An assessment of water quality changes within the Athi and Nairobi river basins during the last decade

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Abstract This paper examines the changes in water quality that have occurred within the Athi and Nairobi river basins in the last decade. The main focus is to examine the trends in water quality degradation, pollutant sources and pollution levels since the early 1990s to year 2000 and beyond. It draws its major findings from two research projects done within the basins over the same period. The two research projects revealed increasing trends in water quality degradation due to changes in land-use systems. Industrial, population (rural–urban migration) growth and agricultural activities were found to contribute significant amounts of water pollutants, thus degrading the water quality status in the two river basins investigated. This is of major concern to national water policy makers and environmentalists, as well as the Kenyan government in general. This paper reviews some of the possible mitigation strategies as means of mitigating against future water quality degradation trends and to abate the problem in good time. The use of riverine vegetation (macrophytes) and stormwater in the basins are recommended for reducing water quality degradation status in the two basins and other similar catchment areas in the country. Plant species *Commelina benglensius*, *Sphaeranthus napirae* and *Xanthium pungens* proved useful in adsorbing some of the pollutants, and especially heavy metals.

Key words trends; water quality degradation; pollution levels; pollutants; riverine vegetation; stormwater; mitigation strategies

INTRODUCTION

The Athi River drainage basin is the second largest drainage basin in Kenya after the Tana River. It drains the eastern flanks of the Rift Valley, the Aberdare ranges and the Ngong Hills and discharges into the Indian Ocean through vast semi-arid parts of Kenya. In the upper catchment areas (headwaters), the basin is drained by the Nairobi River sub-system comprising the tributaries of Ngong and Mathare rivers. The Athi River, with its major tributary of the Nairobi, drains two important urban centres in Kenya: Nairobi city in the upper catchment area and Malindi in the southern outlet, as indicated in Fig. 1. These rivers drain areas of diverse land-use activity including urban settlement, agricultural, industrial and commercial activities within the urban areas. These land-use activities contribute enormous amounts of pollutants ranging from pesticides, heavy metals and sediments to solid wastes, resulting in trends of decreasing water quality status in the two sub-basins.

Investigations into pollution levels, trends and water quality status of the river water have revealed that water quality degradation has reached alarming levels during dry seasons. This requires strategic measures to control and reduce pollution levels,

