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The spatio-temporal characteristics of water transparency and temperature in shallow reservoirs in Kenya

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Abstract

Water transparency and temperature in eight small reservoirs, ranging from 0.065–0.249 km^2, in a rugged escarpment landscape and stepped plateau in the Eastern Rift Valley of Kenya were investigated between 1998 and 2000. Water transparency and temperature were measured with a 20-cm Secchi disk and a portable Jenway probe, respectively. The water transparency ranged from 0.02–0.8 m, which was low, but still similar to some larger reservoirs in the country (such as Masinga Dam). Reservoirs in the rugged escarpment had more water transparency than those in the high altitude plateau. The mean temperature ranged from 15–21°C. The reservoirs were either hypertrophic or oligo-mesotrophic, and mostly polytrophic, based on their water transparency in accordance with the trophic status classification of the Organization for Economic Cooperation and Development. Most of the reservoirs experienced short-lived stratification during the transition from the dry to rainy seasons. The results did not illustrate large spatio-temporal variability in water transparency or temperature, mainly because of physiographic and ecohydrological uniformity. All the reservoirs were considered to be in a poor state of domestic water quality, based on their water transparency.

Key words

catchment, reservoirs, Rift Valley, temperature, transparency, utilization, water depth.

INTRODUCTION

The number of reservoirs in the world has increased tremendously from ≈5000 in the 1950s, 30 000 in the 1970s, to ≈40 000 in the 1980s (International Council for Scientific Unions – Scientific Committee on Problems of the Environment 1972; Naiman & Decamps 1990; Tundisi 1993). The International Commission on Large Dams (1972) recently estimated that there are ≈800 000 small reservoirs worldwide. Most countries, including those in Africa, have numerous small reservoirs created mainly for domestic and livestock water supply (Worldwide Fund for Nature 1999). Despite their widespread distribution, our limnological knowledge of small reservoirs remains sparse, particularly in Africa. This might partly explain why they are underexploited for recreation, ecotourism, fishery development and biodiversity conservation. The lack of limnological information reflects a traditional bias by many scientists who mainly investigate large rivers, lakes and large reservoirs.

Information on the physical characteristics of water is very important because these physical characteristics determine the spatio-temporal dynamics of the broader water chemistry, aquatic biodiversity and utilization of reservoirs (Naiman & Decamps 1990). A wide range of factors, including catchment geology, pedology, landscape, climate, land use and land cover can transform the physical state of water quality in reservoirs, both naturally and culturally. The occurrence of major shifts in the natural state of water quality can affect the overall state of environmental health in reservoirs, thereby affecting long-term production and utilization of resources. Accordingly, this study was undertaken to generate essential water quality information as a guideline for the utilization and sustainable management of small reservoirs in Kenya.

Many scientists have explored ways by which various physical factors regulate the ecology of aquatic ecosystems (Ryding & Rast 1989; Meaden & Kapetsky 1991; Moehl & Davies 1993; Marshall & Maes 1994). Thus, reservoir physical limnology is one of the major areas of interest for aquatic scientists. Temperature and water transparency are among the most important physical factors in the aquatic environment. For example, studies have shown that algal

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and fish growth in water bodies is strongly dependent on light and temperature (Meaden & Kapetsky 1991; Moehl & Davies 1993).

Light penetration in a lake or reservoir can be converted into heat. A wide range of factors, including the depth of the water column, the quantity of particulate matter and the degree of water circulation can affect this conversion. The heating of the water column can eventually result in clear-cut vertical stratification of the water column based on the temperature. This process is common in deep water lakes where complete water mixing is rare (Goldman & Horne 1983). Thus, thermal stratification reflects distinct temperature strata in the water column, usually with a narrow layer (thermocline) separating the upper warmer water (epilimnion) from the lower colder water (hypolimnion). Although not a standard criterion, a thermocline is sometimes taken to represent the part of the water column that manifests a change of at least 1°C m^{-1} (Goldman & Horne 1983). The state of a water body is dependent, in part, on thermal stratification because the latter controls the buoyancy of aquatic organisms, as well as the distribution of dissolved materials including nutrients (Goldman & Horne 1983).

This paper discusses the spatio-seasonal variability of water transparency and temperature in small, high altitude, reservoirs in the escarpments bordering the Eastern Rift Valley in Kenya. It compares their status to those of other reservoirs in the region and the world. The findings are used to make recommendations regarding the utilization and long-term sustainable management of the reservoirs.

