Sediment Dynamics and the Hydromorphology of Fluvial Systems (Proceedings of a symposium held in Dundee, UK, July 2006). IAHS Publ. 306, 2006.

Impacts of land-use changes on sediment yields and water quality within the Nairobi River sub-basins, Kenya

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Abstract Effects of land-use changes on sediment yields and water quality within the sub-basins of the Nairobi River were examined. The approach used assessed spatial variations in river runoff, sediment yields and water quality and involved collection of both water and sediment samples along the river courses. Most attention was given to suspended sediments within the Ngong, Nairobi and Mathare River sub-basins. The results indicated strong seasonal trends for both suspended sediment flux and water quality status. Suspended sediments loads for the Ngong River were 1733 t km^{-2} year^{-1}, Nairobi River 6317 t km^{-2} year^{-1}, and Mathare River to the tune of 2987 t km^{-2} year^{-1}. Close relationships were found between total dissolved solids (TDS), conductivity, turbidity and colour. Generally, pollution levels varied with season and declined with distance downstream of Nairobi due to dilution effects and self-purification of the river waters during the wet season. Strategies to control increasing sediment yields and hence water quality degradation are suggested with a focus given to the Best Management Practices (BMPs) within the watershed and the country in general.

Key words land-use activities; sediment yields; water quality status; water pollution and quality controls

INTRODUCTION

This study is a culmination of a three-year study focusing on three major tributaries of the Nairobi River namely: the Ngong, Nairobi and Mathare rivers. These streams contribute the headwaters of the Athi River and drain through the city of Nairobi. In addition, the streams drain areas of diverse land-use activity, ranging from agricultural in the upper catchments to residential and various business and industrial land uses within the city boundary. The significance of these various land-use activities for pollutants, sediment yields, pollution and water quality degradation is significant and requires study.

Water and sediment samples were collected from multiple locations during the study period on a monthly basis and analysed to reveal the sediment concentration levels as well as water quality parameters. River discharge was also measured throughout the study period. The rating relations thus established enabled an assessment of the sediment fluxes in each of the three sub-basins and evaluation of water quality trends. This is an integral part of understanding the problems associated with urban land development around Kenya’s capital.

