Water Resources Management and Water Quality Monitoring in an African Setting

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Abstract

On African lakes, water quality measurements mainly consisted of basic chemical composition of inorganic elements (conductivity, sodium, potassium alkalinity, sulphate, pH, dissolved oxygen) and physical attributes of temperature and light distribution. These chemical studies were mainly to aid the understanding of fish distribution and biology. Over the years, the problems of eutrophication have been developing in the larger natural lakes of Africa. There is now evidence that eutrophication is widespread. Organic contamination of African waters results from efforts to increase food production by use of agrochemicals and from increased municipal and industrial waste discharges into rivers and lakes. A potential continent-wide contamination with PCBs, DDT, and 2-4-D is a real threat. On Lake Kariba, heavy metal accumulation in sediments was least in estuaries without urban influence. Though the levels of heavy metal in plants compared well with those in temperate regions, the levels of lead and cadmium were considerably higher than those in temperate areas and in some cases exceeded World Health Organization limits. The paucity of monitoring data has lead to lack of appreciation of evolving water quality management issues in Africa generally. This paper discusses these and related issues and describes the contributions made by Horiba’fs Water Quality Monitoring System U-23.

1 Introduction

Recently Kyoto and Otsu hosted the Third World Water Forum. The attendance was well in excel of 5000 participants. The discussion topics covered a very wide range of constituencies and subject areas. This mixture of a wide range of stakeholders is a recent development in the water debate. For a very long time, over half a century in fact, the discourse on water issues was confined to hydrologists and water engineers, and aquatic ecologists. Hydrologists and hydrology engineers had common ground: that of taming rivers and putting water to economic benefits for human kind. Marshy areas were drained to provide more land for growing human populations. River channels were re-engineered to control flooding and to expedite the rapid transit of river flow. Impoundments were constructed to ensure water supply for irrigation to produce more food and or the generation of hydroelectricity.

For millennia, the human race has harvested produce from the aquatic environment: fish for food, game birds and plant produce. But perhaps one of the most important properties of water, which has played an important role in growth of human populations, is its cleansing properties. Water removes the wastes humans produce by either simply carrying the waste away or processing it through its biological functions and rendering the waste harmless. In the language of the Shona people of Zimbabwe, there is a saying that “Mvura haina nganga”, translated to water needs no doctor. The concept is that water is pure and harmless and so to attribute a patient’s illness from having drunk water was senseless. It was this property and the issues of proximity that lead to growth of dense human population by lakes and riverbanks. Communities could draw from the river or lake, and send their waste back into the same water system they drew from. As human technology developed, however, new waste products appeared on the market as it were; products that were alien to the ecological systems, such as pesticides, which the system could not process speedily or could not cope with the rate of supply, such as fertilisers or sewage.

It was this fascination with the seeming eternal renewable capability of water quality that gave rise to the discipline of limnology. Slowly limnologists pieced together the chemical, physical and biological processes that determined the status of water quality of a river or lake. It then gradually became clear that that rivers and lakes did not have an infinite capacity to absorb and process human waste. Slowly they showed that the physical and chemical laws of applied to the natural aquatic environments as well; that lakes and river were merely natural reactors.

While the natural scientists were engaged in these studies and disseminating their findings through the scientific media and conferences, they were generally regarded as irrelevant nature lovers who had little contributions to economic development.

However, early in the latter half of the last century signs of the demise of our freshwater resources began to manifest themselves in such important areas as the North American Great Lakes and economically important waterways and lakes in Europe. Popular game fish species began to decline. Fish and fish products became unsafe for human consumption and new human ailments, such as decline in male sperm counts, began to be manifest and attributable to water quality. Suddenly the discourse on water and water quality expanded from hydrology engineers and limnologists in their private closets to the general public: to households, industry and government. Hence the profile of the Third World Water Forum participants.

Many limnology research organisations have contributed to this global awareness of the importance of understanding the ecology of inland waters for their management. I however would like to single out one organisation for popularising the water issue through its work on inland lakes. At the Third World Water Forum, one of the highlights was the launching of the World Lake Vision. This is a culmination of decades of research on Lake Biwa, the largest of the inland waters of Japan. On Lake Biwa the interrelationship between development, society and the lake environment has been well documented. In parallel the realisation by the citizens of Lake Biwa of the degradation of the values of Lake Biwa, lead to a popular concern and citizens action to rescue the lake from further deterioration. The Lake Biwa research team realised that the involvement of the public in the management of Lake Biwa was essential. Indeed they went further and promulgated this concept at international level and formed the Lake Environment Committee, which plays a significant part in dissemination of knowledge on lake management as well as building capacity, especially in developing countries, on lake management.

2 Status of African Lakes

The early limnologists working on African lakes were struck by the high fish biodiversity of the lakes. Thus, the main interest in African aquatic biology was in the fisheries: their taxonomy and biogeography. Limnological measurements mainly consisted on basic chemical composition of inorganic elements (conductivity, sodium, potassium, alkalinity, sulphate, pH, dissolved oxygen) and physical attributes of temperature and light distribution. These chemical studies were mainly to aid the understanding of fish distribution and biology.

