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Chemistry and pollution of natural waters in western Kenya

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Abstract—Selected water analyses from the literature and current research in western Kenya are tabulated and the relationships between critical water quality parameters described. The waters are chemically characterised with Na as the dominant cation and bicarbonate as the dominant anion and, while waters of obviously different sources are represented, the available chemical data point to a general classification of bicarbonate-Na-rich waters, even for the saline waters of Lake Magadi. Potassium and chloride are among the less abundant constituents. The concentration level of nutrients (nitrate, phosphate and sulphate) is mostly lower than maximum permissible drinking water levels, and salinity is not yet a serious problem in water bodies that are exploited for domestic and industrial purposes. Fluoride levels are variable with the higher values occurring in waters in and around the Rift Valley. Limited analytical data for I in waters from the Eldoret, Kiambu and Nairobi areas indicate concentrations well above world average figures. Mean values of some key water quality indicators such as total dissolved solids, total suspended solids and heavy metals are well below the threshold for contaminated water. These values are however exceeded by several factors in saline waters of lakes and in some springs. Significant organic pollution is reflected by mean values of parameters such as biochemical oxygen demand and faecal coliforms. The present quality of most of the water bodies in this part of the country is considered to be adequate at present for domestic and other purposes, though a gradual decrease in quality is evident from the recent upsurge in industrial activities in the subregion. © 1997 Elsevier Science Ltd. All rights reserved.

Résumé—Une sélection d'analyses d'eaux du Kenya Occidental provenant de la littérature et de nos travaux en cours est présentée. Les relations entre paramètres critiques pour la qualité des eaux sont également décrites. Du point de vue chimique, les eaux sont caractérisées par la prédominance du Na comme cation et du bicarbonate comme anion. Malgré le fait qu'il s'agisse d'eaux provenant de sources manifestement différentes, les données chimiques disponibles indiquent qu'elles appartiennent à la classe générale des eaux riches en bicarbonate et Na, même dans le cas des eaux salines du Lac Magadi. Parmi les constituants les moins abondants, on note le K et le chlorure. Le taux de concentration en substances nutritives (nitrate, phosphate et sulfate) est le plus souvent inférieur aux taux acceptables des eaux potables. Dans des nappes aquifères exploitées à des fins domestiques et industrielles, la salinité ne constitue pas encore un problème sérieux. Les taux en fluorures varient, les eaux provenant de la Rift Valley ou de ses alentours montrant les valeurs les plus élevées. Pour les iodures des eaux des régions de Eldoret, Kiambu et Nairobi, des données analytiques limitées montrent des teneurs dépassant largement les moyennes mondiales. Les valeurs moyennes de certains indicateurs clés de la qualité des eaux tels que le total des solides dissous, le total des solides en suspension, ainsi que les métaux lourds sont nettement inférieures aux seuils critiques d'eaux contaminées. Dans le cas des eaux salines de lacs et de certaines sources, ces valeurs sont, toutefois, supérieures de plusieurs facteurs. Une pollution organique significative apparaît à travers les moyennes de paramètres tels que la demande en oxygène biochimique et les coliformes fécales. A ce jour, la qualité de la plupart des nappes aquifères de cette région du pays paraît convenir à des fins domestiques et autres, encore qu'une diminution progressive de la qualité des eaux est évidente suite à une intensification récente d'activités industrielles dans la sous-région. © 1997 Elsevier Science Ltd. All rights reserved.

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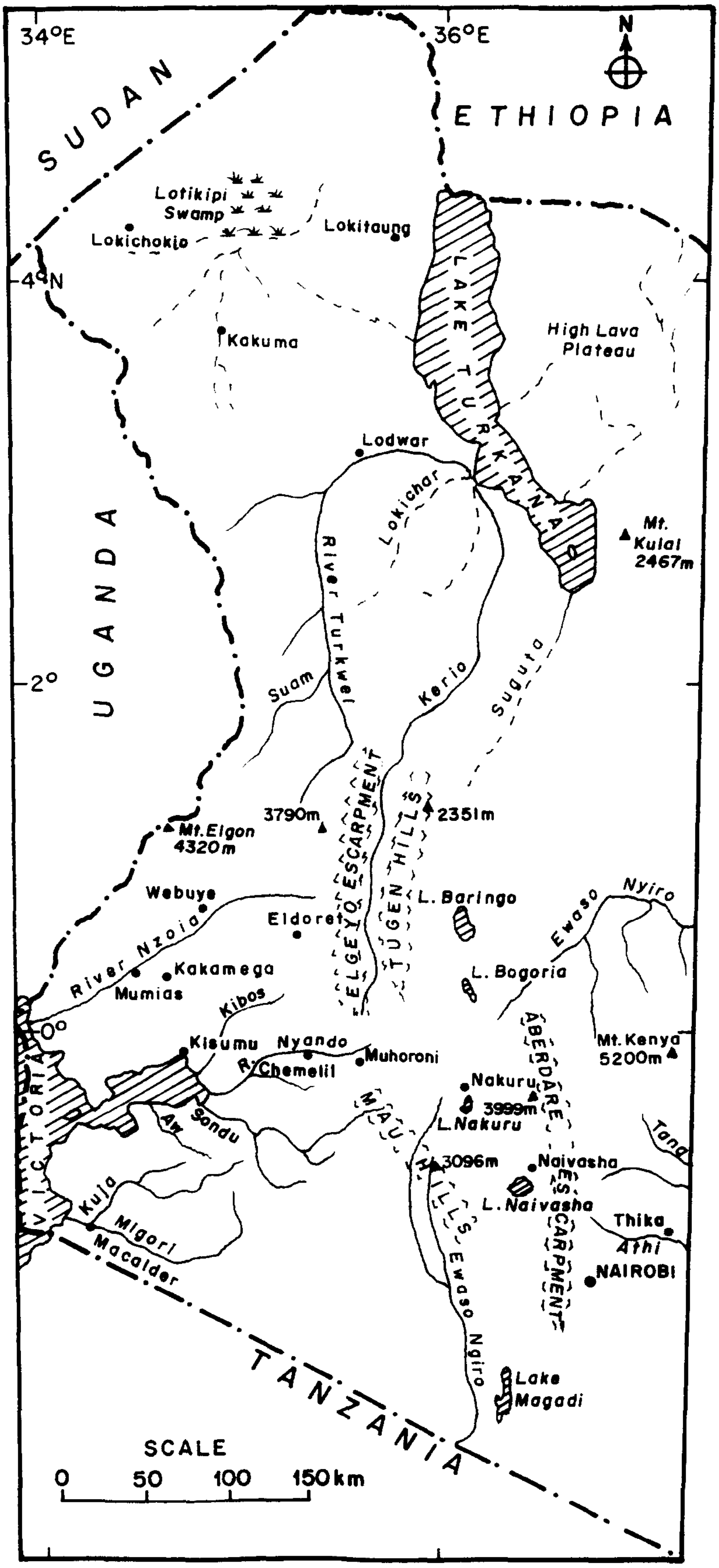