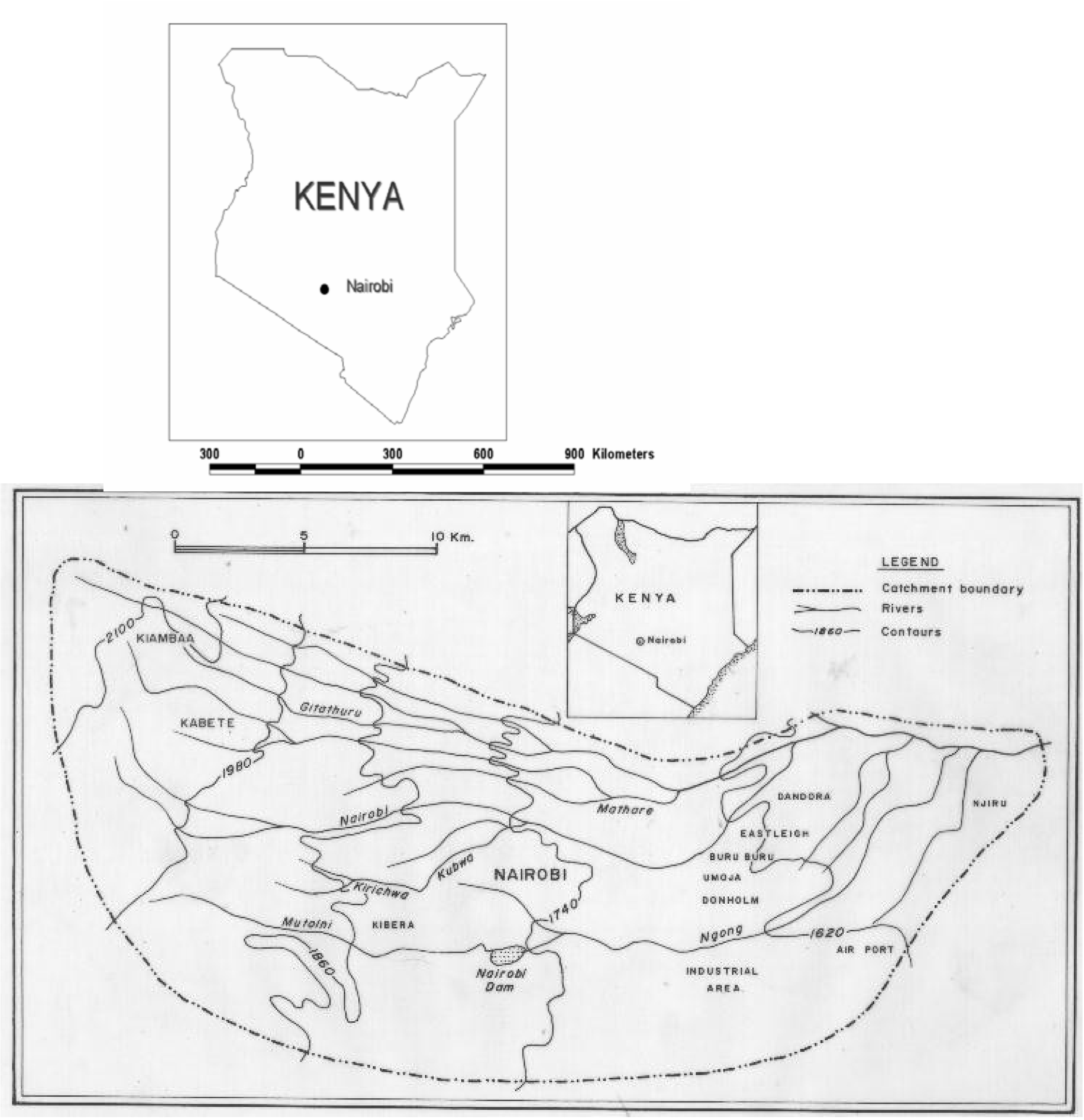

Fig. 1 Location of the study catchments.

STUDY AREA CHARACTERISTICS

The study area is part of the Upper-Athi River drainage basin drained by the Rivers Ngong, Nairobi and Mathare as indicated in Fig. 1. The area is enclosed by latitudes 0°45′S and 1°38′S and longitudes 36°15′E and 37°15′E. Generally, the area slopes in a south-easterly direction with isolated hills as features of the landscape. Elevations range from over 2400 m at the Kikuyu escarpment to 1400 m at Ol-Donyo Sabuk.

Geological characteristics

The geology of the study area comprises mainly Tertiary trachytic lavas, including the Plio-Pleistocene trachytes of the Kikuyu escarpment and the late Miocene phololite of the Kapiti plains. The city of Nairobi and its environs are covered by middle and lower Kerichwa valley tuffs, the Nairobi phonolites and Athi tuffs (Kithiia, 1992). The underlying rocks are Tertiary and younger sediments, volcanic lavas, tuffs and the Basement Complex. Generally, the hydrogeology of the study area is controlled by the nature of the various volcanic lava flows and the configuration of the old land surface of the basement system (Kithiia, 1997).

The area is good for groundwater resources and in fact has a high groundwater potential (MOWD, 1992). The geology of the study area plays a significant role in determining water quality as well as sediment yields. Studies by Kithiia (1992, 1998) and MOWD (1997) found that the upper areas exhibit high concentrations of manganese and calcium ions while in the south high fluoride levels were detected surpassing the recommended WHO value of 1.5 ppm. The present study found a value of 2.0 ppm of fluoride in water samples as indicated in Table 1. This was attributed to both the geology of the area and industrial activities which are more concentrated along the Ngong River sub-basin, implying declining water quality trends.