Concern for water quality in relation to human land use largely arose from urban water supply reservoirs, such as Hartbeespoort dam near Pretoria (Allanson B.R. and Gieskes 1961[1], Walmsley *et. al.* 1978, Department of Water Affairs (S. Africa) [2]) and Lake Chivero (then Lake McIlwaine) near Harare (Thornton and Nduku 1982, Watts 1982, Roberts 1982, Magadza 1994 [3]) and Lake Kafue in Zambia (Magadza 1992 [4]). More intensive work on the limnology of natural Lakes was spearheaded by the UNESCO IBP programme where Lake Chilwa and Lake George were intensely studied. This work was greatly assisted by the advances in the measurement of trace elements in fresh waters, as well as modest advances in field instrumentation to enable the rapid determination of oxygen, pH, conductivity and light penetration. The compilation of these techniques by Golterman *et. al.* (1974) [5], Vollenveider (1969) and Edmondson's (1971) work on secondary production, under the UNESCO IBP project, opened opportunities for developing countries to participate in the study of lakes and reservoirs, as the literature on technical procedures to study lakes and reservoirs became available to areas with limited access to international literature.

What then have we learned from the African limnological literature? The works of early African limnologists was simply exploratory and descriptive. The works of Talling (1965) [6] in east African Lakes, Beadle (1974) on Lake Chad, Allanson (1990) [7] on Lake Sibaya, Carey (1971), Magadza (1992) [4] on the Kafue river, Magadza (1985) [8] on L. Bangweulu have been useful in providing data on state of lake environments in these African inland waters during the early and later parts of the last century.

However, these studies were knowledge, rather than issues driven. The 60's of the last century were decolonising years. The new nations embarked on economic development programmes that invariably called for water resources development for energy, irrigation and water supply. The one consideration in the water development programmes was the hydrological potential of the river basins to be exploited. Few, if any, environmental impact studies to relate the future reservoirs to their watershed environment were undertaken, with the notable exception of the Kafue hydroelectric project in Zambia (FAO, 1968 [9]). In addition, the development of fisheries and other industries attracted large populations to settle around some of the large lakes, such as Lake Victoria, Lake Tanganyika and Lake Malawi. Population growth lead to increased forest clearing for crop production. Rural to urban migration resulted in overloaded urban waste management facilities.

These demographic changes occurred after the initial round of studies on African lakes, and thus their potential impact on water quality in lakes, reservoirs and running waters went largely unmonitored, except for a few cases such as L. Chivero, which had an immediate and visible impact on urban water supply. Further, practically all the major river basins of Africa are transboundary. It is only in the last decade of the last century that protocols on transboundary water resources management pertinent to the issues of water quality rather than just quantity, began to be formulated by the participating riparian states, often with an intermediary, such as UNEP, taking the initiative.

The net result of this historical situation is that, while there was considerable work on monitoring the various inland lake and river fisheries and the development of fisheries management methods (e.g. stock assessment) changes in water quality largely went unnoticed, until crisis situations developed, with perhaps the exception of South Africa, which is the only country with a Water Research Act.

In 1994, the Committee for Inland Fisheries of Africa (CIFA), a committee of the Food and Agriculture Organisation, FAO, undertook a review of pollution in the African Aquatic environment (Calamari and Neave 1994 [10]). They reviewed data on organic pollution, heavy metal pollution and chlorinated hydrocarbons. The review indicated that, apart from hot spots such as Hartbeespoort Dam in South Africa, Lake Mariut in Egypt and Papenkuis River in South Africa, generally the level of pollutants in aqueous medium, sediments and flora and fauna were lower than those of European and North American waters. However, the review stressed the variability of the data both in extent and quality. Most data were from limited project mode studies. The review recommended the establishment of monitoring networks and institutional capacity building, a finding later confirmed for the Southern African Development Community (SADC) (Box 1). Since 1975 when Nakuru began to industrialise heavily, arsenic, cadmium, copper, mercury, lead, chromium, DDT, DDD and some other toxic substances have built up in that lake.

Box 1 Status of Water Quality Monitoring in SADC Area

> There is also a problem of inadequate institutional frameworks for water quality monitoring in a number of member States. However, the level of development in terms of water quality monitoring as well as management varies from country to country with some countries being in the process of establishing them while others are still relying on inadequate facilities and fewer personnel.
>
> http://www.sadcwscu.org.ls/Reports/report.htm

3 The Eutrophication Problem

The paucity of monitoring data has lead to lack of appreciation of evolving water quality management issues in Africa generally. However, the more urbanised parts of southern Africa give a window into the emerging issues. Southern Africa is a water scarce region; therefore, the storage of water in reservoirs and its reuse is higher than other less developed parts of sub Saharan Africa. Fig.1 illustrates this dilemma in the case of Lake Chivero, a water supply reservoir to the city of Harare. The inflow rivers of the lakes watershed are highly seasonal so that the return flow from the city is a significant contribution to the city's water supply. Similarly, in South Africa, the Crocodile River is the only stream in South Africa that has shown an increase in mean annual flow, due to the wastewater from Johannesburg.