Figure 1. *Location map, including some important components of the hydrological system in western Kenya.*

INTRODUCTION

Surface- and groundwater are the primary sources of water for human consumption, as well as for agricultural and industrial uses in western Kenya. This subregion (Fig. 1) encompasses many of the country's major centres of economic and developmental activities and contains more than half the country's population.

A considerable amount of data on the chemistry and water quality of waters of the subregion already exists, but until recently the data collection has been carried out in a largely unsystematic manner. The first attempts at continuous monitoring of water quality in Kenya were made when the Ministry of Water Development initiated a water quality monitoring programme in 1982 (Bartram, 1992). The broad objectives of this programme were:

i) to establish a network of water quality monitoring stations spread over the major surface water resources of the country;

ii) to collect water quality data from all the stations;

iii) to assess the impact on water resources of existing water pollution sources;

iv) to maintain a water quality data bank for use in planning and future development activities, as well as for the protection and conservation of the water resources; and

v) to establish ambient water quality stream standards.

This programme was reinforced in 1977 when UNEP and WHO, in collaboration with WMO and UNESCO, initiated the first global programme on the monitoring of water quality in rivers, lakes, reservoirs and groundwater: the GEMS/ Water Programme (Bartram, 1992). In addition,

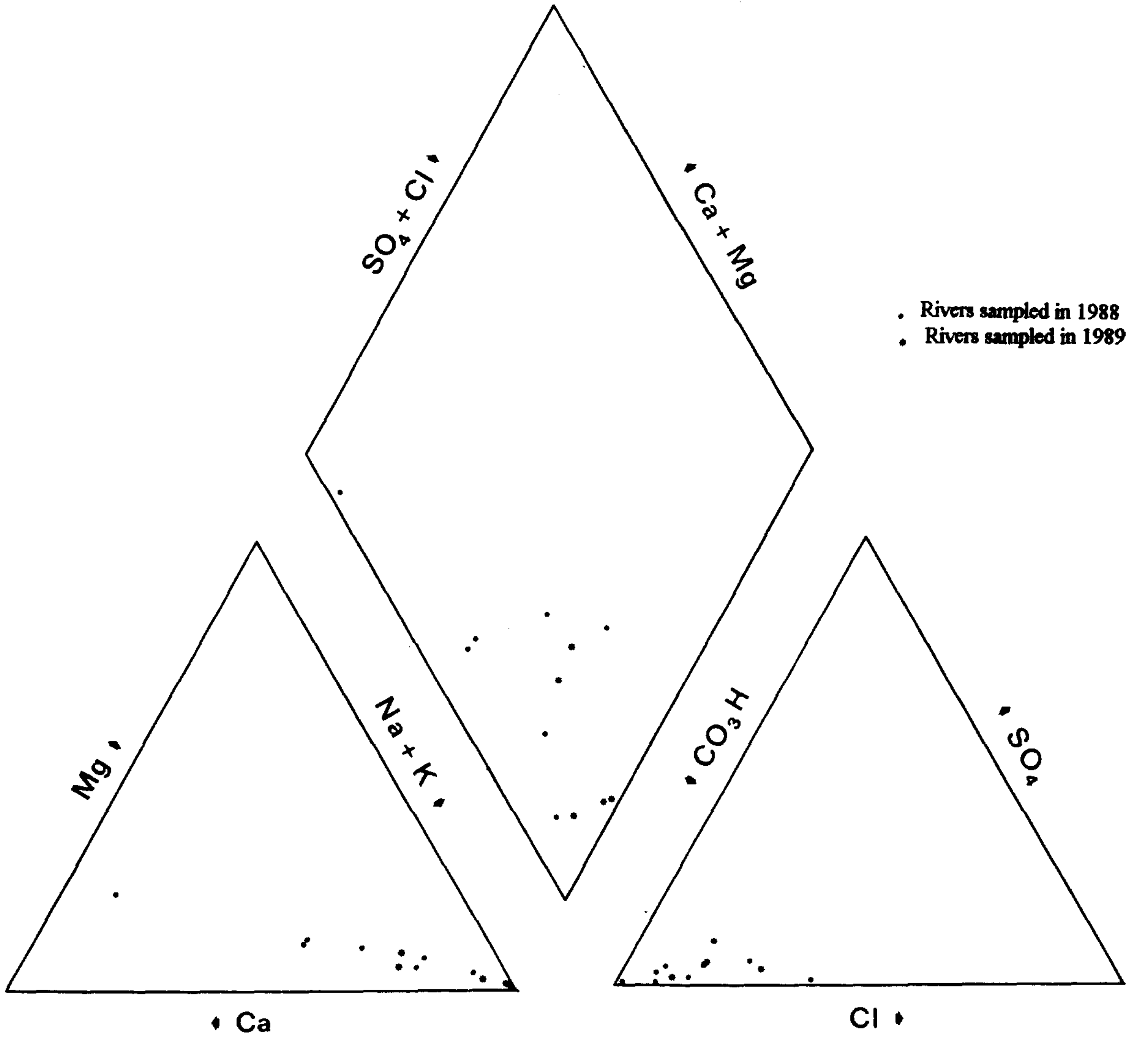

Figure 2. *Piper trilinear plot representing the chemical characteristics of rivers between Lake Baringo and Lake Turkana. Constructed using data from Allen and Darling (1992, Table 7.1).*