Study area

In many highland areas of Kenya, there are numerous small reservoirs of < 1 km^2 in area. They were constructed in the 1950s and 1960s to ensure a year-round supply of water for the European farmers who settled in those highlands during the colonial era (Mwaura 2003). When Kenya achieved its independence, most of the land in those highlands, also known then as the 'White Highlands', was transferred back to the indigenous communities. Most of the small reservoirs, however, became community property, and are being utilized today as sources of domestic and livestock water supply on a 'free-for-all' basis (Mwaura 2003).

The study reservoirs were located 100–200 km northwest of Nairobi, Kenya, in the central part of the Eastern Rift Valley. The floor of the Eastern Rift Valley lies between 1700 and 1800 m above sea level (a.s.l.), being flanked to the east and west by escarpments and plateaus whose altitudes generally exceed 2000 m a.s.l. (Fig. 1).

The study reservoirs were in the Nyandarua and Nakuru districts, which are administratively located in the Central and Rift Valley Provinces of Kenya. Most of them are drained by first to third-order streams, which originate from the Aberdare Ranges and Mau Escarpment along the Rift Valley. The reservoirs are fed primarily by surface drainage through river flow. However, one reservoir (Kiongo Reservoir) is fed almost entirely by diffuse wet season surface run-off and seepage into the water body. Both Muruaki Reservoir and Kahuru Reservoir are considered to be hydrologically distinct because the former overflows into the latter during periods of high water. Many of the rivers in the area are ephemeral and do not flow in the dry season. Consequently, the surface areas of the reservoirs vary considerably depending on the seasonal variability in the hydroperiod or the seasonal pattern of the reservoir water level, which is equivalent to their hydrologic signature. Table 1 illustrates the general features of the study reservoirs.

The study reservoirs were located within two major regional physiographic zones, namely the upland plateaus and escarpments. The average slope of the land is between

Table 1. Geographic, morphometric and age characteristics of the study reservoirs (Mwaura 2003)

Reservoir	Location	Age (years)	Surface area (km^2)	Catchment area (km^2)	Water volume (10^3 m^3)	Mean depth (Z_{max}, m)
Muruaki	0°38′S, 36°33′E	45	0.102	29.10	230	3.5
Kahuru	0°37′S, 36°32′E	46	0.088	31.40	240	4.5
Murungaru	0°36′S, 36°30′E	48	0.116	57.30	280	3.8
Kanguo	0°12′S, 36°25′E	45	0.114	14.10	240	2.2
Gathanje	0°03′S, 36°19′E	45	0.119	22.40	400	6.0
Kiongo	0°10′S, 36°15′E	48	0.249	0.05	580	3.3
Rutara	0°17′S, 36°15′E	46	0.072	1.50	230	3.6
Gathambara	0°27′S, 36°02′E	40	0.065	50.00	50	1.5