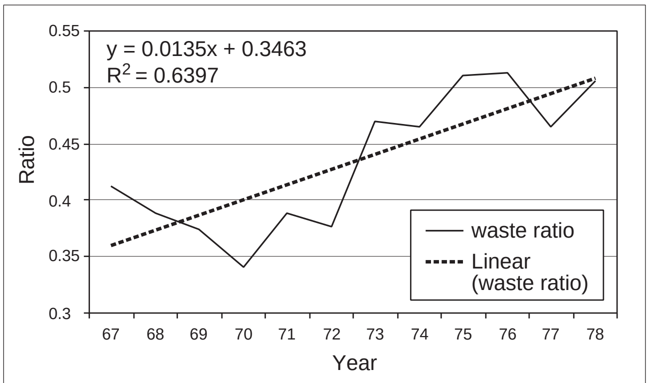

Fig.1 Ratio of Abstarction to Returned Treated Sewage in Lake Chivero (Magadza 2003 in Press [11])

Fig.2 is a historical record of the concentration of dissolved phosphorus in the Lake Chivero, while Fig.3 is a sample phosphorus depth profile at two sites in the Lake. The Manyame site is an upstream site while the Dassie site is closer to the dam wall. The survey of the eutrophication monitoring programme in South Africa gives a range of phosphorus levels in South African dams as ranging between 0.012 mg/L and 0.545 mg/L (Table 1). The data for Lake Chivero thus show that the lake has been in the hyper eutrophic state for the period shown.

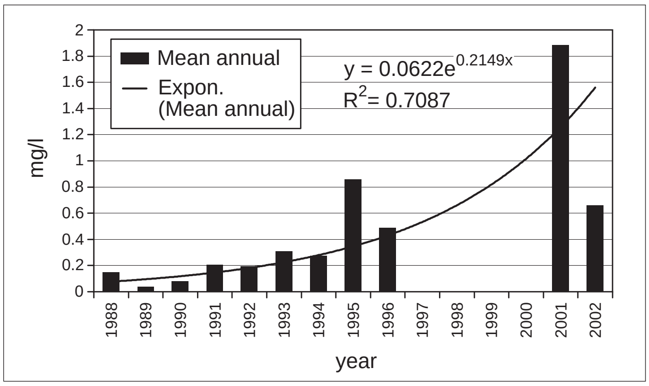

Fig.2 Annual Mean Phosphate Levels in Lake Chivero

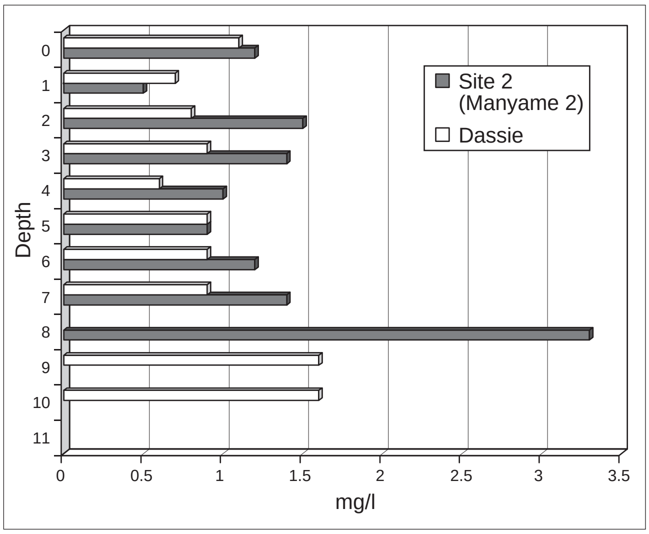

Fig.3 PO_4 Depth Profile in Lake Chivero

Table 1 Trophic Status of Some South African Reservoirs (Department of water Affairs, 2001, Carin van Ginkel (2002) [12])

Trophic state	Total Phosphorus		No of dams
	Lower range (mg/L)	Upper range (mg/L)	
Hypereutrophic	0.145	0.545	9
Eutrophic	0.084	0.221	11
Mesotrophic	0.034	0.115	10
Oligotrophic	0.012	0.047	10

In southern Africa and other parts of Africa, the major urban areas are located on the plateaux, normally above 900 m above sea level. This pattern was determined by the need to avoid areas of endemic diseases such as malaria, yellow fever and veterinary diseases transmitted by blood sucking insects, such as sleeping sickness. This located future major urban areas along the watershed, or in areas of low stream order where stream flow is normally low, with possibilities of dry season flow cessation in the sub-humid areas as in Southern Africa. As the urban areas grew the need for more reliable, secure water supply lead to drawing water from reservoirs downstream to the settlements, with the possibility of urban waste flowing to the water supply source.