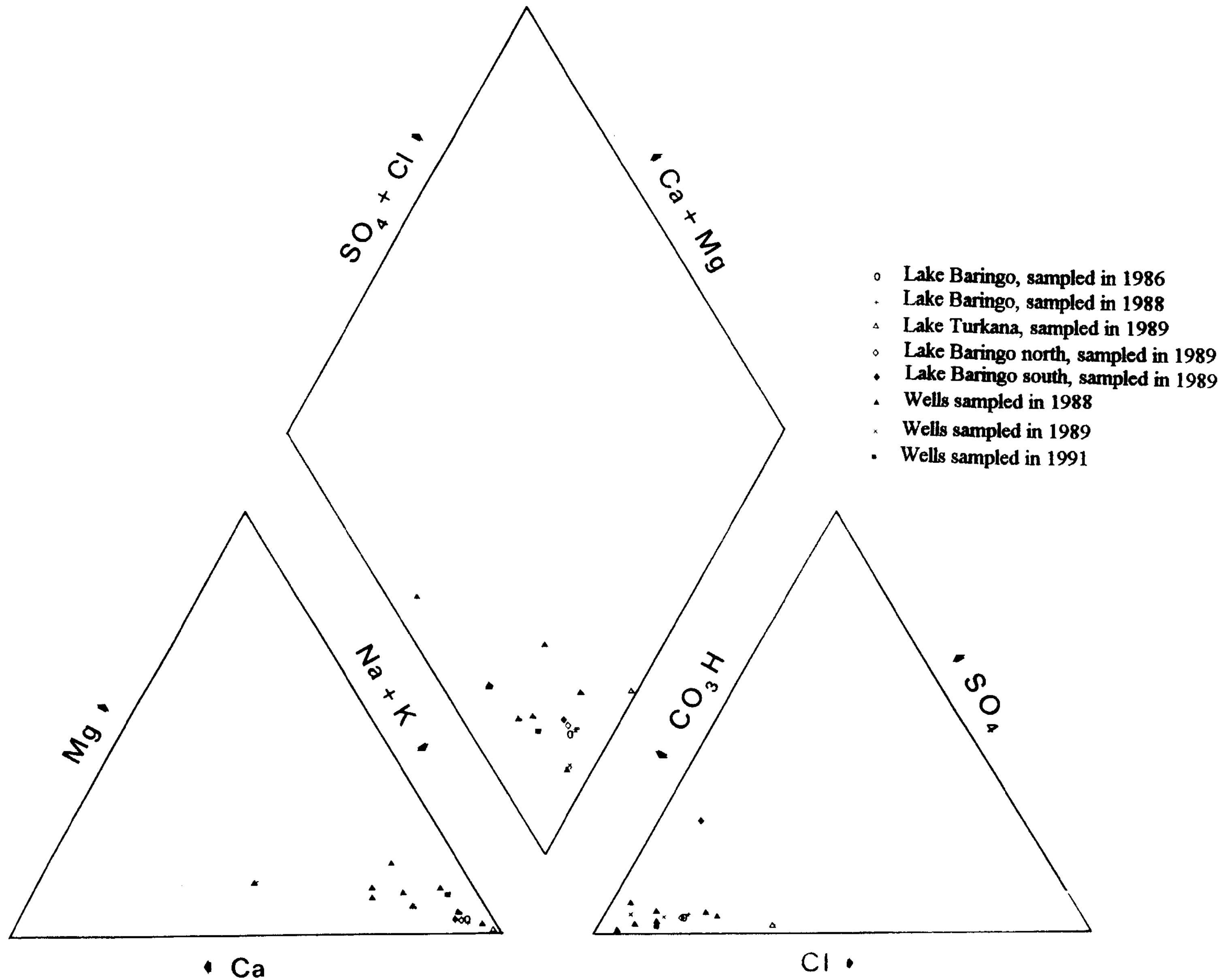

Figure 3 Piper trilinear plot representing the chemical characteristics of lakes and wells from Lake Baringo to Lake Turkana. Constructed using data from Allen and Darling (1992, Table 7.1).

