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Managing the water quality of the Kafue River

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Abstract

Most vital surface water bodies in developing countries are under serious threat of degradation resulting from constant discharge of polluted effluents stemming from industrial, agricultural, mining and domestic/sewage activities. The most affected river systems are those traversing cities and towns in urban areas. The Kafue River in Zambia is one such river system that is threatened with serious degradation and probable loss of biodiversity. Kafue River cuts across the country in a North–South direction, stretches for about 1576 km before draining into the Zambezi River. It covers an area of 152,000 km^2 and generates a mean annual runoff of 350 m^3/s which represents about 12% of the Zambezi's mean annual runoff at the confluence [Water Resources Development and Vector-borne Diseases in Zambia: Report of a National Seminar held at Kafue Gorge, Zambia, WHO, Geneva, 1995]. The area coverage of the Kafue River Basin (KRB) is approximately 20% of Zambia's land area (743,000 km^2) and approximately 17% of the Zambezi Basin [Water Resources Use in the Zambezi Basin: Proceedings of a Workshop held at Kasane, Botswana, IUCN, 1993]. More than half of Zambia's population live in the KRB, of which about 65% are in urban while 35% are in rural areas. Over the years, however, the Kafue River has been receiving all sorts of pollutant and effluents from all sectors of economical development in Zambia that include mining, industrial and agricultural. The continuous discharge of pollutants into the Kafue river has led to the deterioration of the river water quality. The consequences have been heightened eutrophic conditions, increased heavy metal concentration in the river sediments and aquatic life, increased suspended solids, etc. leading to proliferation of *Salvinia molesta* in some sections of the river, decreased fish catch and fish size and objectionable taste of the Kafue River water. Fishermen along the Chanyanya–Kafue Gorge stretch of the Kafue River have complained about the alleged loss of taste and the decrease in both the fish catch and size in these areas of the Kafue River. The communities along the same stretch have also complained about the objectionable taste of the river water [Report of the Proceedings of the First Multi-sectoral Workshop on the Effects of Environmental Pollution and Degradation on the Kafue River Basin (KRB) on the Community in the Kafue Town Area, AREZ, 2001]. This paper reviews the water quality of the Kafue River resulting from anthropogenic activities and proposes the framework for the sustainable management of river water quality.

Keywords: Kafue River; Chemical; Nutrient; Contaminant; Sustainable management; Poverty

1. Background

The Kafue River is one of the five major rivers that drain Zambia. It stretches for about 1576 km from its source on the Zambia-Democratic Republic of Congo border, in the northwestern region of Zambia, and its confluence with the Zambezi River, traversing through the Copperbelt, Central, Southern and Lusaka Provinces. Major commercial, agricultural, industrial and mining activities are concentrated in the Copperbelt, Southern and Lusaka Provinces. The Kafue River is therefore the heart of Zambia's economic and developmental base. Furthermore, due to its geographical locality, the Kafue River is an important source of water supply to over 40% of the Zambian population, rural and urban, living in the Kafue River Basin (KRB). Box 1 gives some facts on the Kafue river as summarised from Matiza et al. (1995) and WHO (1995).

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Box 1: Some facts about the Kafue River

- Total area coverage of basin 152,000 km^2.
- Mean annual runoff 350 m^3/s.
- Area coverage of the Kafue River Basin represents approximately 20% of Zambia's total land area (743,000 km^2).
- Source of portable water for approximately 40% of the Zambian population.
- Host to the Kafue Gorge Hydroelectric Power Station that generates about 60% of Zambia's electricity supply.
- Supports and sustain vital ecological systems like wetlands, game reserves, bird sanctuary, etc.
- Provides for daily water demand of 42,228,650 m^3/day to holders of 130 water abstraction rights of which 14,515,200 m^3/day or approximately 34% is used for hydroelectric generation.

