995, 2001) and WHO guidelines (WHO, 1995).

RESULTS AND DISCUSSION

Sediment sources

These studies revealed that most of the sediment load fluxes emanate from the diverse land-use activities within the basin. The most significant land-use activities included; agriculture, settlements, quarrying and construction works in the upper catchment areas (Kithiia, 2006). In the middle and lower reaches, sand harvesting, agricultural and grazing activities dominate as the major sources of sediments. In addition, the many seasonal rivers, coupled with limited soil and water conservation and control measures in these areas, contribute enormous surface and river bank erosive power during the rains and are a source of increasing sediment load fluxes along the river profile to the mouth.

The increasing trend in sediment load fluxes in the lower reaches of the Athi River (Machakos and Makueni districts) is attributable to a high soil erodability due to poor soil structure, which together with the low vegetation cover at the beginning of the rain season, and the high intensity of torrential rainfall, lead to increasing susceptibility to land degradation (Tiffen *et al*., 1984). These two districts falls into category 50–85% in terms of the extent of aridity and represents about 10% of the total Arid and Semi-arid (ASAl) area in Kenya (MRDAWS, 1992). At the river mouth, high amounts of deposited sediment are attributable to the cumulative effects of the sediment fluxes from the middle and headwater areas, in addition to the oceanic current and tidal effects. Tables 1 and 2 indicate the increasing trends in sediment load along the river profile. Other sources of

Table 1 Measured suspended sediment along the Athi River Profile (1992–2002).

Tributary	River profile area	Suspended sediment, TSS (mg L^{-1})	TSS (t $year^{-1}$)
Ngong Nairobi Mathare	Headwater areas	1 019	13 457
Athi (Thwake, Kiboko, Muooni, etc Athi (Tsavo)	Middle areas	1 456	131 089
Athi-Galana-Sabaki	Lower/outlet-mouth	6 078	2 057 487

Source: Kithiia (1992, 2006)

Table 2 Suspended load, and its volume, of selected streams in the Athi River drainage basin.

Stream	Designation area	Catchment area (km^{-2})	Mean annual discharge (m^3 s^{-1})	Suspended load (flux) (t $year^{-1}$)
Mbagathi	Upstream/Headwater areas	272	1.6	4 456
Nairobi		75	1.3	2 231
Riara		41	0.4	1 474
Ndarugu		312	4.4	29 356
Athi (Thwake confluence)	Middle areas	5 724	23.6	131 089
Athi (Tsavo)		10 272	33.6	753 627
Athi-Sabaki	Lower areas/Mouth/Malindi	25 203	33.2	2 057 487

Source: Adapted from Kithiia (2006) p. 87.

sediment include rural roads, paths, livestock tracts and other human settlement features including grazing areas (Wain, 1983; Ongwenyi, 1985). Most streams and rivers in the southern part are ephemeral, except for those which derive their flow from underground sources, such as the Kibwezi and Kambu rivers. In addition, the growing demand for sand for building construction has led to a rate of extraction which exceeds the renewal in stretches of certain or most of the seasonal rivers. This has, in some places, resulted in a decrease in water stored in the dry river beds and an increase in river bank erosion, due to a lowering of the level where runoff joins the river, and to trucks creating tracks that have led to the formation of gullies (Mburu, 1990). Rivers from the Basement land surface receive the biggest proportion of flow from surface runoff; most of the water courses are choked with sand and water can be found in the dry season by digging below the surface. Africa as a continent experienced high rates of soil erosion during the episodes of devastating drought in the 1970s and 1980s which resulted in high sediment loads in the rivers as observed by Wain, 1983.

Impact of sediments on water quality and marine life

Increasing trends in sediment fluxes and loads within and along the Athi River basin implies a decreasing water quality status of the river waters. The river water has been found to degrade in quality over the study periods and this trend appears to be increasing (Kithiia, 1992, 2006). Degraded water quality in turn affects the various uses of the water ranging from domestic, agricultural, livestock watering, and aesthetic enjoyment of the water for recreational purposes. This same finding has been found to occur in most African countries as a result of environmental degradation trends (Ongwenyi *et al*., 1993; Tiffen *et al*. 1994).