A scan of eutrophication literature in Africa shows that most of it originated from South African studies. This shows the heightened awareness in this water stressed part of Africa. However there is evidence that eutrophication is more wide spread in Africa. The case of Lake Victoria is an illustrative example. This lake has been regarded as pristine for many decades. However, in the last two decades the lake suddenly showed signs of serious eutrophication, with massive water hyacinth growth and cyanobacteria blooms.

Talling and Lemoalle (1998) [13] compared changes in chemical composition of Lake Victoria water between 1961 and 1990. In the 1960 data ammonia nitrogen, and nitrate nitrogen were barely detectable, while in the 1990 data ammonium and nitrate nitrogen had attained values of 0.5 mmol/m^3 and 2 mmol/m^3 respectively in surface waters, increasing to over 5 mmol/m^3 below the thermocline. Because of the volcanic origin of the basin soils phosphorus naturally occurred at levels of about 1 mmol/m^3 in the 1960 data, while in the 1990 data hypolimnetic phosphorus had risen to 4 mmol /m^3. The deoxygenated layer has risen from 60m in the 1960 data to 40 m below the surface in the 1990 data. In the 1961 data chlorophyll α averaged about 2 mg/m^3, with maximum at about 20 below the surface, while in the 1990 data epilimnetic chlorophyll α levels ranged between 14 mg/m^3 and 24 mg/m^3, with the maximum at about 10 m below the surface. These changes were accompanied by drastic reduction in epilimnetic silica levels from around 7 mmol/m^3 to less than 1 mmol/m^3.

Hecky (1993) [14] and Hecky *et. al.*(1994) [15] have shown drastic changes in the phytoplankton composition and primary productivity of Lake Victoria that accompanied the changes in nutrient content of the lake. In essence, the flora changed from diatom and green algae domination to blue greens and virtual disappearance of the diatom flora.

An interesting outcome of the eutrophication of Lake Victoria is its impact on cichlid fish diversity. The drastic decline in cichlid species in Lake Victoria has traditionally been ascribed to the introduction of the voracious Nile perch, *Lates nilotica*, into the lake. Recently Seehousen et al (1997) [16], argued that the cichlid species of Lake Victoria are able to interbreed and produce fertile offspring. Species isolation is controlled and maintained by the mate recognition system, based on species colouration. Increased turbidity due to eutrophication disrupts this genetic isolation mechanism, leading to greater interbreeding between species, and thus loss of species diversity.

The Lake Victoria case illustrates how, over the years, the problems of eutrophication have been developing in the larger natural lakes of Africa. These concerns are now being voiced for Lake Malawi and Lake Tanganyika, and other east African lakes, such as Lake George and Lake Edward.

While industrial and municipal waste contributes to nutrient loading of inland waters, the emerging problem is that of unmonitored diffuse source run off. Magadza (2002) [17] has noted that a feature of many African urban centres is the short doubling period of the urban population. Fig.4 illustrates the growth of urban population in sub-Saharan Africa. The mean doubling period for urban population growth is 15.4 years.

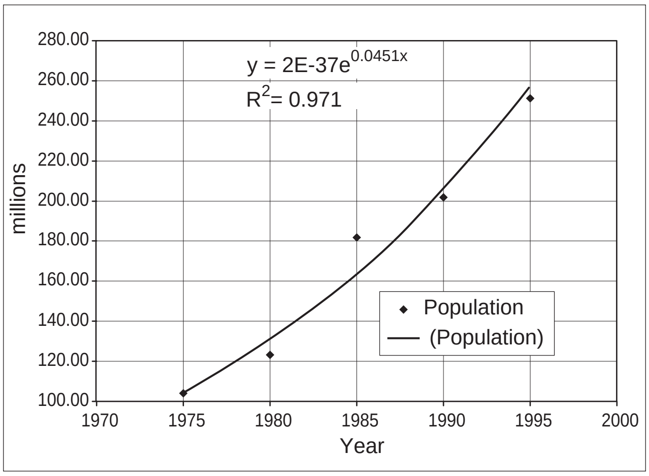

Fig.4 Growth of Urban Populations in Africa (Magadza 2003 in Press [11])

The main driver for urban population growth is the rural to urban migration. The fiscal facilities of the urban authorities are unable to meet with growing demands for services because:

- The short doubling period requires the upgrading of facilities on the average every 1.5 decades.
- The urban migration is not complemented by the employment opportunities in the urban economy.

The result is the growth of high density settlements with poor services, such as waste disposal and sanitary facilities. Because of the low income status of such residential areas urban agriculture, including animal husbandry, is widely practiced to supplement incomes.

Table 2 gives comparative nutrient exports from types of settlement in the Harare municipality. The data show the high levels of storm water nutrient export from the high density generally low income and poorly serviced suburbs. The low P: N ratio indicate an anthropogenic source of phosphorus, in addition to that derived from degradation of organic material. This arises from several sources, including use of phosphate fertilizer in the urban cultivation lots characterising the high density areas. In addition, some industries, such as the fertilizer factory on the Mukuvisi catchment, periodically release factory effluent high in phosphorus.