The KRB is also core in poverty reduction in Zambia since it does not only provide a livelihood for communities living in the basin but also offer a life support to industrial, mining and agricultural sectors, the majors sectors that provide employment and sources of income as well as survival to most a Zambian urban population. Projections indicate that about 80% of Zambians live in income poverty and suffer from other deprivation such as little access and poor quality of the social services. Poverty is more prevalent in the rural areas as compared to urban areas (83% and 56%, respectively) even though the poverty levels in urban areas have risen faster lately due to falling industries and rising unemployment levels (Ministry of Finance and Economic Development, 2001).

Pollutant effluent loads from mining, industrial and agricultural activities discharged into the Kafue River Basin over the years have led to deterioration in quality of the river water and the environment. The proliferation of *Salvinia molesta* (water hyacinth) especially on the stretch between Mazabuka and Kafue Gorge suggests the presence of nutrients-rich river water (ECZ, 2000). The loss in fish diversity could be supported by alleged loss of taste and decrease in both fish catches and sizes in certain areas of the Kafue River, especially along the Chanyanya–Kafue Gorge stretch (Kambole and Chilumbu, 2001). The river water objectionable taste as noted by Kambole and Chilumbu (2001) could be attributed to effluent originating from industries, mining, agricultural, sewage works, trade and commercial, etc.

2. Water quality of the Kafue River

The Kafue River drains one of the world's greatest stratiform metallogenic provinces, the Copperbelt Province in Zambia (Unrug, 1988 as cited by Pettersson and Ingri, 2001) and further passes through major industrial, mining and agricultural provinces in the country carrying with it a variety of pollutant loads. Intense mining operations on the Copperbelt Province have resulted into elevated concentrations of cobalt (Co) and copper (Cu) in water, sediments and fish in the river. Numerous research studies have revealed elevated concentrations of Co and Cu in water, fish and sediments on the Kafue River (Kasonde, 1990; Pettersson and Ingri, 1993; Mwase, 1994; JICA, 1995; Nkandu, 1996; Norrgren et al., 2000 as cited by Pettersson and Ingri, 2001). These high concentrations of heavy metals in the Kafue River have negatively affected the aquatic life forms as well as animals. Mwase (1994) demonstrated that the hatching frequency and mean survival time for Zebra fish (*Brachydanio rerio)* were highly reduced for fish exposed to sediment collected from the Kafue River within the Copperbelt. ZCCM (1982) reported copper poisoning of cattle, which unfortunately occurred when the animals went into the river and stirred up the bottom sediment thereby re-suspending the heavy metals back into the water when drinking the water. Consequently, Pettersson and Ingri (2001) closely linked the toxicity of the sediments in the Kafue River to the formation of authigenic particles rich in Co and Cu. Appraisal of the quality of the Upper Kafue River water between 1971 and 1997 by Sinkala (1998) showed sources of pollutants from mining activities to be waste rock piles, overburdened rock waste piles, tailings dams and water pumped from mine through dewatering processes of mines. For example, Konkola Copper Mines pumps about 400,000 m^3/day of water from underground. Although this water is of fair quality, it is harder than surface water and contains high contents of suspended solid (CDG, 1994 as cited by Sinkala, 1998). Nonetheless, heavy metals concentration in river water, fish and sediments decreases in concentration downstream the mining activities. The impacts of mining on the water quality of most Zambian rivers are illustrated in Fig. 1.

Although elevated heavy metals concentration in river water and sediments are attributed to mining activities, industries equally contribute polluted effluent to the Kafue River. Notables include textile industries (dyeing and bleaching, knitting mills, etc), fertilizer (NPK) manufacturing plant, sugar processing plant, cotton plants (ginning and bailing), leather tannery company (tanning and finishing), yeast manufacturing company, food and beverage manufacturing, petroleum refining and blending, etc. The composition of pollutant effluent from these industries ranges from chemical to nutrient-rich pollutants. Apart from Nitrogen Chemicals of Zambia (NCZ), the NPK manufacturing plant, sewage treatment plants are a major source of nutrient-rich effluent discharges into the Kafue River Basin (KRB) as their treating efficiency have been affected by