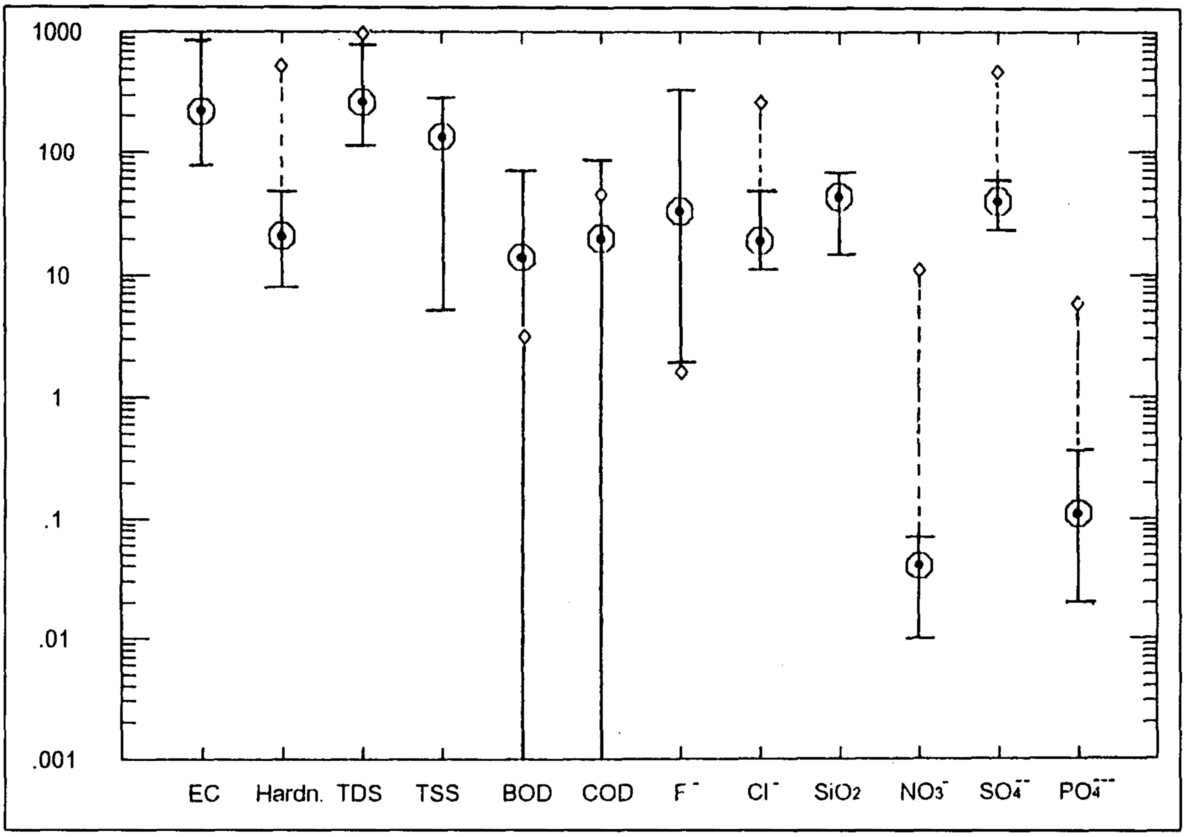

Figure 4. *Bar plots showing range (I), arithmetic mean (⊙) and maximum permissible level (◊) of some hydrochemical parameters in the drinking water from natural waters of the Kerio Valley area, 1992. Units as in Table 1.*

several water quality surveys and small-scale monitoring programmes focusing on selected waterways in western Kenya have been undertaken by the University of Nairobi and other water management institutions in the country (e.g. Allen and Darling, 1992; Davies, 1993, 1994).

Within the limits of seasonal fluctuation in water quality parameters and variability in sampling and analytical methodologies, data accrued from these various sources are largely comparable. This data comparability has provided the major impetus for attempting the following broad synthesis, which also takes into account the health implications for populations in the subregion and the quality of the ecosystem as a whole.

PROCESSES CONTROLLING NATURAL WATER COMPOSITION

The chemical composition of natural waters of western Kenya, deduced from water analyses data from the literature and from recent research, is summarised in trilinear plots (Na + K, Ca, Mg and SO_4, Cl and HCO_3) (Figs 2 and 3) and as bar graphs showing range and mean values (Figs 4-9). The available data indicate that the major factors affecting the chemical composition of natural waters in Kenya are:

i) geological characteristics such as lithology, volcanic activity, chemical weathering and soil leaching;

ii) climatic conditions: such as temperature and rainfall; and, perhaps most importantly,

iii) anthropogenic activities: such as sewage disposal, agricultural and food processing activities and other industrial and land-use activities, which, to a limited extent, include mining and ore-processing.

The chemical composition of surface- and groundwater is influenced by the type and depth of the soils and subsurface geological formations over and through which the water passes. A summary description of the principal rock formations in Kenya is given by Mathu and Davies (1996). The lithology is dominated by volcanic rocks (and their metamorphosed equivalents) associated with the formation of the Rift Valley. This volcanism, thought to be of the HF type, could account for the presence in the surrounding rocks and natural water system of anomalous contents of halogens, notably F and I (see Davies, 1996a). The volcanic rocks

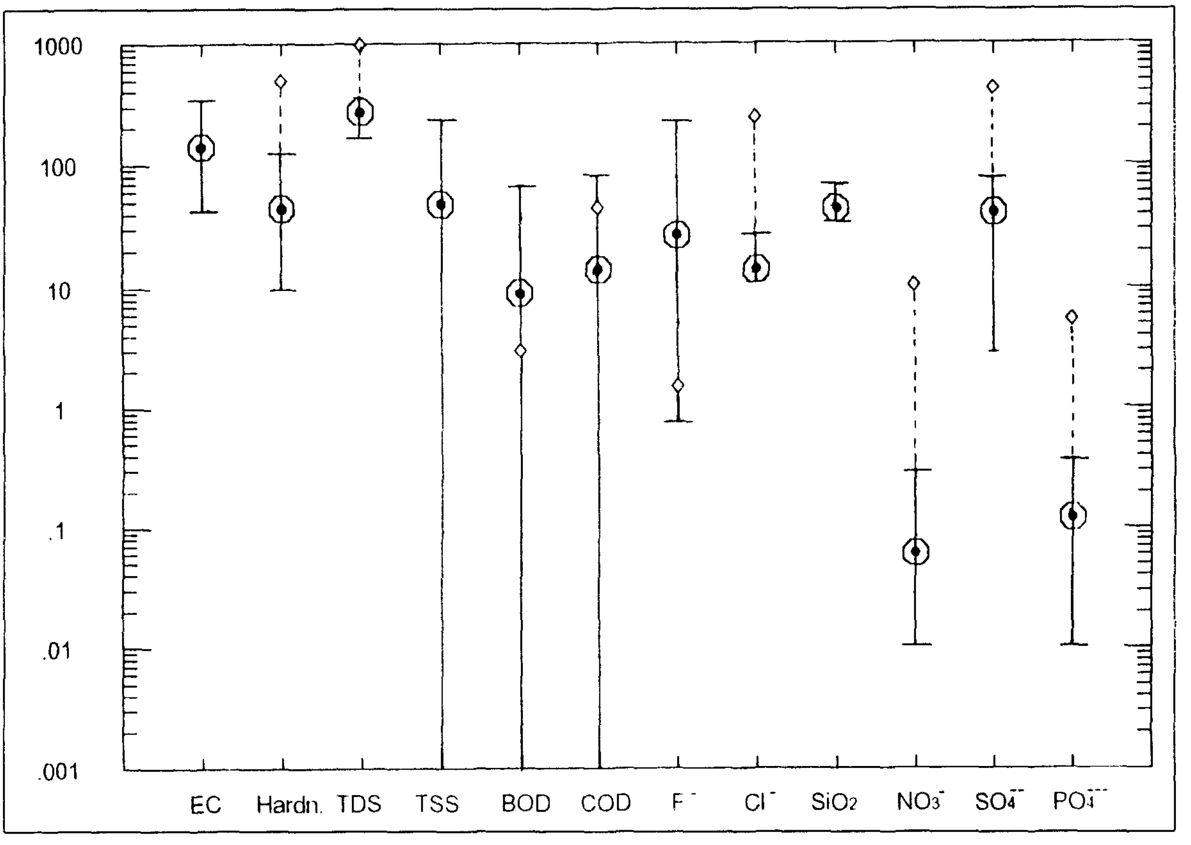

Figure 5. *Bar plots showing range, arithmetic mean and maximum permissible level of some hydrochemical parameters in the drinking water from natural waters of the Kerio Valley area, 1993. Symbols as in Fig. 4, units as in Table 1.*