Table 1 Mean concentration of selected water quality parameters compared to WHO values and Kenya guideline standards (mg L^{-1}).

River	Mg	Ca	F	Na	Cl
Nairobi	7.1	18.6	2.0	48.8	52.9
Mathare	8.2	18.5	0.6	42.7	39.4
Ngong	8.2	25.8	2.3	64.0	49.1
WHO (1995)	0.1	200	1.5	200	250
Kenya Standards (1985)	0.1	200	1.5	200	250

Hydrological characteristics

The hydrological characteristic of the area correlates closely with the rainfall pattern experienced in the basin. The region experiences a bi-modal pattern of rainfall with rain peaks in the months of March–May and October–December. Generally, the northern and western areas (high altitude or highlands) receive high amounts of rainfall of between 1000–2000 mm $year^{-1}$, while the east and southern areas receive lower amounts of 500–1000 mm $year^{-1}$. This in turn affects the streamflow, runoff, sediment yield and pollutant wash off characteristics in the study area.

Population characteristics

The area is densely populated with a population density of 3079 persons km^{-2}, which is six times higher than the national average according to the 1999 population census. The study area's population characteristics are generalized by the population dynamics in the Nairobi metropolitan area and the surrounding districts of Kiambu, Machakos and Kajiado as indicated in Table 2. The population growth is about 5.5% $year^{-1}$ which is due to a number of factors, including the fact that Nairobi city is the administrative and commercial centre of the country and the Eastern Africa region. The growth in population increases the pressure on the city's infrastructure for provision of water and sanitation.

Table 2 Population dynamics of Nairobi, Kiambu, Machakos and Kajiado (Republic of Kenya, 1999).

Area	Population	Density (people km^{-2})	Land area (km^2)	Annual growth (%)
Nairobi	2 143 254	3079	719	5.0
Kiambu	744 010	562	2 549	3.2
Machakos	906 644	144	14 209	3.3
Kajiado	406 054	19	21 960	5.6

The city boundaries, last reviewed in 1963, extend over an area of 689 km^2, which has increased from 76 km^2 in 1927. These boundaries have remained ever since with expansions only focusing on the functions and activities within the urban centre (Kithiia, 1998). The consequence of this is increased water demands, waste generation and higher turbidity associated with reduced water quality in the rivers. The collection of garbage and supply of treated water has been declining in the recent past, with most of the solid waste dumped directly into the Nairobi River at various points along the river course or left uncollected in some parts of the city. This has resulted in water quality deterioration mainly downstream of the city's central business district (CBD) (Kithiia, 1992; Okoth & Otieno, 2001; Mavuti, 2003).

Land-use characteristics

Land-use patterns are highly influenced by topography within the city, most notably industrial and commercial activities (Krhoda, 1992; Kithiia, 1997). Other land-use activities of significant importance are the informal settlements (slums) located along the river courses and banks. These contribute significant amounts of sediment and human waste to the rivers due to the lack of sanitation facilities. In addition, the ever increasing population density in the city has added pressure on the existing sewage and drainage system thus occasioning frequent sewer bursts. This results in increasing BOD_5 and COD values in the waters of the streams investigated.

The three sub-basins investigated have distinct land-use systems and exhibit distinctive water quality characteristics in terms of pollutant levels and sources. These affect adversely the amounts of sediment yields and quality of water resources, especially the processes of urbanization and industrialization.

STUDY METHODS AND DATA

Water samples were obtained once in a month using standard methods according to APHA (2001). The water samples were obtained from ten sampling points distributed in accordance with the level of importance in terms of land-use activities within the streams investigated. The Nairobi River had six sampling points in total; the Ngong and Mathare rivers had two each. In total 100 samples were collected within the period of study and for each 15 water quality parameters analysed.