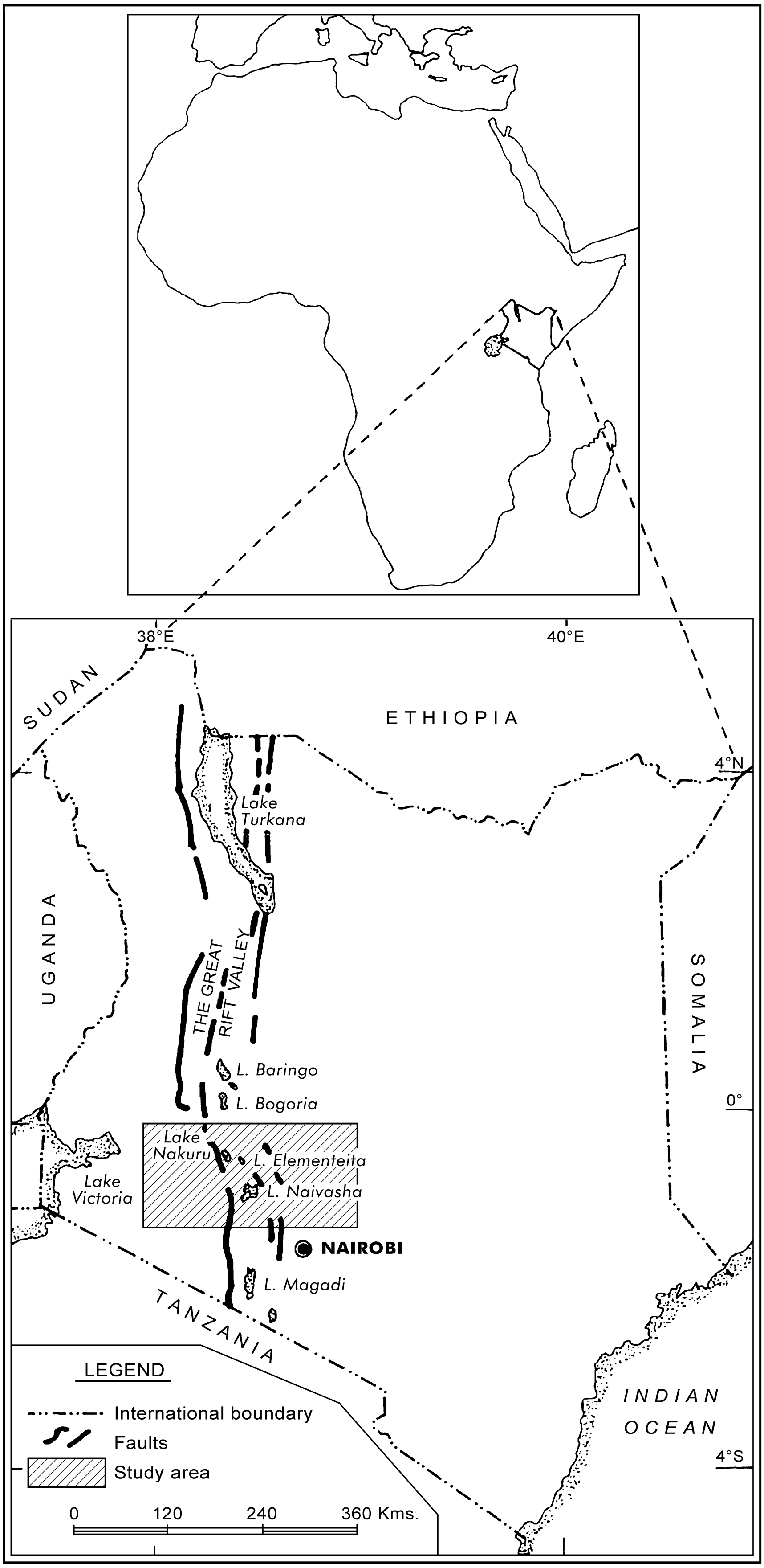

Fig. 1. Location of the study area (Mwaura 2003).

4–5% on the plateaus, to almost 20% in the escarpments (Mwaura 2003). Soft pyroclastic rocks, in the form of light-coloured tuffs underlie the Kinangop-Olkalou plateau to the east of the Rift Valley. According to Thompson (1962), these rocks probably belong to the Lower Middle Pleistocene period. The Mau escarpment to the west is composed of rocks with largely soft volcanic ashes and tuffs. Thus, due to their extremely soft nature, the rocks underlying this area are highly vulnerable to erosion. Within the rift floor, the rocks vary from undersaturated tephrites to highly acidic and sodic rhyorites. According to Thompson and Dodson (1958), ≈10% of the rift floor is characterized by strongly alkaline lava from historic sites of intensive volcanic activity, including olivine basalt, quartz and kataphorite.

The climate in the area is cool and subhumid within the uplands, and dry to semiarid within the rift floor, with a mean annual rainfall of 800 and 1100 mm in the rift floor and upland, respectively (Government of Kenya-Japan International Cooperation Agency 1992). The rainfall pattern is predominantly bimodal in nature, with 'long rains' coming between April – June and 'short rains' in October – November. Like most other parts of Kenya, the period from January – March is the driest. During this period, water levels can be low and most reservoirs become hydrologically isolated because of the absence of significant surface water inflow.

The mean human population density in the area ranges from 100–400 individuals km^{-2}, while the average house density surrounding the reservoirs is ≈100 units km^{-2} (Mwaura 2003). The land usage in the area is predominantly small-scale agriculture and livestock husbandry (Mwaura 2003). Agriculture is the predominant land use in the region, constituting ≈85% of the land use in the reservoir catchments. The major crops include maize (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), potatoes (*Solanum tuberosum*), onions (*Allium cepa.*), beans (*Beta vulgaris*), cabbages (*Brassica oleracea*) and peas (*Pisum sativum*), which require large quantities of agro-chemicals.