cover the whole of the central and northern parts of the country, occurring in the floor of the Rift Valley and on the peneplains.

Soils resulting from the weathering of these rocks are generally clayey, being enriched in aluminosilicates as well as Fe and Ti oxides. The plastic nature (high sorption capacity) of these volcanic soils easily leads to periodic flooding whenever the level of rainfall in the Rift Valley areas becomes high. The occurrence of landslide events in the central highlands of the country is also associated with the level of rainfall and the volcanic soil type (Davies, 1996b).

DISSOLVED SOLIDS

As noted in the preceeding section, the age and type of lithology exert a principal control on the natural chemical quality of water in western Kenya. As natural water moves through the hydrological cycle, it reacts with geological formations encountered throughout its flow history, increasing the content of dissolved solids. If other influences on water quality are insignificant, the waters may be described as being 'unmodified waters', defined by Clarke *et al.* (1990) as waters whose chemical composition is derived from normal water-rock interaction at moderate temperatures. Unmodified waters are seldom encountered and a number of hydrochemical parameters show elevated values due either to the Rift Valley volcanic activity (e.g. F and I) or to pH conditions, frequent periods of heavy rainfall and the metabolic products of organisms. Bouts of heavy rainfall and the consequent rapid erosion of soil and leaching of associated bedrock can dramatically raise the dissolved solids content. The role of chemical weathering by the Rift Valley volcanics on natural water composition has been reviewed by Yuretich (1982) for lake waters.

Typical values for the total dissolved solids (TDS) in selected water bodies in western Kenya are given in Tables 1 to 6. In spite of the relatively high rate of soil erosion and leaching of associated bedrock in these examples, the mean TDS values are relatively low when compared to the maximum permissible drinking water level of 1000 mg l^{-1} (WHO, 1984). Elsewhere in the subregion, much higher values for TDS are obtained, such as in the Baringo catchment where the TDS values reach 655 mg l^{-1} in rivers of the eastern flanks (Allen and Darling, 1992). Evaporative concentration, a factor commonly

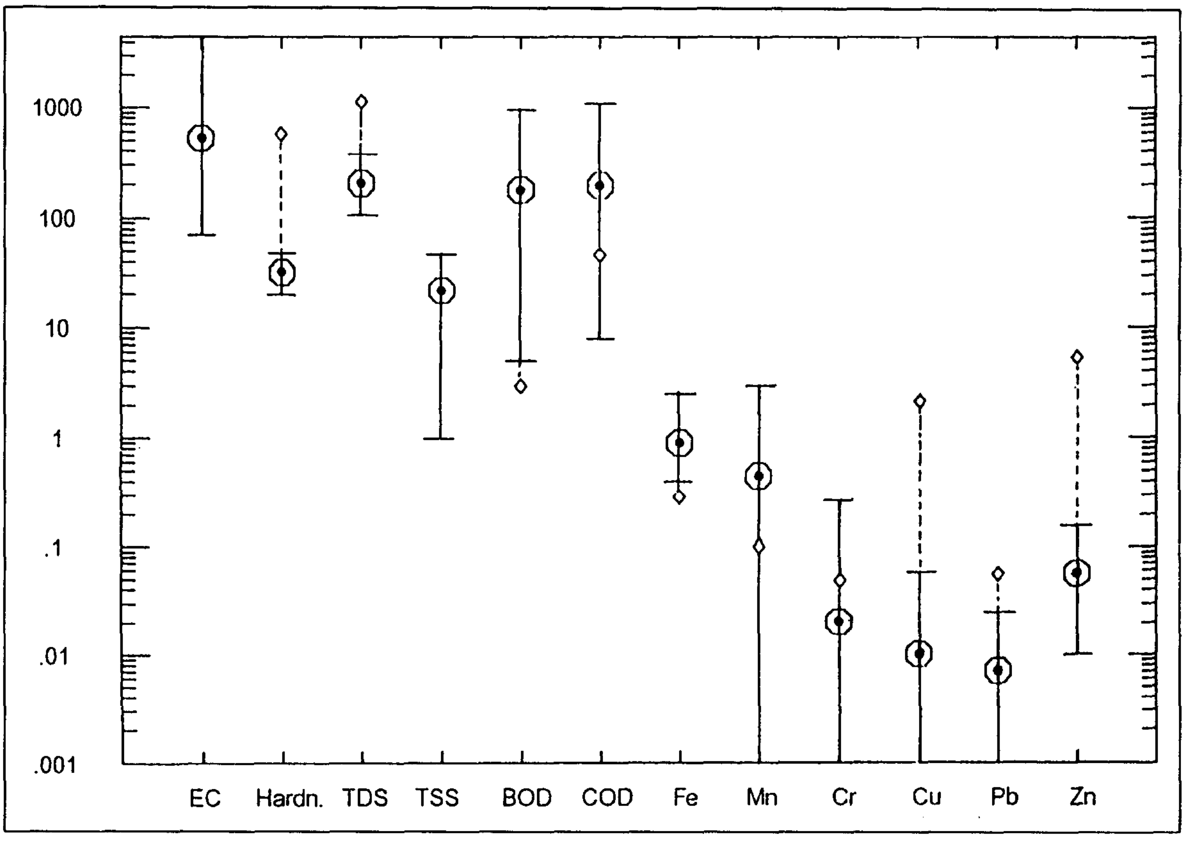

Figure 6. *Bar plots showing range, arithmetic mean and maximum permissible level of some hydrochemical parameters in the drinking water from natural waters of the Thika area. Symbols as in Fig. 4, units as in Table 1.*

invoked to account for exceptionally high TDS values, does not seem to have significantly affected any of the river water compositions according to isotopic results, except perhaps for the Mukutan River to the southeast of Lake Baringo (Allen and Darling, 1992). For Lake Baringo itself, an evaporative concentration factor of 2.5 is suggested based on a comparison of the average Cl^- content (unweighted) of rivers feeding it, although considerable seasonal fluctuations in terms of solute load are thought to occur.