Water samples for water quality determination were collected at the designated sampling points in a depth integrated manner at the middle, left and right bank of the river. The parameters determined included: BOD_5, COD, TSS, pH, TDS, total alkalinity, conductivity, Ca, Mg, Na, K, Cl, F, hardness and turbidity. The heavy metals analysed were Cu, Zn, Pb, Al, Mn, Cd, Ni and Cr. The results of the analysis represent filtrate (dissolved) metals. Quantification of the metals was based upon calibration curves of standard solutions of the metals with a set limit of 0.001 mg L^{-1}.

RESULTS AND DISCUSSIONS

The results of some of the water quality parameters along the river course are presented in Table 3. The results indicated a general trend for suspended sediment concentration to increase with increased discharge. Away from the urban centre streams were less physically and chemically polluted due to downstream dilution. The Ngong River exhibited high concentrations of toxic substances at the Embakasi sampling station which is downstream of the industrial activities in the city. This was followed by Nairobi River at the outer-ring road, the point immediately below the effects of urban activities in the city centre and the Gikomba open air market.

The mass loadings value of the various water quality parameters measured in t day^{-1} and t $year^{-1}$ gives a clear picture of declining water quality with increased discharge as indicated in Tables 4 and 5 for the Ngong and Nairobi rivers, respectively. Thus, water that appears clean or less polluted may be highly polluted if evaluated in terms of mass loadings. If the same water is therefore used over a long period of time, it may cause serious health problems due to the effects of biological magnification in the food chain web. This was found to be quite significant in plant tissues sampled along the river courses. Other human activities were found to contribute significant amounts of water pollutants in addition to industrial, commercial and residential land use types. The motor garages, petrol filling stations and car washing sites are point sources for oil films found floating on the water surface in virtually all sub-streams, while “*Kiosks*” are notoriously known for dumping of food solid wastes into the rivers.

MITIGATION MEASURES

Industrial activities were found to be major sources of heavy metals and therefore legal measures should be taken on those industries discharging harmful waste effluents to

Table 3 Mean measured values of physical water quality parameters at various sampling points.

Sample station	River system	Q ($m^3 s^{-1}$)	TSS (mg L^{-1})	COND (µs cm^{-1})	TDS (mg L^{-1})	TUR (mg L^{-1})
Muthangari	Nairobi	0.772	157.6	392.1	239.7	69.4
Museum	Nairobi	1.376	129.4	397.7	244.2	69.3
Outering Rd	Nairobi	2.140	255.7	564.5	290.9	65.5
Njiru 1	Nairobi	5.083	199.2	509.5	310.9	67.8
Njiru 2 (10)	Nairobi	5.341	95.5	474.8	298.8	28.5
Thika Rd	Mathare	0.738	161	352.2	215.5	35
Outering Rd	Mathare	1.371	251.2	527.1	349.9	85
Kibera slums	Ngong	0.110	164	233	88	126
Langata Rd	Ngong	0.305	59	598.8	59	42
Embakasi	Ngong	0.949	180	611.7	174.4	71

Table 4 Mean mass loadings of selected water quality parameters for Ngong River at Langata and Embakasi sampling points.

Water quality variables	Unit	Mass loadings (t day^{-1} and t $year^{-1}$): Langata Q = 0.315 $m^3 s^{-1}$ Mean	Mass loads (t day^{-1})	(t $year^{-1}$)	Embakasi Q = 0.953 $m^3 s^{-1}$ Mean	Mass loads (t day^{-1})	(t $year^{-1}$)
BOD_5	mg L^{-1}	17.9	0.2	56.8	59.5	1.6	571.1
COD	mg L^{-1}	88.4	0.8	280.7	266.2	7.1	2556.1
TSS	mg L^{-1}	59.2	0.5	188.0	180.5	4.8	1733.2
COND	µs cm^{-1}	610.3	5.4	1937.3	605.9	16.2	5819.3
Mg	mg L^{-1}	8.6	0.1	27.3	7.8	0.2	75.2
Na	mg L^{-1}	58.5	0.3	185.7	69.5	1.9	667.1
K	mg L^{-1}	25.3	0.2	80.4	15.6	0.4	149.4
Cl	mg L^{-1}	52.3	0.5	166.1	46.3	1.2	444.8
F	mg L^{-1}	0.8	0.01	2.6	1.1	0.03	10.9
TDS	mg L^{-1}	370.7	3.3	1176.9	375.4	10.0	3605.2
Turb	NTU	41.8	0.4	132.7	71.4	1.9	685.5

Table 5 Mean mass loadings of selected water quality parameters for Nairobi River at Museum, Outering road and Njiru 1 sampling points.