In addition, the heavy deposition of silt at the harbour sites along the coastal belt may have a great economic effect on the country. The present sediment load of the Sabaki River (Athi), which is being deposited in Malindi, has had a marked effect not only on the development of Malindi as a tourist resort, but also on the development and utilization of the Sabaki River water for municipal and public water supply in parts of the coast province, and especially Mombasa town. The deposited sand has thus far formed the Mambrui Sands to the north of Malindi town, which are part of the tourist attraction sites near the town. The increasing sediment loads in the river water and subsequent deposition along the coastal belt has also affected the transparency of the seawater and as a result the proliferation of the marine life near Malindi town. This affects the breeding grounds of fish and other marine organisms. Reduced numbers of fish species and fish quantities have been reported caught by local fishermen, although the sediment load may provide much needed nutrients to the marine organisms.

The continued deposition of silt in the seawater and on sand beaches has affected both the water quality by increasing the turbidity and colour of the water, and hence polluting the sand beaches near Malindi. The deposition rate is currently over 2×10^6 t year^{-1}, as indicated in Table 1. This has affected the tourist industry near Malindi town negatively and effectively reduced the economic stability of the local communities and societal benefits in general.

IMPROVISED CONTROL TECHNOLOGIES

The increasing quantities of total suspended sediments (TSS) conveyed along the Athi River have decreased water quality and increased the colour and the turbidity of the water. This has affected marine life along the coastal belt both positively and negatively. The deposited silt may be rich in nitrates and phosphates which are necessary for the well-being of some aquatic organisms, while the TSS may reduce or impair water transparency and water light penetration, thereby reducing the photosynthetic activity of some aquatic organisms fed on by the marine organisms. Interestingly, this basin is a major source of clean sand for the construction industry in the major towns within the basin, especially Nairobi city and Mombasa town.

Along the river course, public water supply has also been affected by the increasing cost of water treatment, as well as affecting the fertility of the top soil for agricultural purposes. Harvesting of sand from the river beds has affected the capacity yields of groundwater aquifers in the investigated areas. The following are some of the recommended improvised control strategies for addressing the problem of sediment transport and deposition, and consequently water quality degradation:

1. In the headwater and middle reaches, construction of benches on the steep slopes would effectively reduce soil detachment and velocity of runoff. This will increase rates of infiltration and could reduce sediment loads in the river water.
2. Well designed, constructed, and maintained terraces can be used to control runoff and soil losses, and thereby reduce the amounts of sediments conveyed by the river water.
3. Increasing community participation in soil and water conservation activities along the river course should include practice of better agricultural techniques for both livestock keeping and crop cultivation. The emphasis should focus on the crops that require minimal amounts of water and mature within a short period of time. This will slow rates of soil fertility reduction and erodability.
4. Encouraging people to avoid cutting down trees but rather plant more trees can help to reduce soil erosion and sediment load generation. Population settlements should also be well planned to discourage people from settling on steeper slopes that tend to increase the rates of sediment delivery and runoff.
5. There is a need to address the issue of sand harvesting within the Athi River basin, which presently is the main supplier of sand for construction and building activities in the city of Nairobi and other major towns within the basin. Sand harvesting increases the probability of soil detachment and sediment generation and if stopped or controlled, the result would be a drastic reduction in sediment fluxes into the river and the associated consequences. A suitable approach needs be employed in managing sand harvesting activities.

6. Sediment traps and ponds should be constructed in well designated areas along the river course, basically to trap the flow and allow the deposition of sediments as the river flows downstream. These can be constructed in the middle reaches of the river where the river velocity is moderate and the slope is generally gentle.
7. All these measures will help in reducing the sediment loads in the water and, by extension, reduce water quality degradation along the river course and at the mouth. This will allow the ocean currents to wash out (ebb effect) the deposited sediments and restore the clean sand beaches near Malindi town as well as the tourism industry. This is likely to accrue more societal benefits through the tourist industry by creating more employment opportunities.
8. Practicing of the Best Water and Soil management Practices (BMPs) within the catchment will also be necessary, including the protection of water catchment areas through afforest-ation, revegetation, natural regeneration and legal measures.

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