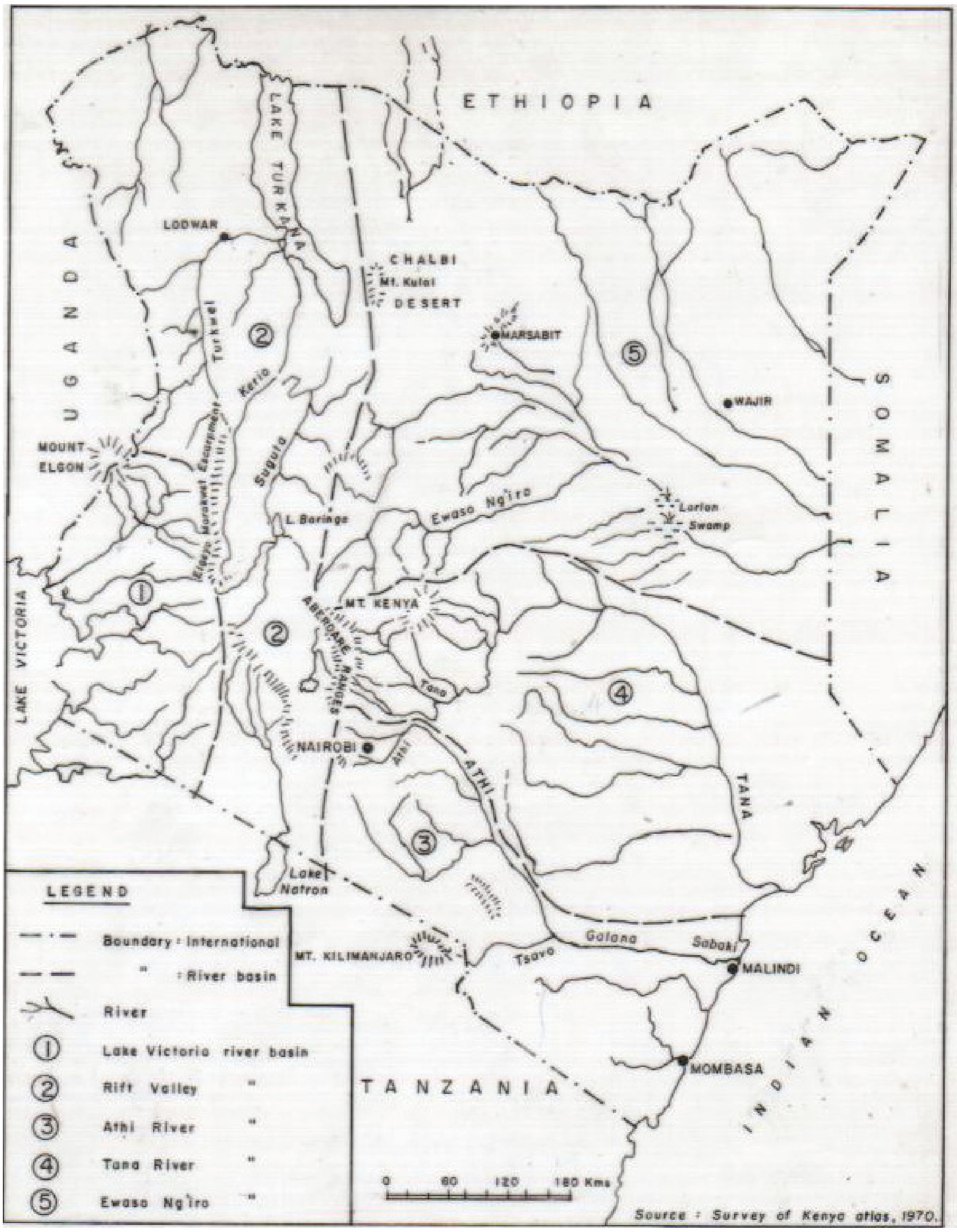

Fig. 1 Drainage basins in Kenya.

reverse trends in water quality degradation, and to restore the desired water quality standards and aesthetic enjoyment of the river water systems.

BACKGROUND INFORMATION

The problem of water quality degradation is not a new phenomenon in Kenya. Initial research reports on the problem in the country and within the study area date back to the 1950s. Such problems were also highlighted by a recent study undertaken by the

Ministry of Land Reclamation and Regional Development (MLRRD, 1997 (now the Ministry of Water and Irrigation) covering the same area and the entire Athi River drainage basin. This indicated that groundwater resources are not seriously threatened with water pollution problem but the major concern has been over the surface waters especially in river systems.

In Kenya, the problem of water quality degradation was first exposed by the MOWD (1976a,b) in case studies of the Nzoia, the Nyando and Kerio rivers. These reports document the chemical characteristics of water shortly before and after establishment of factories along their courses. The Nzoia River, which drains into Lake Victoria, carries the effluents discharged from the Pan Africa Paper Mill in Webuye, upstream, and from the Mumias Sugar Factory, downstream. The Nyando, which also discharges its waters into Lake Victoria, receives molasses from sugar factories, at Chemilil and Muhoroni. The Kerio River drains the Kerio Valley with intermittent flow into Lake Turkana. This is now periodically polluted by effluents from a fluorspar factory established three decades ago. It is clear that the effects of industrial growth and their effluents have been a major contributing factor to water quality degradation in the vicinity of industrial activities. Nairobi City, which is the capital and the industrial and commercial centre of Kenya and the East African region, contributes significant amounts of pollutants to the Nairobi River, its tributaries and the main Athi River.

Other research reports which indicate water quality deterioration in Kenya and the study basins are those by Njunguna (1978) and Ongwenyi (1979). Njunguna (1978) also noted that pollution in the river (Nairobi-Athi-Sabaki) was chiefly due to domestic waste, industrial wastes and runoff (both rural and urban). A study by Kinyua & Pacini (1991) of the Nairobi-Athi river system showed an increase in the levels of heavy metals as a result of industrial effluents. Wandiga (1996) reported the same results within the study area.

The most recent studies by Kithiia (1992, 2006a,b), Aketch & Olago (2000) and Mavuti (2003) revealed trends of degradation in water quality within the river system due to changes and in the type and intensity of land-use activities. The study by Kithiia (1992) in the same area revealed high concentration levels of mercury and lead surpassing the critical WHO and the Kenya standards guideline values of 0.03 and 0.1 mg L^{-1} for mercury and lead, respectively. In the same study, pesticide residues of notably DDT, "*Ambush*", "*Ridomil*", and "*Malathion*" were all found to surpass the WHO and Kenya standards for drinking water. DDT was measured at 0.000086 mg L^{-1}, Ambush at 0.1413 mg L^{-1}, Ridomil at 0.147 mg L^{-1} and Malathion at 0.00039 mg L^{-1}. In addition, the study by Kithiia (2006a,b) within the same river systems indicated a downstream increase in water pollutants and water quality degradation. Sediment and heavy metal concentrations were found to increase downstream in the river courses. The trends of increasing pollution levels and water quality deterioration are attributed to increased land-use activities and population growth rates within the urban area and the basins in general. This calls for stringent measures to address the problem.