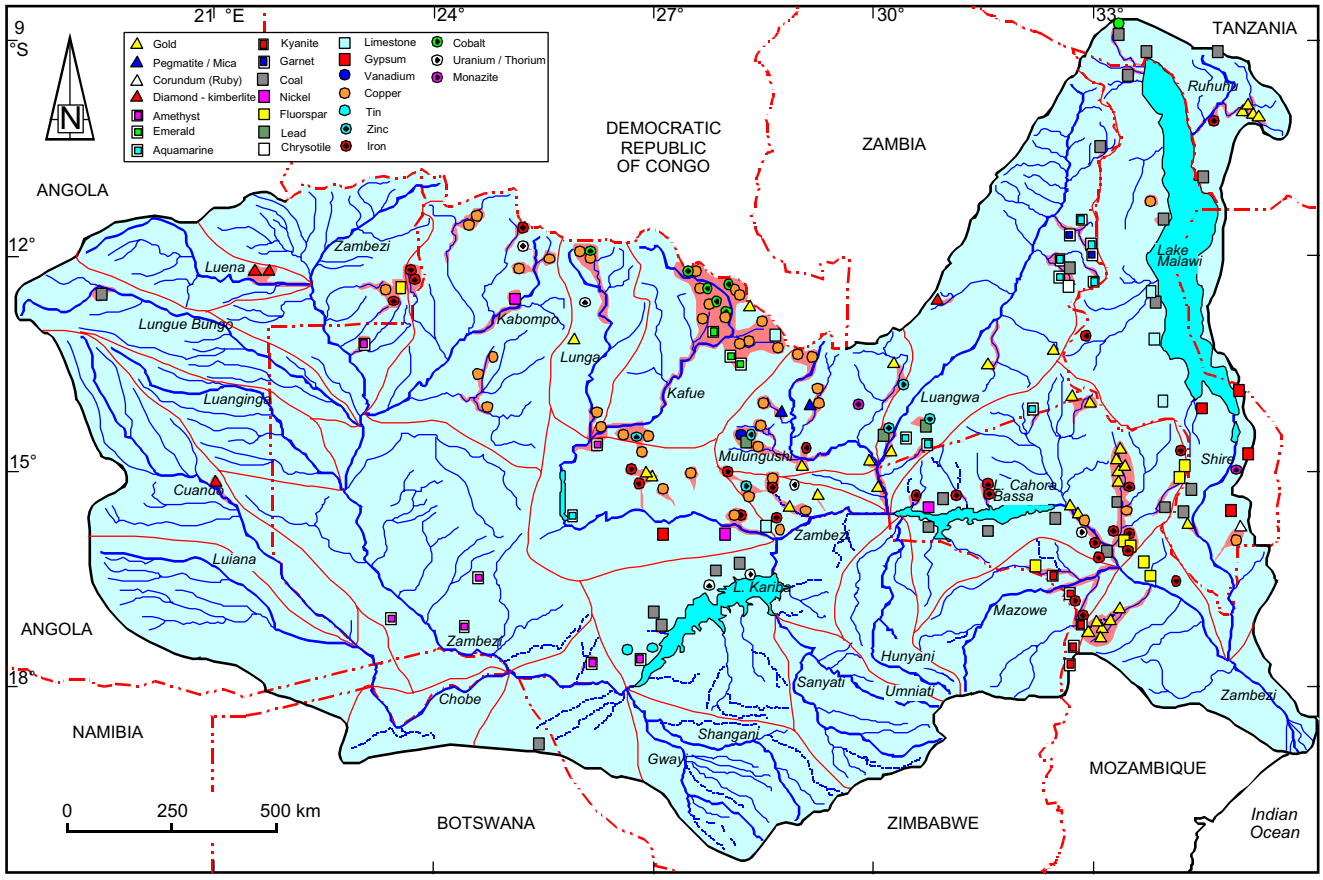

Fig. 1. Impact on water quality on selected Zambian rivers (Adapted from Ashton et al., 2001).