Table 2 Phosphorus and Nitrogen Export through Surface Runoff from Harare Suburbs

		Phosphorus		Nitrogen			Total export	
Catchment/ Suburb	Type	Tonne km^{-2}	Kg $Capita^{-1}$	Tonne km^{-2}	Kg $Capita^{-1}$	Ratio P: N	P-Tonne	N-Tonne
Gwebe	Low	0.02	0.04	0.16	0.42	5.81	0.99	9.31
Muwisindale	Low	0.07	2.31	1.22	41.39	5.99	5.24	93.96
Kuwadzana Mukuvisi	Medium High/ Industrial	0.08 10.28	0.17 1.00	0.47 39.98	0.96 3.89	3.89 3.61	2.88 98.99	16.75 385.04
Marimba Budiriro	High/ Industrial High	0.13 2.30	0.77 0.23	0.86 13.77	4.98 1.35	3.68 9.42	9.28 22.08	60.31 132.17
Epworth	High	3.38	1.11	12.20	4.00	17.95	103.12	371.88
Glenview	High	0.30	0.39	1.09	1.44	6.50	30.23	111.39
Total or mean		1.62	0.56	7.53	6.38	5.69	272.81	1180.81

Table 3 shows the changes in the phosphorus loading of Lake Chivero. The lake was already considered hypereutrophic in the late 1960s, with a phosphorus loading of some 288 tones per anum, which included treated sewage effluent contribution. However Table 3 and Fig.5 show that the export from surface runoff from Harare city now contributes 272 tonnes of phosphorus. Thus even if the piped sewage could be treated to very high standards of phosphorus and nitrogen removal the diffuse source surface run off is now sufficient to maintain a state of hyper eutrophy in the lake.

Table 3 Historical Changes in Summer Phosphorus Regime in L. Chivero (after Thornton, 1982, Magadza 1997)

Parameter	1967	1978	1996
P-load (tonnes pa)	288	39.6	350
Mean P- conc	2.25 (μl^{-1})	0.13 (mg/l)	1840 (μl^{-1}) (Manyame)
Conductivity μScm^{-1}	160	120	800 (Summer)

It has been noted that within the next half century most of the West African coastline and the eastern seaboard of Southern Africa will experience the merging of coastal urban settlement into large megalopolitan continua (Magadza 2000). Thus, the case study illustrated by the Harare situation is likely to be the general situation in African urban areas, unless there is a significant upturn on the economic performance of Africa as a whole. Urban poverty, unless addressed by innovative economic strategies, is likely to be a significant source of inland waters eutrophication in Africa.

These data on surface runoff presented here are only a small window in the evolution of water resources management paradigms in Africa. The data derive from a period of a few months during the wet season of Zimbabwe. It thus emphasises the need for robust monitoring protocols to track the development of water quality management issues in Africa.

4

Pest Control

Africa has several endemic vector borne diseases. Some of these are transmitted by vectors associated with freshwater in their life cycle, such as malaria and schistosomisis, onchocercaiasis (river blindness) or purely land based parasites, such as Trypanosomiasis transmitting tsetse flies. Fig.5. Shows bare soil in the L. Kariba environs after bush fires lit before spraying DDT in tsetse control.

Fig.5 Bare Soil in the L. Kariba Environs after Bush Fires Lit before Spraying DDT in Tsetse Control

In either case, the control of these vectors involves the use pesticides. Table 4 shows the levels of DDT and its derivatives as well as levels of PCB in mothers milk in Zimbabwe.

Table 4 Comparison (amounts) of DDT, DDT Derivative and PCB in Mothers Milk (Adapted from Chikuni *et. al.* 1997b); Concentration in ng/g Milk Fat

Area	Characteristics of land use	Mean Age of mothers	Sum_ PCB	pp-DDE	Pp-DDT	Sum DDT	Ratio DDT/ DDE
Kariba	DDT for vector control	23	2.78	13606	9080	25259	0.6
Kadoma	Cotton	22	59.55	5049	1254	7047	0.2
Esigodini	Subsistence farming	25	13.27	1176	250	1607	0.22

DDT has been widely used for the control of the tsetse fly, Glossina, the vector for Trypanosomiasis, as well as for the control of anophelenes, which transmit malaria. Its use as an agricultural crop pesticide has been banned for several decades now in southern Africa, but there is still a western pest management school who are of the opinion that the benefits of the use of DDT outweigh its ecological and human health impacts, arguing that in tropical environments DDT is rapidly lost from the environment (Douthwaite *et. al.* 1995 [18], Wandiga 2001 [19]). The issue of the behaviour of DDT in tropical environments must be viewed against a number of variables. In the Lake Kariba environs the tsetse control teams would extensively burn the areas that they intended to spray, leaving bare surface before the onset of the rains (Fig.5). The early rains runoff in these areas is characterised by high silt content, implying that one of the processes of DDT removal from soils is simply erosion into receiving waters (Berg 1995 [20]). The volcanic east African soils discussed by Wandiga are also easily erodable. Support for this scenario can be found in the extensive work of the Swedish sponsored programme Tracking Pesticides in the Tropics reported by Carvalho *et. al.* (1998)[21]. In this study persistent pollutants, including DDT were found to accumulate in marine environments in coastal areas supplied by rivers draining hinterlands with persistent pesticides usage. In all, the World Health Organisation has come to a consensus opinion of the need to eliminate the use of DDT (Box 2).