Similarly Lake Turkana, a slightly alkaline lake to the north, is believed to contain evaporated water. Yuretich (1982) gave an average TDS value of 2500 mg l^{-1} and a pH of 9.2. The lake represents a permanent water body and is fed chiefly by the Turkwel and Omo Rivers, the chemical composition of which are not well known.

For Lake Victoria few water chemistry data exist, although electrical conductivity measurements by Foxall *et al.* (1985) gave values of 86 ± 4 μS cm^{-1} and 132 ± 7 μS cm^{-1} for the nearshore and offshore areas, respectively, of the Winam Gulf, thus suggesting a TDS value of less than 150 mg l^{-1}. Other known aspects of the water quality of this important lake are described later.

More extreme values of TDS are encountered further south in Lake Magadi, where water samples range from dilute inflow (TDS < 100 mg l^{-1}) to very concentrated brines (TDS > $3x10^5$ mg l^{-1}). Evaporative concentration is the dominant process in the chemical evolution of these waters (Jones *et al.*, 1977).

The TDS content of most of the groundwater tends to be higher than in uncontaminated surface waters, but are generally less than 1500 mg l^{-1}). Extreme values are encountered in the humid and northeastern parts of the country where about 30% of the groundwater is reported to have TDS of 10,000 mg l^{-1} or more (Ojany, 1974). Since most thermal groundwater (e.g. hot springs) occurs in areas where temperature gradients with depth are relatively steep, it also often shows very high TDS contents and contains unusual amounts of metallic ions.

SUSPENDED MATTER, COLOUR AND TURBIDITY

The occurrence of suspended matter is a major water quality problem in western Kenya, as it is the main carrier of inorganic and organic

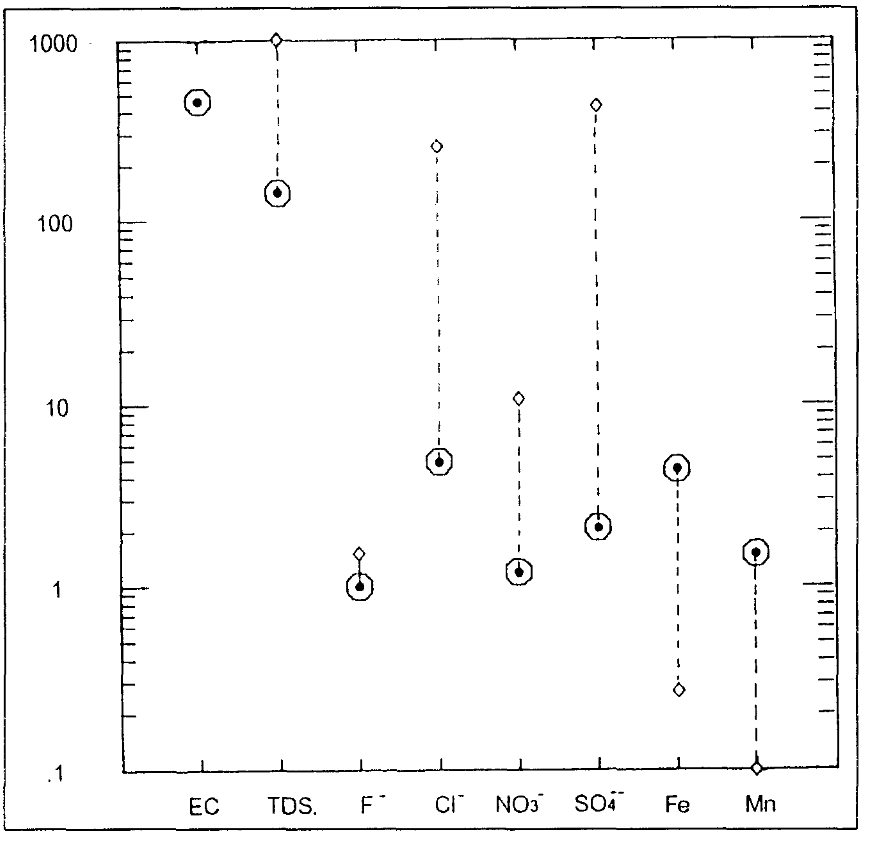

Figure 7. *Bar plots showing range, arithmetic mean and maximum permissible level of some hydrochemical parameters in the drinking water from natural waters of the Nyando River. Symbols as in Fig. 4, units as in Table 1.*

pollutants, as well as nutrients. The type and concentration of suspended matter control the turbidity and transparency of the water. In Kenya, many of the streams are turbid, due largely to soil erosion which is especially high in the rainy seasons. Most surface water samples are also coloured as a result of high concentrations of Fe and Mn, as well as the occurrence of algae and water weeds. In groundwater, high colour is found where the water table, rainfall and population density are high.

In spite of its role in the degradation of water quality, waterways in Kenya are rarely surveyed for suspended matter. The parameter is also extremely variable between rivers (commonly two to three orders of magnitude) and it is difficult to refer to an average level of suspended matter in water bodies. Regional averages are clearly biased by the most turbid rivers, which represent only a small part of the total volume of water flowing over the region. Meybeck (1988) has estimated the global, discharge-weighted, average suspended matter to be approximately 450 mg l^{-1}, but 50% of rivers have waters with suspended matter averages of less than 150 mg l^{-1}.