the obsoleteness of the plants and machinery and increased volumes of wastewater due to increased populations and urbanization. Countrywide, raw sewage effluent is discharged into aquatic environment from these sewage plants. Whereas chemical pollutants may cause poisoning of the aquatic life and might eventually lead to death, nutrients have been linked to the proliferation of aquatic weeds (i.e. *Salvinia molesta*) and may lead to eutriphication, blocking of navigation routes, increased BOD and COD concentrations, decrease in overall dissolved oxygen (DO) concentration, etc. Furthermore, ingestion of chemically polluted water could have fatal effects to both humans and animals while consuming water contaminated with nutrients might result in various intestinal infections like gastro enteritis, diarrhea, etc. Nitrogen in water commonly found as nitrate (NO_3) in it self is not particularly toxic but certain bacteria commonly found in intestinal tract of infants can convert NO_3 to highly toxic nitrites (NO_2) resulting in fatal condition called *methemoglobinemia* which is commonly referred to as 'blue baby' syndrome.

Furthermore, agricultural schemes within the KRB contribute to the deterioration of the Kafue River water quality. Major causes of concern are the fertilizers and chemicals. Runoff from agricultural schemes mostly contain chemical residues and fertilizers, which may pollute the water, and depending on loads may result into various hazards to the aquatic life and other lives depending on the river as a habitat and source of water supply. Agricultural activities in the KRB range from crop production to animal and fish farming. Nakambala Sugar Estate, for example, is the biggest agricultural scheme in the KRB. It has over 11,000 ha of land under sugar cane production. It is estimated that not less than 105,000 metric tons of fertilizers have been applied in the last 35 years at Nakambala Estate (ECZ, 2000). On the other hand, Kafue Fisheries located on the northern bank of the Kafue River integrates pig and fish farming. The farm produces over 3500 pigs and 1200 tons of fish per year (ECZ, 2000). Kafue Fisheries thus is another key source of nutrient into the KRB. Table 1 presents results of some selected analyzed parameters of Kafue River water samples from 1984 and 1999 collected between Mazabuka and Kafue Town stretch.

Increase in nitrates, calcium and potassium concentrations in the Kafue River water between 1984 and 1999 suggests intensified activities utilizing products rich in nutrients while the decrease in average dissolved oxygen concentration by about 65% implies increased discharge of oxygen demanding wastes in the river water. This can be demonstrated by the increase in the BOD concentration in the same period (1984–1999) by about 349%.

Table 1
Water quality of the Kafue River between Mazabuka and Kafue Town

Parameters	Average		% Change in concentrations
	1984/85[a]	1998/99[b]	
pH	7.8	7.12	−8.3
Nitrate (mg/l)	0.2	11.1	4400.0
Phosphates (mg/l)	0.3	0.22	−34.0
Iron (mg/l)	0.3	0.22	−33.3
Calcium (mg/l)	23.3	28.9	23.9
Potassium (mg/l)	1.5	2.97	93.7
Ammonia (mg/l)	0.4	0.31	−29.5
Magnesium (mg/l)	12.3	13.1	6.2
BOD (mg/l)	2.2	10.0	347.8
DO (mg/l)	6.6	2.32	−64.7

[a] Kasonde (1986).
[b] ECZ (2000).