Box 2 WHO Consensus on DDT Usage

> In sum, the WHO and its experts, to varying degrees and using various semantic formulations (Integrated Pest Management, integrated control), have slowly embraced Integrated Vector Management and reduced reliance on DDT. The challenge now is to speed this process along, making even more explicit the need to reduce reliance on DDT specifically and pesticides more generally, and establish the financial and institutional mechanisms to make this happen

Magadza (1996) [22] noted that the levels of DDT in fish in Lake Kariba (Berg *et. al.* 1992 [23], Berg and Kutsky 1994 [24]) exceed those cited as causing larval mortality in New Zealand Salmon by Samiullah (1990) [25]. Further Magadza, using data from Sanyanga (pers. com) noted a large discrepancy between expression of sexual maturity in males and females of Synodontis zambeziansis, with male populations showing much lower incidences of sexual maturity after the Stage 4 age group, whereas the sex ratios at lower age groups were nearly equal. Although no data on DDT levels in this species are available, data from other species in the lake would suggest that this species had significant levels of DDT and derivatives (Berg et al 1994 [24]). Dose response essays in East Africa indicate that DDT loads of just over 0.01 mg kg^{-1} body mass can cause mortalities of up to 50% in fish and brine shrimps (Mutaaga and Yebiyo, 1999 [26]).

DDT has now been found to be present in eggs of flamingos in Etosha pan, a once a pristine saline wetland in the arid part of northern Namibia (Berry et al 1973 [27]). DDT has also been widely reported in East African rift valley lakes and Lake Victoria (Wandiga 2001 [19]), and in West African Environments. There are similar report of pesticide and heavy metal toxicity causing the deaths of thousands of flamingos in East African rift valley .

5 Chemical Spills

The PCB data from mother's milk in Zimbabwean waters illustrate a not uncommon problem in Africa; the lack of appreciation of the consequences environmental spills. The source of the PCB was from decommissioned electrical transformers, which were disposed of by selling them to metal scrap dealers. In recovering the metal the PCB oil was simply spilt into public drains or on soil (Fig.6).

Fig.6 Soil Soaked with PCB in Harare Suburb

Though the authorities were alerted to the possible health and environmental hazards which this episode posed, there was no official reaction to the situation. Though governance contributed to the lack of response to this major environmental pollution event the reality of the matter was the lack of monitoring capacity. As this happened in every major city of Zimbabwe, and all major cities are located on the watershed most rivers would have been contaminated. The evidence of the degree of contamination only surfaced in a survey of mothers' milk. Thus, the shear scale of monitoring and correction measures needed were well beyond the capability of the nation. In other words the general lack of awareness of the health and environmental impacts of materials used in industry, and thus the lack of set procedures for managing industrial waste can lead to major pollution problems that may go unnoticed.

6 Control of Aquatic Weeds: 2-4.D

The eutrophic state of Lake Chivero has resulted in a permanent weed infestation by Eichhornia, Hydrocotyl and other weeds such as Myriophyllum (Fig.7). While in the mid to late 1970s ecological management was the main approach to the control of aquatic weeds in Lake Chivero, the application of herbicides, particularly 2-4.D. has now become the standard solution to the weed problem in that lake. The health and ecological impact of the use of this herbicide on now a regular basis has never been evaluated.

Fig.7 Water Hyacinth in Lake Chivero

The invasion of inland waters by water hyacinth in Africa is now quite widespread (Navarro and Phiri 2000 [28]), with the most spectacular occasion of the invasion of L. Victoria. Navaro and Phiri (loc cit) note that though water hyacinth has been known in Africa since late 1800 in Egypt, the explosive spread of the weed occurred in the 1980s. This period also coincides with efforts to increase food production by use of agrochemicals as well as increased municipal and industrial waste discharges into rivers and lakes. Consequently, the weed is now reported in all the major river systems of Africa. Thus, the potential continent wide contamination with 2_4.D is a real threat.

7 Salinisation

Fig.8 (Magadza in press) shows the chloride depth profile measured with a Horiba Water Quality Monitoring System U-23 (Fig.9) in Lake Chivero in September 2000. Chloride levels in natural streams in the catchment of this lake are undetectable, as the geological underlying rocks are granitic. Conductivity in this lake over the years has risen from around 50 μS cm^{-1} to current values of over 1000, depending on extent of seasonal flushing of the lake.