As a result of the link between suspended matter and water discharge (Meybeck, 1989), the budget of particulate material and of all associated pollutants and nutrients at any survey station is greatly influenced by the high-water stage and storm events. Any budget of suspended matter and particulate pollutants should therefore take account of the highest discharges.

The highest sediment yields to the major basins in Kenya exceed 500 t km^{-2} a^{-1}, considerably more than the world average yield estimated to be 150 t km^{-2} a^{-1}. The sediment yield for the River Tana, for instance, is 1000 t km^{-2} a^{-1}, which is a high figure and is due mostly to over-grazing around the river (Milliman and Meade, 1983). In most of the rivers where land erosion is appreciable, the average suspended matter levels exceed 10 mg l^{-1} (Tables 1, 2, 4 and 5).

It is essential that suspended matter be removed from water supplies. Various treatment methods are available, such as siltation in storage tanks and sand filtration. These treatments depend on the physical and chemical nature of the particles.

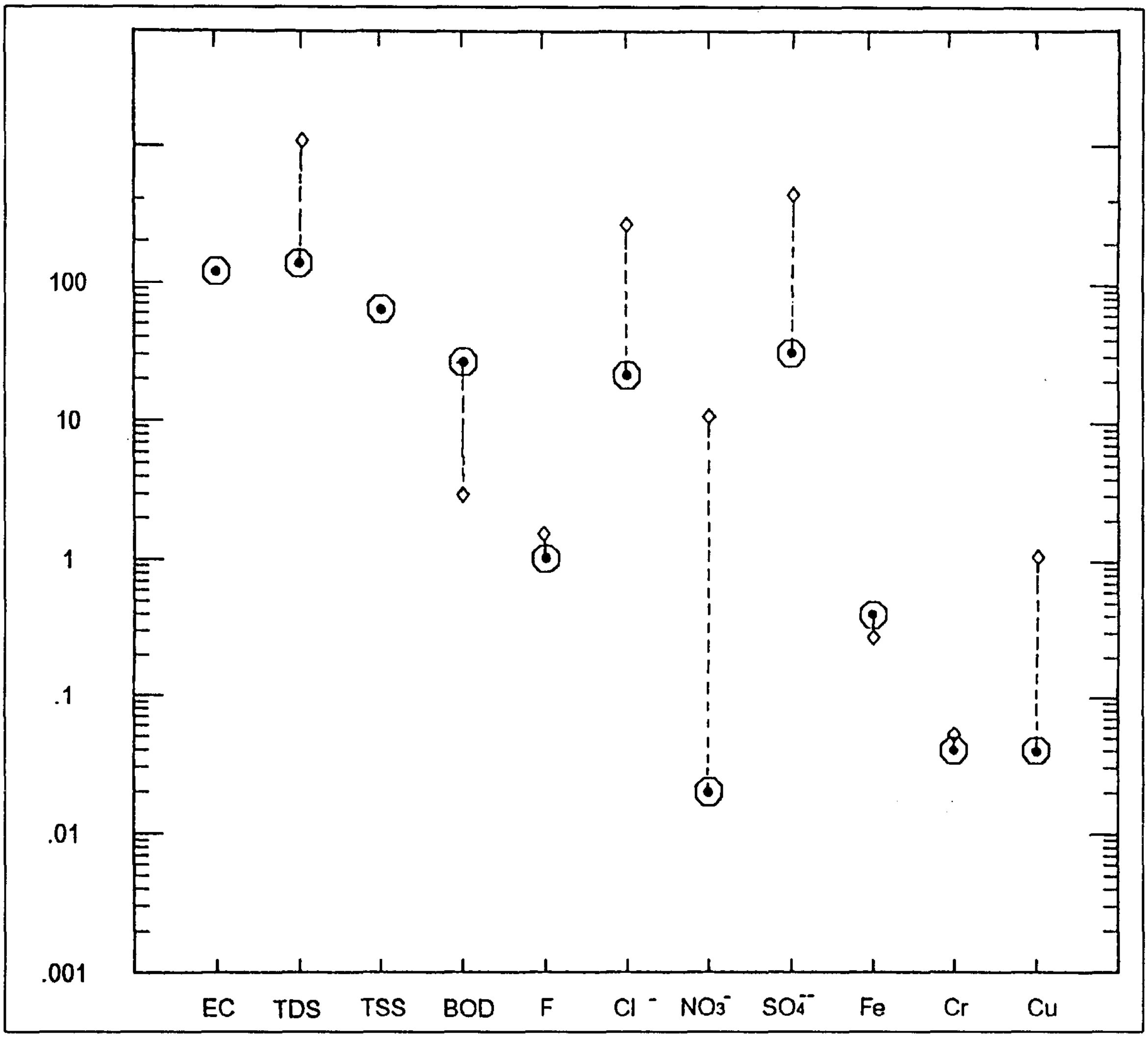

Figure 8. Bar plots showing range, arithmetic mean and maximum permissible level of some hydrochemical parameters in the drinking water from natural waters of the Migori/Kuja River. Symbols as in Fig. 4, units as in Table 1.

HEAVY METALS AND TRACE ELEMENTS

As already noted, suspended material can be considered as a major pollutant carrier. Most toxic heavy metals, organic pollutants, pathogens and nutrients, such as P, are found in the suspended matter. Mechanisms are legion-adsorption, chemisorption, complex formation, etc. (e.g. Davies, 1994). The measured concentrations of Fe and Mn are apparently low (Tables 1 to 5) in relation to the high colours observed in most water bodies (see previous section), but these values were determined in sample fractions from which all suspended matter were routinely filtered off (0.45 μm pore filter). Thus, the importance of the possible sequestering action of these elements by suspended matter is emphasised.