3. Towards sustainable management of water quality of the Kafue River

The survival of KRB ecological system and biodiversity depends on the extent to which the degradation and pollution is controlled. Nonetheless, it is clear going by the country's economic development policies and strategies that more new industries and agricultural schemes will be developed. The KRB seems likely to be the target for these new industries and agricultural schemes due to its strategic geographical locality and the abundance of water. It will therefore become very difficult to control the discharge of polluted effluent into the KRB from the newly established industries and agricultural schemes should the current pollution levels from the already established industries, mines and agricultural schemes are left unabated. Options available include:

- Setting up primary treatment facilities at sources.
- Encourage recycling, reuse of wastewater and resource recovery.
- Strict enforcement of Zambia's statutes and laws regarding quality of effluent being discharged into the aquatic environment.
- Investigate viability of use of wetlands for treatment of wastewater.
- Minimize and control run-on/run-off from cultivated lands.

The use of wetlands (natural or constructed) for supplementary wastewater treatment in Zambia needs to be seriously considered. Right now, Zambia requires huge amounts of money to rehabilitate and expand existing wastewater treatment facilities if the quality of the treated effluent from these facilities, which are not only old but also obsolete and in most cases nonfunctional, has to be improved. The use of wetlands for additional treatment of effluent from conversional treatment facilities would positively improve the quality of the final treated effluent. Pollutant removal by natural wetlands receiving treated wastewater range between 70% and 96% BOD_5; 60% and 90% SS; 40% and 90% Nitrogen while Phosphorous removal varies from season to season (US EPA, 1991). Constructed wetlands on the other hand have the positive characteristics of a natural wetland and can also be controlled to eliminate the negative aspects of natural wetlands. Table 2 gives the removal efficiency of typical pollutants.

The efficiency of wetlands for wastewater treatment is attributed to their ability to support a large and diverse population of bacteria that grow on the submerged roots and stems of aquatic plants and are of particular importance in the removal of BOD_5. In addition, the

Table 2
Summary of nutrient removal from constructed wetlands (after US EPA, 1991)

Project	BOD_5 (mg/l)		SS (mg/l)		% Reduction	
	Influent	Effluent	Influent	Effluent	BOD_5	SS
Listowel, Ontario	56	10	111	8	82	93
Santee, California	118	30	57	5.5	75	90
Arcata, California	36	13	43	31	64	28
Sydney, Australia	333	4.6	57	4.5	86	92
Emmitsburg, Maryland	62	18	30	8.3	71	73
Gustine, California	150	24	140	19	84	86

quiescence water conditions of a wetland are favorable to the sedimentation of wastewater solids. Other aspects of wetlands that facilitate wastewater treatment are the adsorption/filtration potential of the aquatic plants' roots and stems, the ion exchange/adsorption capacity of wetlands' natural sediments, and the mitigation effects that the plants themselves have on climatic forces such as wind, sunlight and temperature (US EPA, 1991).

4. Conclusion

It is obvious that anthropogenic activities in the Kafue River Basin are responsible for deteriorated water quality of the Kafue River. The Kafue River being a source of water for industrial and mining activities, domestic use, agricultural activities, hydroelectric power generation, etc., at the same time acting as a sink of pollutants from domestic, mining, industrial and agricultural activities, has constantly received polluted wastewater and effluent for several decades. This pollution and degradation of the KRB ecological system and biodiversity has gone on unabated, thereby threatening the rivers' capacity to assimilate the pollutants by dilution and consequently endangering the ecology of the river system. Significantly, apart from being a key source of water for agricultural, mining, domestic and industrial activities, the Kafue River is a main source of fish protein to most urban and rural populations of Zambia. As such, the Kafue River is core in ensuring poverty alleviation and food security in Zambia. Unfortunately, the continuous discharge of polluted effluent into the Kafue River will continue to contribute to the river's loss of biodiversity. Sustainable management practices are therefore needed to guarantee improved quality of the Kafue River water. These management practices must be developed around Integrated Water Resources Management (IWRM). A healthy Kafue River will not only promote increased biodiversity but also will also sustain livelihoods and contribute to poverty eradication. Nonetheless, the quality of the influent water into the Kafue River will ultimately determine the overall water quality of the river. Thus more efforts have to be directed at improving the quality of wastewater and effluent that is discharged into the Kafue River.

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