MATERIALS AND METHODS

Four reservoirs were randomly selected from the plateaus; namely, Muruaki, Kahuru, Murungaru and Kanguo. The other reservoirs in this study (Gathanje, Kiongo, Rutara, Gathambara) were selected in the rugged escarpment below the plateau. Initially, all the permanent reservoirs in the study area, which had a surface area > 0.05 km^2, were marked on topographic maps for selection via a random method. The map grid cells were used to generate a table of random numbers for site selection, after which the inaccessible reservoirs were eliminated. This stratification was done in order to compare water quality conditions in the two distinct physiographic zones within the area. Although all the study reservoirs were located within the Ecoregions III and IV, as described by Pratt *et al.* (1966), transformations in landscape exert a strong influence on elevation, climate, hydrology, land use and land cover, all of which affect the morphometry and state of the physical quality of the reservoirs.

Twenty-one sites in the upper, middle and lower sections of the reservoir, including 2–3 in each reservoir, were randomly selected for water temperature and transparency measurements. These measurements were undertaken seasonally between 1998 and 2000. The seasonal sampling protocol was arranged in clusters, based on the dominant seasons, as follows:

1. The hot dry season during February – March, when the water levels in the reservoirs are usually quite low and they are hydrologically isolated following the dry spell.

Table 2. Mean monthly Secchi depth (m) in the reservoirs between 1998 and 2000 (Mwaura 2003)

	Months							
Reservoir	February	March	June	July	September	October	December	Mean
Muruaki	0.10	0.200	0.30	0.30	0.40	–	0.5	0.28
Kahuru	0.20	0.200	0.60	0.40	0.20	–	0.4	0.32
Murungaru	0.10	0.300	0.30	0.30	0.40	0.2	0.5	0.28
Kanguo	0.20	0.100	0.20	0.20	0.40	0.3	0.5	0.25
Gathanje	0.50	0.500	0.80	0.70	0.70	1.4	0.9	0.80
Kiongo	0.60	0.300	0.80	0.50	0.60	1.2	1.3	0.78
Rutara	0.70	0.500	1.00	0.60	0.70	1.0	1.3	0.84
Gathambara	0.04	0.004	0.64	0.04	0.29	0.1	0.2	0.08
Mean	0.30	0.400	1.20	0.40	0.50	0.7	0.7	–

2. The long rain season during May – July, when reservoirs are usually full and discharge water downstream.

3. The short rain season during September, October and December, when the reservoirs are expected to manifest moderate hydro-ecological conditions.

Water transparency was measured seasonally, using a 20-cm Secchi disk. The water temperature was recorded seasonally at uniform vertical intervals, using a Jenway model 4075 portable digital readout probe (Goldman & Horne 1983). The data collected were used to generate water transparency and temperature charts for the reservoirs. Statistical analysis involved the computation of basic or summary statistics. Advanced analyses included single-factor analysis of variance (ANOVA) and stepwise multiple regression analysis.

Table 3. ANOVA results for Secchi depth water transparency data 1998–2000 (Mwaura 2003)

Month	F	d. f.	α
March	27.4	7.11	0.001
June	94.9	5.80	0.001
July	6.8	3.40	0.050
September	24.0	2.30	0.010
October	90.5	4.60	0.001
December	9.6	7.10	0.001

d. f., degrees of freedom.