STUDY METHODS

The study methods employed in the investigations involved collection of water samples along the river courses at designated sampling points in addition to measurements of river discharge at the same points to determine pollutant concentrations and loads. River sediments and riverine vegetation were sampled to investigate the levels of heavy metal adsorption as well as the uptake by the water macrophytes as means of reducing and cleaning up the river systems. Samples were collected at downstream points of major land-use activities, as indicated in Fig. 1.

The water, sediment and riverine vegetation samples were transported to the main laboratory for analysis and quantification. The study of 1990–1992 focused on heavy metals and pesticide residues while that of 1998–2003 had an emphasis on heavy metal concentrations and strategies to control and reduce the trend towards water quality degradation.

RESULTS AND DISCUSSION

The results from analysing water, sediment and plant samples suggest increasing pollution relating to both heavy metals and pesticide residues (Tables 1 and 2). Table 1 clearly indicates increasing water quality degradation over the study periods. Some heavy metals with serious health implications were undetected in 1990–1992 but were recorded in 1998–2003. This was attributed to heavy manufacturing industries established after the first study period.

Table 1 Variability of toxic substances (parameters) at different sampling stations and rivers (mg L^{-1}).

Parameter	Mean concentration per river station 1990–1992:			1998–2003:			
	Nairobi at Museum	Nairobi at Njiru 1	Ngong at Embakasi	Nairobi at Museum	Ngong at Embakasi	Nairobi at Njiru 1	Nairobi at Njiru 2
Iron	0.73	0.8	1.84	1.99	1.3	1.44	0.60
Manganese	0.4	1.0	1.60	8.4	7.8	7.2	4.4
Sodium	ND	0.1	0.1	59	69.5	46.6	42.5
Magnesium	ND	0.02	0.03	8.4	7.8	7.2	4.4
Chloride	2.4	3.2	1.2	47	46.3	39.5	29
Mercury	ND	ND	0.03	<0.01	0.01	<0.01	<0.01
Copper	0.01	0.01	0.1	0.04	0.15	0.18	0.02
Lead	ND	ND	0.10	0.05	0.07	0.04	0.03
Zinc	ND	ND	0.10	0.01	0.02	0.02	0.02
Fluoride	0.1	0.1	1.8	0.8	2.0	0.6	1.17
TSS	43.78	167.68	172	115.85	180.46	244.56	503.1
Turbidity	41.80	53.26	49	69.31	71.38	67.78	133.28

Source: Field data (1992 and 2006). ND = not detected.

Table 2 Pesticide residues in water compared to WHO and Kenya standards guideline values (mg L^{-1}) for samples from Gitathuru, Riara, Kamiti and Gatara river sub-systems.

Pesticide	Measured value	WHO guideline value (1984, 1995)	Kenya standards limit (1985)
DDT	0.000086	1.0	1.0
"Ambush"	0.1413	-	-
"Malathion:	0.00039	-	-
"Ridomil"	0.147	-	-

Source: Field data 1990–1992, WHO (1993) and GOK (1985), Std # KS-05-459.

Table 3 Mass loadings of the major industrial pollutants for Ngong River at Embakasi sampling point.

Parameters	1990–1992 ($t\ d^{-1}$)	($t\ year^{-1}$)	1998–2003 ($t\ d^{-1}$)	($t\ year^{-1}$)
Lead	0.064	23.337	0.78	117.69
Zinc	0.064	23.337	0.85	120.76
Copper	0.064	23.337	0.94	131.63
Mercury	0.019	7.001	0.15	10.15
Aluminium	1.343	490.069	7.62	756.35
Manganese	0.831	303.376	5.73	516.88
Iron	1.918	700.099	9.60	1500.50
Total suspended sediments	56.80	17448.58	110.70	41138.90

Source: Field data 1990–1992 and 1998–2003.

Table 4 Mean mass loadings of selected water quality parameters for Nairobi River at Museum, Outering road and Njiru 1 sampling points.