The usual main causes of salinity increase in inland waters are following.

- Coastal saline water intrusion due either to reduced river flow in coastal areas, such as the River Gambia;
- Coastal subsidence due to a number factors, including falling water table due to reduced river flow
- Long term changes due to irrigation.

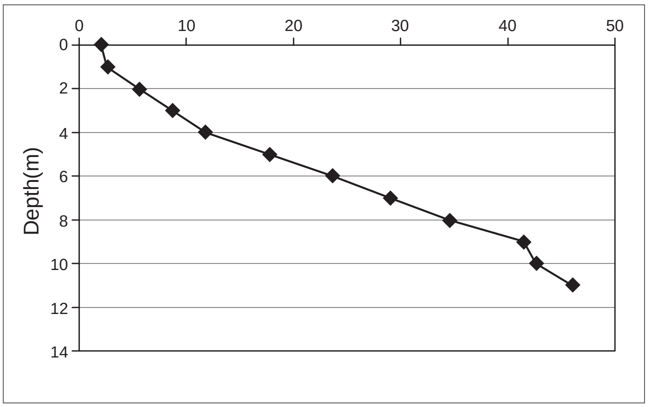

Fig.8 Chloride Depth Profile in Lake Chivero (Magadza 2003 in Press [11])

Fig.9 HORIBA's Water Quality Monitoring System U-23

The Lake Chivero salinity is another illustration of human impact on fresh water resources; i.e. the increasing proportion of return wastewater to public streams, in an environment of increasing water stress. Magadza (1997) has attributed the increase in salinity in Chivero to increased wastewater return from the city of Harare.

The data on salinity and eutrophication raise the issue of wastewater and water resources management under water stress and climate change. Southern Africa is already a water stressed region, and by 2025, it is projected to be a water deficit region. Wastewater recovery for reuse will thus become a real option to meet water demand. In Namibia, for example, there is now an almost full recovery of wastewater for reuse in Windhoek. In South Africa, the Crocodile River flow now primarily consists of return flow from industrial effluent and agricultural run off (Department of Environmental Affairs and Tourism. 1999 [29]). In order to meet future challenges of water demand waste water treatment technology now needs to be upgraded to standards that can produce reusable water as a matter of routine.

8 Bacterial Contamination

One of the IPCC (TAR) projections for the African region is the possible increase in enteric disorders associated with flooding frequency. In Zimbabwe Chapungu, cited in Magadza (2002) [17] found considerable levels of faecal coliform bacteria in street runoff in Harare. Feresu and Van Sickle (1990) [30] found a plume of feacal coliform bacteria extending for well over 25 km downstream of the Victoria Falls and Livingstone urban area on the Zambezi River. Masundire (1998) [31] noted that the sewage outflow from sewage treatment ponds at Livingston Town accounted for less that 10% of total sewage output from that riverside town, implying that the bulk of the wastewater was discharged into the Zambezi River untreated. Magadza and Dhlomo (1996) [32] found considerable amounts of faecal coliform bacteria on the shores of Lake Kariba associated with lakeshore settlements. Recently in Bamako the state had to use the military to clean congested sewer drains.

Fig.11 shows the incidences of bloody diarrhoea in over 5 year old children in a high-density suburb of Harare, Zimbabwe. The main wet season lasts from November to March. The data show the close relationship between wet season and enteric disorders. Though all households in this suburb would have waterborne sanitation, a combination of overcrowding and lack of public sanitary amenities outside the home unit and frequent breaches of the sewers due to overloading, results in overland transport of faecal material during street flooding (Magadza 2002 [17]).

The African continent has many large urban areas located by river banks or lake shore that have inadequate or no wastewater treatment facilities. In the middle of the last century, these settlements were relatively small with populations hardly exceeding 50000 persons. At that level the dilution factor of receiving waters was considered adequate to cope with the wastewater outfall; However now the population in these urban areas are in millions wastewater disposal is now a major health and ecological consideration.

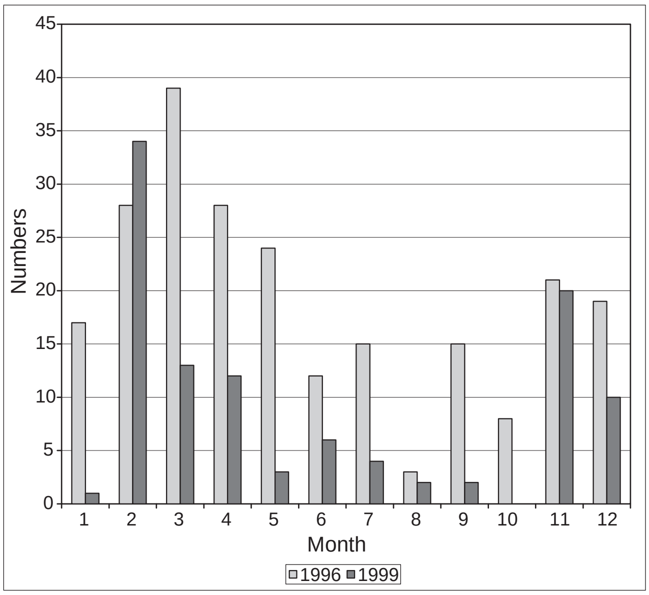

Fig.10 Bloody Diarrhoeia, over 5 Year Olds, Mbare (Magadza 2001)