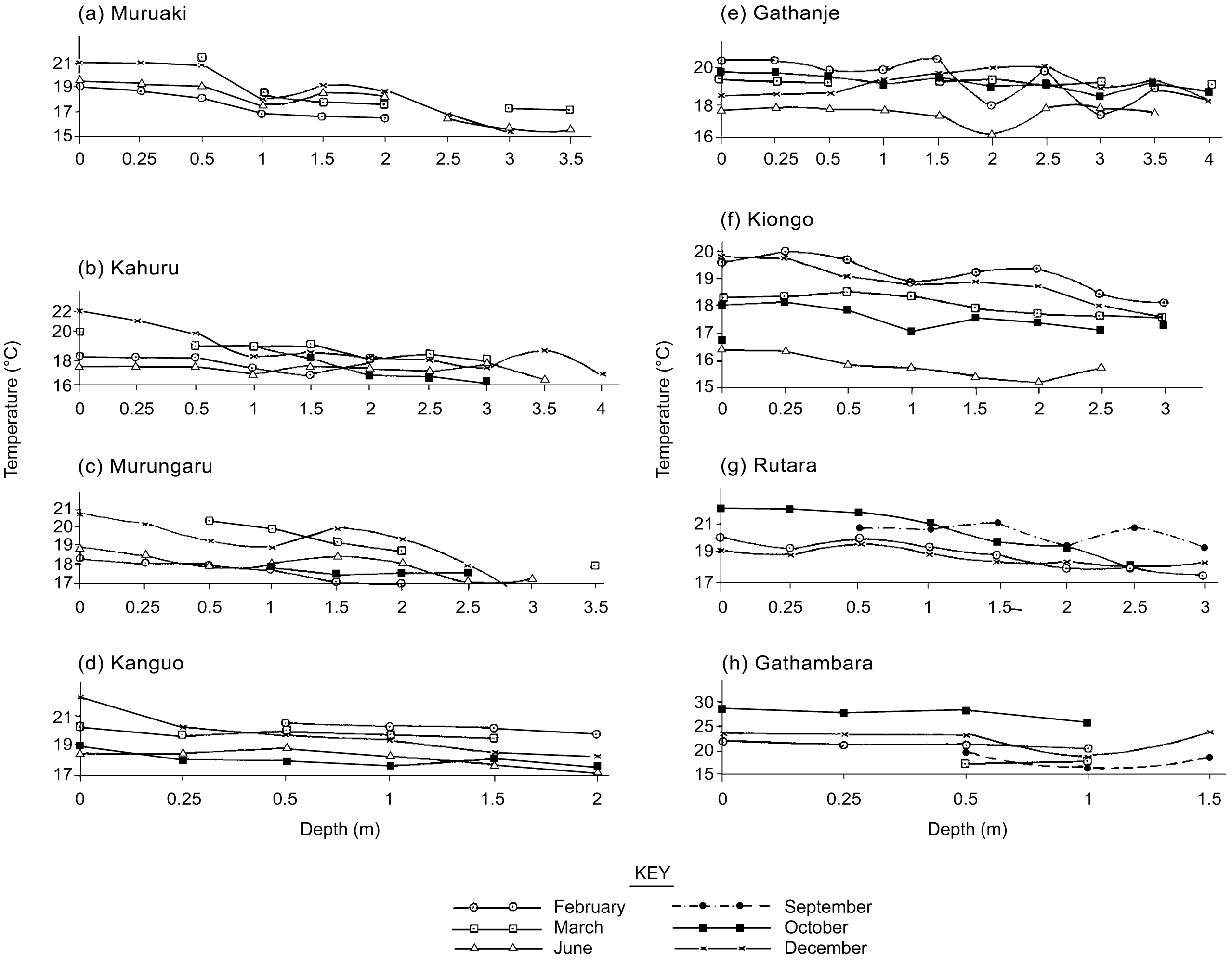

Fig. 2. Water temperature profiles of the study reservoirs (Mwaura 2003).

RESULTS

Table 2 provides a summary of the mean monthly Secchi disk transparency in the reservoirs over the duration of the study. The smallest monthly Secchi depth was 0.3 m at the beginning of the year during the dry season in February – March. The largest was 0.8 m towards the end of the year

Table 4. Mean monthly water temperatures in the study reservoirs 1998–2000 (Mwaura 2003)