Water quality variable	Mass Loadings in $t\ d^{-1}$ and $t\ year^{-1}$ Museum $Q = 1.38\ m^3\ s^{-1}$ Mean	Mass loads $t\ d^{-1}$	$t\ year^{-1}$	Outering $Q = 2.10\ m^3\ s^{-1}$ Mean	Mass loads $t\ d^{-1}$	$t\ year^{-1}$	Njiru 1 $Q = 5.08\ m^3\ s^{-1}$ Mean	Mass loads $t\ d^{-1}$	$t\ year^{-1}$
BOD_5 ($mg\ L^{-1}$)	6.92	0.27	96.24	143.25	8.42	3031.62	82.78	11.77	4237.90
COD ($mg\ L^{-1}$)	55.37	2.14	770.04	301.30	17.71	6376.46	253.11	35.99	12957.9
TSS ($mg\ L^{-1}$)	115.85	4.48	1611.15	298.50	17.54	6317.20	244.56	34.78	12520.2
T.Alk ($mg\ L^{-1}$)	70.00	2.70	973.51	179.60	10.56	3800.90	163.78	23.29	8384.67
COND ($\mu\ cm^{-1}$)	388.46	15.0	5402.40	558.20	32.81	11813.3	459.00	65.27	23498.4
Ca ($mg\ L^{-1}$)	19.26	0.74	267.85	17.90	1.05	378.82	17.07	2.43	873.89
Mg ($mg\ L^{-1}$)	6.42	0.25	89.28	8.37	0.49	177.14	7.18	1.02	367.58
Na ($mg\ L^{-1}$)	44.69	1.73	621.51	59.00	3.47	1248.63	46.56	6.62	2383.63
K ($mg\ L^{-1}$)	9.18	0.35	127.67	16.70	0.98	353.42	14.24	2.03	729.01
Cl ($mg\ L^{-1}$)	55.46	2.14	771.29	47.00	2.76	994.67	39.56	5.63	2025.26
F ($mg\ L^{-1}$)	1.03	0.04	14.32	0.80	0.05	16.93	0.57	0.08	29.18
TDS ($mg\ L^{-1}$)	237.69	9.18	3305.61	337.50	19.84	7142.57	282.33	40.15	14453.8
Turb (NTU)	69.31	2.68	963.91	65.50	3.85	1386.19	67.78	9.64	3469.98

Source: Field data 1998–2003.

Tables 3 and 4 illustrate a downstream increase in the mass loadings and concentrations of the various water quality parameters along the river profiles. This correlates well with increasing river discharge downstream in the Nairobi River from Museum through Outer-ring road to Njiru 1 sampling points as reported by Kithiia (2006a,b). There is a concern that degradation of water quality both over time, and in the downstream direction, may lead to serious health problems.

Increasing river discharges during the wet season proved useful in reducing solid wastes along the river banks, and construction of ponds to trap sediments in storm waters or the use of treatment methods, such as flocculation, filtration and sedimentation, to remove particulate material carried at high discharges would benefit water quality. Furthermore, construction of artificial waterfalls along the river courses may prove useful in improving the oxygen content and aeration of the waters.

Kithiia & Ongwenyi (1997) recommended use of an Integrated Management Plan (IMP), involving the use of lagoons and discharge channels, to mitigate water quality degradation in the upper catchment areas of the Nairobi River, while. Kithiia (2006a,b) recommended the use of Integrated Water Resources Management (IWRM) with an emphasis on community participation and policy formulation.

Table 5 indicates that the plant species *Sphaeranthus napirae* had high concentration values of zinc metal and therefore can be quite useful in cleaning up the rivers. *Commelina benghalensis* and *Pennisetum purpureum* are sometimes used as fodder for livestock and could have some significant human health implications if the livestock meat is consumed by human beings due to a heavy metal biological magnification effect along the food chain.

Heavy metals and pesticide residues were detected in water and soil samples in the upper catchment. Suspended sediments varied with season and appeared river specific. The suspended solids load in the Ngong River at Embakasi was measured as 3.416×10^3 t year^{-1} during peak flows and as 2.68×10^2 t year^{-1} during low flows. Suspended solids loads for the Nairobi River at Museum were 1.627×10^3 and 4.18×10^2 t year^{-1} for peak and low flows respectively, while those for the Nairobi River at Dandora (Njiru 1) were 6.208 × 103 t year^{-1} during peak flows and 2.397 × 103 t year^{-1} during low flows.

Kithiia (1992) suggested sources of water pollution mainly comprised runoff from agricultural, industrial, urban and commercial areas. In addition, industrial activities contributed most of the heavy metals while agricultural activities provided the main sources of pesticide residues in water.