Water quality variable	Unit	Mass loadings in (t day^{-1} and t $year^{-1}$): Museum Q = 1.38 $m^3 s^{-1}$ Mean	Mass loads (t day^{-1})	(t $year^{-1}$)	Outering Q = 2.10 $m^3 s^{-1}$ Mean	Mass loads (t day^{-1})	(t $year^{-1}$)	Njiru 1 Q = 5.08 $m^3 s^{-1}$ Mean	Mass loads (t day^{-1})	(t $year^{-1}$)
BOD_5	mg L^{-1}	6.9	0.3	96.2	143.3	8.4	3031.6	82.8	11.8	4237.9
COD	mg L^{-1}	55.4	2.1	770.0	301.3	17.7	6376.5	253.1	36.0	12957.9
TSS	mg L^{-1}	115.9	4.5	1611.2	298.5	17.5	6317.2	244.6	34.8	12520.2
COND	µs cm^{-1}	388.5	15.0	5402.4	558.2	32.8	11813.3	459.0	65.3	23498.4
Mg	mg L^{-1}	6.4	0.3	89.3	8.4	0.5	177.1	7.2	1.0	367.6
Na	mg L^{-1}	44.7	1.7	621.5	59.0	3.5	1248.6	46.6	6.6	2383.6
K	mg L^{-1}	9.2	0.4	127.7	16.7	1.0	353.4	14.2	2.0	729.0
Cl	mg L^{-1}	55.5	2.1	771.3	47.0	2.8	994.7	39.6	5.6	2025.3
F	mg L^{-1}	1.0	0.04	14.3	0.8	0.1	16.9	0.6	0.1	29.2
TDS	mg L^{-1}	237.7	9.2	3305.6	337.5	19.8	7142.6	282.3	40.2	14453.8
Turb	NTU	69.3	2.7	963.9	65.5	3.9	1386.2	67.8	9.6	3470.0

the rivers. Each industrial discharge outlet should be installed with an automatic water quality recorder/detector to ensure that no illegal wastes are discharged into the rivers at night. Random and impromptu water samples should be taken at these outlets at night when most of the industries discharge waste effluents into the rivers.

In the informal settlements (slums) adequate sanitation facilities should be provided to reduce direct discharge of human wastes into the river courses. A buffer zone should be set aside between the river banks and human land-use activities to avoid any tendency for dumping of any waste into the rivers. The best management practices (BMPs) should be encouraged in order to control the increasing trends in sediment yields and water quality degradation. These should involve construction of retention ponds to trap the sediments, practice of soil conservation measures in the upper catchment areas and use of artificial water falls or rapids to increase water aeration and the rate of biological oxidation to reduce water quality deterioration trends. Community participation should be encouraged in garbage collection and disposal where sorting of litter will be given priority. Overall, there is need for an integrated Environmental Education (EE) programme within the sub-basins investigated. The programme should focus on the need of the people living within Nairobi and its environs to promote a cleaner environment. It should support efforts of people to manage properly their domestic raw wastes and avoid dumping into the rivers.

Siva *et al.* (2001) noted that water purification using artificial wetlands and aquatic macrophytes is attracting attention as a river water purification technology that can create rich ecosystems while imposing minimal load on the environment. The root system of the riverine vegetation had the highest adsorbed values of heavy metals indicating their importance in cleaning up the river systems investigated.

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