Depth (m)	Mean	Minimum	Maximum	*n*
February				
Surface	19.64 ± 1.40	17.9	22.6	19
0.25	19.34 ± 1.23	17.9	21.6	17
0.50	19.28 ± 1.27	17.5	21.6	19
1.00	18.73 ± 1.40	16.8	20.9	18
1.50	18.57 ± 1.59	16.5	21.0	14
2.00	17.88 ± 1.13	16.3	19.7	13
2.50	17.10 ± 1.53	14.9	19.4	6
March				
Surface	19.86 ± 3.00	14.8	28.2	19
0.25	19.29 ± 0.71	18.1	20.0	7
0.50	18.61 ± 2.52	12.1	23.0	19
1.00	17.91 ± 2.82	11.0	20.3	17
1.50	16.96 ± 3.84	9.1	19.9	13
2.00	15.67 ± 4.79	6.6	19.5	11
2.50	16.02 ± 5.63	6.0	19.1	5
3.00	15.34 ± 5.17	5.5	19.0	8
June				
Surface	18.04 ± 1.08	16.3	19.8	14
0.25	17.90 ± 1.04	15.5	19.3	14
0.50	17.71 ± 1.07	15.0	19.2	14
1.00	17.37 ± 1.07	15.5	19.1	15
1.50	17.33 ± 1.16	15.1	18.6	11
2.00	16.83 ± 1.59	13.4	18.4	9
2.50	16.73 ± 0.66	15.7	17.7	6
3.00	16.85 ± 0.97	15.5	17.6	4
3.50	16.65 ± 0.82	15.6	17.4	4
September				
Surface	19.53 ± 1.85	16.5	22.2	9
0.50	19.66 ± 1.76	16.5	22.7	8
1.00	19.22 ± 1.65	16.3	22.2	9
1.50	18.86 ± 2.00	16.2	22.4	9
2.00	18.04 ± 1.94	16.4	22.3	8
2.50	18.70 ± 2.22	16.3	22.1	7
3.00	18.45 ± 2.90	16.0	21.9	4
October				
Surface	21.43 ± 3.96	18.1	30.2	12
0.25	21.11 ± 3.67	17.8	28.9	12
0.50	20.98 ± 3.77	17.5	29.8	12
1.00	19.69 ± 2.59	16.9	25.0	11
1.50	18.92 ± 1.17	17.2	20.7	10
2.00	18.60 ± 1.15	17.1	20.4	7
2.50	17.90 ± 0.96	17.1	19.3	4

Table 4. (continued)

Depth (m)	Mean	Minimum	Maximum	*n*
December				
Surface	20.86 ± 2.02	18.5	25.1	19
0.25	20.38 ± 1.74	18.3	24.8	19
0.50	19.87 ± 1.62	17.8	24.3	19
1.00	18.87 ± 1.04	17.0	21.2	19
1.50	19.33 ± 1.30	18.2	22.7	15
2.00	18.91 ± 1.08	18.1	21.8	12
2.50	18.46 ± 1.35	16.8	21.8	11
3.00	17.77 ± 1.28	15.3	20.2	10
3.50	18.27 ± 1.41	16.5	20.6	6
4.00	18.27 ± 2.05	16.3	22.1	6

during the short rains of October and December. Table 2 illustrates that moderate Secchi depths existed in the middle of the year during the long rains. The data pattern indicates that the plateau reservoirs had an overall smaller water transparency of less than 50 cm. Those in the escarpment exhibited greater water transparency, with Secchi depths exceeding 50 cm during most of the observation time. Gathambara Reservoir on the Mau escarpment, however, was exceptional in registering the lowest water transparency. During the dry season, the mean Secchi depth in Gathambara Reservoir was only 2 cm. This reservoir is located in a steep gradient area containing highly erodible soft nitosols and luvisols, and also has a high population density in its drainage basin (Mwaura 2003).

Table 2 indicates that the reservoir with the greatest water transparency during the study period was Gathanje Reservoir, with a Secchi depth of 1.4 m measured in October. The Secchi disk transparency also was high in Kiongo and Rutara reservoirs, both of which are located in the escarpment zone. The results also showed a 14% improvement in water transparency at Kahuru Reservoir, located 3 km below Muruaki Reservoir. These results indicated that the upstream impoundment operated as a natural sink for suspended matter. The ANOVA procedure applied to the measured data provided significant results ($\alpha \leq 0.05$) for all months (Table 3). Higher spatial variability occurred in June, September and October. The difference was attributed to the effects of the long and short rains on the water transparency, which increased both the water depth and the total suspended sediment load.

Regression analysis between water transparency and both reservoir and catchment morphometric variables (surface area, water depth, water volume) did not yield any significant results. Only 3% of the total variation in water transparency in December, for example, was explained by the mean depth, and rainfall and land slope only accounted for 19.2% and 12.7%, respectively, of the variation in water transparency. During the same month, the catchment area accounted for 48% of the total variance in transparency, although all the results were not statistically significant.

Table 4 provides a summary of the mean monthly water temperature values for the study reservoirs during the study period. The mean water temperature ranged from 15–21°C. There was clear seasonal temperature variation between the dry and hot months of February and March, with slightly higher temperatures (15–19°C) compared to the wet and cold months in June and July (15–18°C). Towards the end of the year in September, October and December, the water temperature was higher, ranging from 18–21°C.