The measured concentrations of the various water pollutants were in excess of the critical values recommended by WHO (1993, 1995) and the Government of Kenya (1985). For example, mercury concentrations were 0.02–0.03 mg L^{-1}, so higher than the WHO (0.001 mg L^{-1}) and the Kenya standards guideline value (0.001 mg L^{-1}) for drinking water quality. This poses a potential risk to human health and all living organisms in general.

Table 5 Mean concentration values in selected plant species along Nairobi River (1: *Sphaeranthus napirae*, 2: *Commelina benghalensis*, 3: *Pennisetum purpureum*, 4. *Xanthium pungens*.

Sampling point	Plant Spp.	Measured heavy metal concentrations (mg L^{-1}) (ppm or μg g^{-1})					
		Pb	Cu	Zn	Cd	Cr	Ni
Muthangari	1	0.13	0.13	0.34	0.08	0.10	0.10
	2	0.10	0.14	0.31	0.08	0.10	0.11
	3	0.19	0.14	0.22	0.10	ND	0.12
	4	0.10	0.17	0.21	0.10	0.10	0.12
Museum	1	0.16	0.16	0.35	0.09	0.13	0.14
Outering RB	1	0.18	0.20	0.36	0.10	015	0.15
	2	0.10	0.19	0.32	0.10	0.16	0.13
	3	0.09	0.14	0.19	0.08	0.12	0.13
	4	0.10	0.18	0.28	0.11	0.11	0.18
Njiru 1	1	0.13	0.25	0.37	0.10	0.17	0.17
	2	0.13	0.32	0.34	0.11	0.18	0.14
	3	0.15	0.15	0.33	0.11	0.09	0.15
	4	0.16	0.20	0.32	0.14	0.12	0.23
Njiru 2	1	0.20	0.26	0.44	0.13	0.19	0.22
	2	0.16	0.37	0.34	0.13	0.18	0.21
	4	0.20	0.25	0.34	0.17	0.18	0.25

Source: Field data 1998–2003.

River sediments and riverine vegetation were found to contain significant amounts of heavy metal as reported by Kithiia (2006a,b). This was due to the high affinity to sediments in the transport of some heavy metals and deposition of metal-rich sediments at low flows. Certain species of macrophytes, *Sphaeranthus napirae*, *Commelina benghalensis* and *Xanthium pungens* were found to absorb more zinc, nickel, lead, cadmium and copper, implying that they can be used for river water quality cleaning purposes and environmental quality restoration.

The effect of dilution, and hence, water quality improvement, increases downstream and especially at Ol Donyo Sabuk and Malindi town (Sabaki outlet) about 156 km and 650 km below the city of Nairobi, respectively. In addition, there is an effect of self purification of the river due to aeration conditions, settling, deposition of sediments and additional inflows into the main rivers from other tributaries with less polluted or good quality water.

WATER QUALITY CONTROL STRATEGIES

Sources of the various pollutants should be identified and mechanisms put in place, especially proper land management practices, which minimize surface runoff and maximize ground infiltration of surface runoff. The application of pesticides including the amounts, rates and types should be monitored by a group of advisory personnel from the Ministry of Agriculture in order to avoid major environmental deterioration.

An integrated approach to the management of water resources should be adopted to encompass soil conservation and management, forest conservation and re-afforestation, protection of water catchment areas as well as river courses and prohibition of dumping of wastes into river courses and onto banks. Buffer zones along the river systems should also be created to allow for the growth of riverine vegetation (macrophytes) which can take up some of the water pollutants and hence reduce water quality degradation and restore the quality of water. In the slum areas with inadequate drainage and sewerage systems, well constructed pit latrines should be provided far away from river banks, in addition to a better drainage system. Good housing structures with toilets will also reduce direct discharge of raw human wastes into the rivers flowing through these slum areas.

Land-use changes and activities have had profound effects on water quality and there is a need to review the existing land-use policy in the country to guard against detrimental encroachment of land-use activities into watershed areas. This will encourage land management control and conservation measures as well as riparian use of water resources in the headwaters and downstream areas. Use of modern techniques and strategies (Best Management Practices – BMP) to control water quality degradation and maintain the quality of water need be emphasized. These should include Integrated Water Resources Management (IWRM) with an emphasis on community participation and policy formulation.

There is a need for public awareness regarding the pollution problem and its consequences and a sound integrated Environmental Education (EE) programme needs be adopted with the emphasis on community participation and use of green environmental policies.

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