In arid and semi arid areas where surface water is scarce wells have become to a common solution to water supply. Health workers have promoted so called protected wells as a solution both to water scarcity and safe water supply for rural households. Conboy (1999) [33] has found evidence of well waters that exceed the WHO limits of bacterial contamination in rural areas in Zimbabwe. Work in progress (Mukwashi per com) on tube wells of over 20 m depth is also giving similar results.

The IPCC in its Third Assessment identified water borne diseases, associated with increasing flooding frequency as a cause for concern. Poor sanitation and flooding and warmer climate increase the risk exposure to diseases such as cholera.

The water quality management issue here is that monitoring of bacterial contamination in surface and ground waters, because of its costs and infrastructure requirements, is often anecdotal and the continent's full exposure to waterborne diseases may be underestimated. The survey by Calamari and Neave (1994) [10] of pollution in Africa did not particularly high light this aspect of water pollution, mainly because of lack published data.

9 Heavy Metals

In their review of pollution in Africa Calamari and Neave (loc cit) concluded that the heavy metal levels in aquatic environment and in biota was lower than that from industrialised areas, but compared well with other developing regions, such as South East Asia. In order to make this regional comparisons the authors excluded what they termed "hot spots", i.e. cases of anomalously high levels. In management planning, the identification of such hot spots might give a timely warning in the monitoring of development of pollution problems. We have noted above that heavy metal and agro chemical toxicity have been implicated in deaths of flamingos in the East Africa rift valley lakes. The role of human settlements in modifying the aquatic environment with respect to heavy metal content can be illustrated by two studies from Zimbabwe. Greichus et al (1978) found that the blues green algae of Lake Chivero (then Lake McIlwaine) had the highest content of Zn (190 $\mu g\ g^{-1}$), Pb (78 $\mu g\ g^{-1}$), Cd (1.5 $\mu g\ g^{-1}$), and second highest in As (2.9 $\mu g\ g^{-1}$) dry weight. In a study of the catchment of the lake Heatherly and Viewing (1982) found anomalously higher heavy metal concentrations in sediments from artificial drains servicing high density residential areas townships in comparisons to sediments from natural streams in the same area and the parent bedrock.

Similarly, on Lake Kariba (Berg et al, 1995 [34]) heavy metal accumulation in sediments was least in estuaries without urban influence. Though the levels of heavy metal in plants compared well with those in temperate regions, the levels of Pb and Cd were considerably higher than those in temperate areas and in some cases exceeded the WHO limits.

Although in Africa environmental studies of this nature very rarely extend to human health impacts one resident of Kariba town confided to the present author that they had been medically diagnosed for Hg and DDT poisoning.

10 The Social Background

The material cited here has, with a few exceptions, come mostly from project mode investigations, often by interested scientists, rather because of state policy directed monitoring programmes.

The problems of environmental management in Africa have their origins in historical, economic, sociological and political factors. The infrastructure of many cities in Africa was designed for small urban expatriate communities. Some of it has aged considerably. However, the post independence Africa has seen a surge of urban drift, primarily due rural poverty. As noted above Magadza (2002)[17] notes that the mean doubling period of many Africa cities is close to the project development, funding and implementation cycle for such projects as wastewater treatment works. Thus, many urban settlements are caught in a spiral of growing services demands and diminishing resources.

Another important factor is the issue of governance, which ranges from lack of public awareness because the state does not canvas for citizens involvement and consensus building in environmental management, to shear state dereliction due to the absence of democratic institutions. Successful environmental monitoring requires legal and institutional frameworks that ensure sustainability at both policy and operational level.

Nevertheless, perhaps the most important issue in water quality monitoring is lack of resources, where limited state funds are channelled to activities that appear to need urgent attention, such as health services. Environmental monitoring is viewed as of no immediate benefit. However, the situation leads to unmonitored environmental deterioration, which leads to higher health risks, and more costly remedial measures.

11 Conclusion

This brief overview of the state of water quality in Africa has aimed at demonstrating that there are emerging concerns of water quality management associated with both growing water stress, especially in southern Africa, urban demographic trends and a lack of sustained monitoring programmes to build a chronology of water quality trends. These concerns apply as much to large natural lakes as to artificial impoundments and rivers. Resource scarcity and institutional and governance issues are major contributors to the emerging water quality management problems. Low public awareness of the economic, social and ecological consequences of water quality deterioration results in a lack public impetus on citizen participation in water quality management.

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