Because of the relatively shallow nature of the reservoirs, permanent thermal stratification was uncommon. However, Table 4 indicates that, because of surface heating, slightly higher surface temperatures were common in most reservoirs up to ≈0.5 m. Most of the reservoirs, except the very shallow ones of Kanguo, Kiongo and Gathambara, manifested lower bottom temperatures by between 0.5°C and 1°C.

The greatest spatial variability in water temperature throughout the water column occurred in the reservoirs during the month of March, which was climatically a transitional period between the hot-dry and cold-wet seasons. An average temperature change of at least 1.7°C m^{-1} was recorded for this month. There was reduced temperature variability in June and September, and slightly higher variability in October at the onset of the short rains, during which an average change of 1.3°C m^{-1} was recorded. Figure 2 illustrates the average monthly water temperature profiles for each reservoir.

In terms of on-site variability, Fig. 2 indicates that most of the reservoirs experienced greater surface temperature fluctuation up to a depth of ≈3 m. A zone of consistent temperature decrease characterized the lower parts of the water column in most reservoirs. Greater temperature variability was common in the upper part of the water column because of constant heating and cooling. Such water column temperature variability was generally greater during the wet season, probably because of the more turbulent nature of river currents, which mixed the water and totally disrupted the systematic profiles created by surface heating (Fig. 2).

DISCUSSION

The results of the study show that the water transparency in the reservoirs was quite low (0.02–0.8 m), although it was similar to large reservoirs in Kenya, such as Masinga (0.5–1.5 m; Pacini 1994) and the neighbouring Rift Valley lakes, such as Lake Naivasha (2.6 m), Lake Elementaita (0.2 m) and Lake Nakuru (0.3 m) (Kalff & Watson 1986). For reservoirs in the Missouri region of the United States, Jones and Knowlton (1993) reported reservoir transparencies ranging from 0.2–4.7 m.

The low water transparency in the study reservoirs is attributed to a large suspended matter load, in the form of soil particles, as demonstrated in other studies. In a previous study of the relationship between Secchi disk visibility and particulate matter content in ponds, it was demonstrated that water transparency ranging between 0.5 and 1.0 m was an indicator of high particulate concentration in the water. This relationship is conspicuous in this study, especially from the patterns observed at Gathambara Reservoir. Soil erosion studies in the study area indicated relatively high rates of soil loss. For example, the work of Syren, as cited in Mochiemo (1994), reported an estimated average rate of soil loss of ≈9 t/km^2/year (1931–1959) in the Kinangop area. This loss should now be at a much higher rate because of increased human settlements since the 1960s. The maximum daily transport of suspended sediment load in the River Malewa, which flows into Lake Naivasha, was calculated to be ≈10 000 t.

The results of this study indicate that soil erosion and reservoir siltation were more the result of poor land management than human population density, as has been suggested in other studies (Golet & Parkhurst 1981; Frayer *et al.* 1983; Wilbur & Chrieastansen 1983; Grootjans *et al.* 1985). In this study, the water transparency in some of the reservoirs located in high population density catchments, such as Rutara (150 persons km^{-2}) and Gathanje (400 persons km^{-2}), was still very high. This phenomenon was due to the presence of substantial remnants of riparian macrophytes and indigenous forest cover, which are known to act as natural buffers against sedimentation, pollution and eutrophication. This finding confirms the observation by Oygard *et al.* (1999) that environmental carrying capacity depends not only on soils and climate, but also on environmental management. In fact, intensification of agricultural activities and livestock husbandry can be sustained on smaller land areas, provided there is an increased investment in labour and technology.

The water temperature patterns measured in the Rift Valley reservoirs were not very different from those in other tropical water bodies. Higher water temperatures were common in the reservoirs, which are located in warmer environments, and lower in the higher altitude areas of cooler climate. The small reservoirs considered in the study were almost isothermal in February as a result of limited water inflows and discharges. Most of the shallow reservoirs manifested isothermal conditions, implying almost constant vertical mixing throughout the year. This occurred because mixing was easily maintained by both turbulent upwelling and wind-driven shear. Limited thermal stratification occurred briefly in the deeper reservoirs during the transition from the dry to the rainy seasons, and at the beginning of the short rains in October, indicating that such reservoirs are dimictic in nature. According to Thornton (1987), similar water bodies in South Africa exhibit monomictic mixing, although a few can be polymictic. However, Thornton (1980) also reported dimictic conditions for some Zimbabwean reservoirs, where thermoclines form prior to the summer rains and, thereafter, in the spring dry season.

Based on their water transparency characteristics, the reservoirs fall under the polytropic category of the Organization for Economic Cooperation and Development classification (Ryding & Rast 1989). The low water transparency in some study reservoirs is a clear indication of a poor state of catchment health resulting from improper land use. Catchment land use and land cover are critical influences on water transparency in lakes and reservoirs because they control the rate of soil movement from land to water.

CONCLUSIONS AND RECOMMENDATIONS

The results do not show high or unique spatio-temporal variability in the water transparency and temperature of the study reservoirs, primarily because of the uniformity in physiography, climate and ecohydrology within the study area. The observed variability is mainly attributed to rainfall patterns and to catchment disparities in terms of land use and land cover. The water transparency was found to change slightly between the dry and wet seasons. Furthermore, the reservoirs were isothermal throughout almost the entire year, except for the short stratification observed at the onset of the wet season. The isothermal conditions are attributed to the shallow depths of the reservoirs, which facilitated complete mixing of the water column, especially in the late afternoons, due to wind action.

The low water transparency in the reservoirs indicate that turbidity is high, suggesting the water quality in most of the reservoirs might be unhealthy for human consumption. Only three escarpment reservoirs (Gathanje, Kiongo, Rutara) had slightly better water quality, in terms of water transparency. Thus, efforts must be made to improve the water quality of the study reservoirs upon which large populations of people and livestock are dependent.

A number of precautionary measures should be taken to minimize the risks to public health of the consumption of unsafe reservoir water. The following two adjustments would probably eventually improve the quality and quantity of the reservoir resources, especially water, and minimize the risk of future disease epidemics:

First, technical purification of the water before use is necessary in some reservoirs (Kiongo, Gathanje) as they supply a large population, including schools. Regular monitoring of the water quality in such water bodies is imperative to avoid possible public health disasters.

Second, public awareness of the value of wise use of public reservoirs should be encouraged, including facilitating the construction of reservoir perimeter fences. Thereafter, appropriate means of handling livestock within public reservoir drainage basins could be identified as a means of minimizing reservoir degradation. This might require installation of dry season livestock watering points outside the reservoir, preferably below the dam, in order to reduce nutrient build-up and minimize transmission of livestock diseases.

Several options are recommended for the long-term maintenance of good water quality and quantity standards in the reservoirs, as follows:

De-encroachment of waterways by creating sufficient riparian buffer zones along rivers and around reservoirs would improve water storage and quality. The presence of riparian buffers will reduce the movement of soil particles from the land surface to the water body, which should also reduce nutrient loadings to the reservoirs. Such de-encroachment of waterways could be achieved through the new Environmental Management and Co-ordination Act, which prohibits any form of development within critical water banks. The success of the EMCA, however, will depend on the effectiveness of the policy and legal mechanisms for its implementation.

Restoration of degraded stream banks and reservoir shore areas are a means of rehabilitating lost waterways. One approach could involve the natural regeneration of macrophytes, including their re-introduction in the reservoir. Some potential species for this process include *Cyperus*, *Phragmites*, *Ceratophyllum*, *Potamogeton, Egeria and Hibiscus. Hibiscus canabinus* (Kenaf), for example, is a tropical plant used for the phyto-remediation of water supply reservoirs in Japan (Mazzeo *et al.* 2001). The introduction of macrophytes in degraded reservoirs also could improve aeration in water bodies experiencing hypolimnetic oxygen depletion, which can ultimately transform the biodiversity. The restoration of waterways through the introduction of non-native species, however, requires significant research on the possible overall impacts of their introduction in order to avoid possible ecological disasters.

Mechanical desedimentation of the highly silted reservoirs (such as Gathambara) might ultimately prove inevitable in order to maintain a good water supply in rural areas. Although this might prove to be an expensive venture, it could greatly improve water quality by removing nutrients from their sinks in the lake bottom sediments.

Good catchment management should be a long-term effort towards good water quality. This can include improvements in soil and water management, restoration of degraded catchments through reforestation and promotion of organic farming as a means of reducing the leakage of agro-chemicals into the reservoirs.

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