Partitioning of heavy metals and toxic trace elements into the suspended matter phase means that only the dissolved fraction would have any toxicological significance since the suspended matter could easily be removed. There is therefore little concern with the high heavy metal content found in some surface- and groundwaters in western Kenya. Chromium values >20 mg l^{-1} are encountered at effluent discharge points of the Thika River (Davies, *in prep.*), although the WHO guideline figure is 0.05 mg l^{-1} (WHO, 1992). Some groundwater samples in the Migori/Macalder area can contain up to 0.8 mg l^{-1} Fe (Davies, *in prep.*) compared with a WHO guideline figure of 0.3 mg l^{-1} (WHO, 1992). Nevertheless, hardly any cases are found in the literature of acute intoxication of humans or animals by elevated heavy metal concentrations in drinking water.

The main sources of heavy metal and trace element contaminants are industrial effluents such as from the leather, sugar and coffee factories and fertilizers. Many trace elements

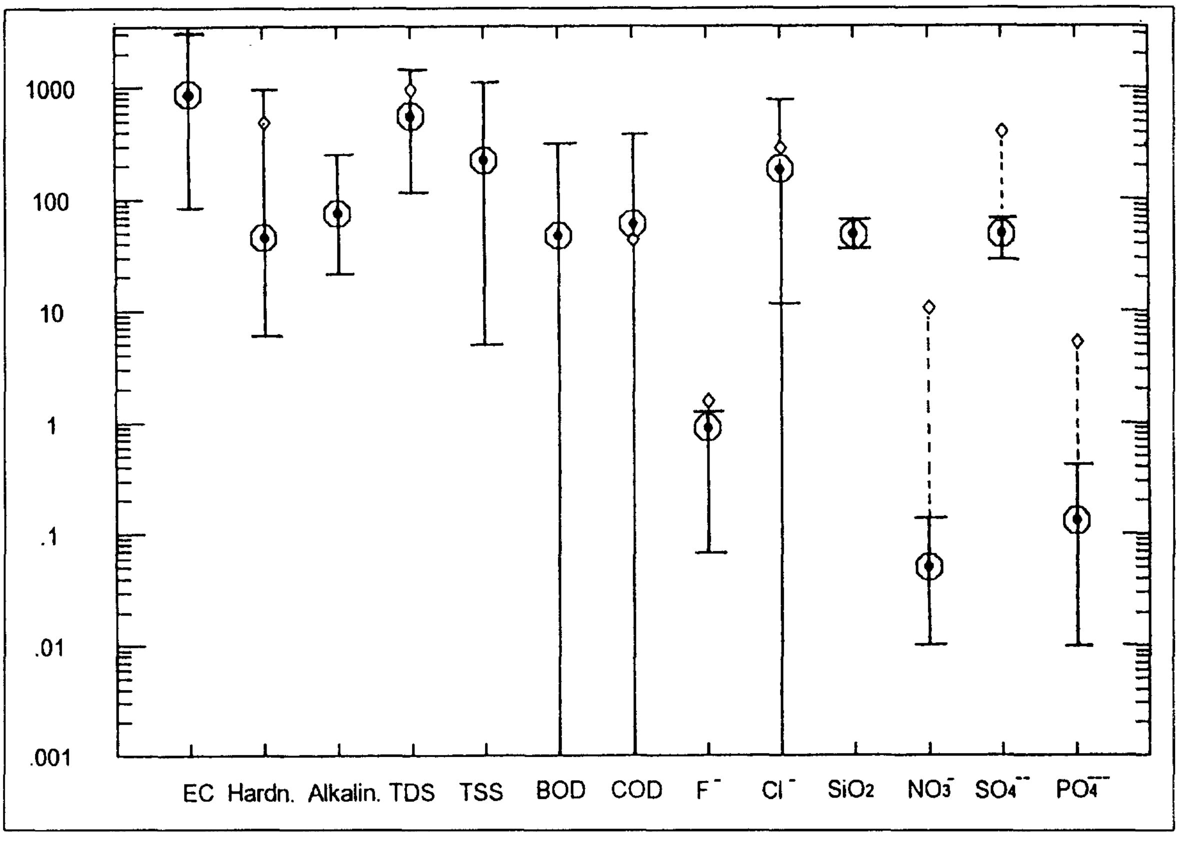

Figure 9. Bar plots showing range, arithmetic mean and maximum permissible level of some hydrochemical parameters in the drinking water from natural waters of the Nzoia River. Symbols as in Fig. 4, units as in Table 1.

are present in pesticides as well, but well documented cases of serious water quality contamination by trace elements from fertilizers and pesticides are very limited.

ANIONS

Of the major anions only the halogens F and I are consistently higher than global averages (Tables 1, 3, 4, 5 and 7). The occurrence of excess F and I in these waters can be explained in purely geochemical terms, namely the HF volcanism accompanying rift formation (Gaciri and Davies, 1993), which could have released a considerable amount of halogen compounds.

Groundwater with high F^- has long been known in Kenya. According to Bartram (1992), 61% of boreholes have a F^- concentration above 1 mg l^{-1} and almost 20% are above 5 mg l^{-1}. A random survey for total I involving 30 samples of surface- and groundwaters in the Eldoret, Kiambu and Nairobi areas yielded a mean value of 11.4 μg l^{-1}, compared with a mean of less than 2 μg l^{-1} in waters from I deficient areas of the world (Davies, *in prep.*). Typical I values for waters in the Kiambu area from where the third highest goitre rates in Kenya are reported, are given in Table 7.

Chloride concentrations on the other hand are relatively low, as is the case for most natural water systems (Hem, 1970). Important exceptions, however, are water bodies in and around the Rift Valley (Table 6; Allen and Darling, 1992, Table 7) and rivers receiving industrial effluents, such as the Nzoia River (Fig. 9) where Cl^- values may reach several hundred mg l^{-1}.

The concentrations of the other major anions, NO_3^-, $Si(OH)_4$, SO_4^{2-} and PO_4^{3-}, are variable and, though higher than global averages, they are still well below the WHO (1984, 1992) maximum permissible levels for drinking water (Tables 1 and 3-6) and do not appear to pose any serious concern as yet. Some investigators consider that the waters of East Africa have too low a sulphate content, which may limit biological productivity (e.g. Beauchamp,1954). Livingstone (1963), however, argues that sulphate is actually much more abundant than has been reported and it is unlikely that most aquatic organisms suffer a serious shortage of it in East Africa. That sulphate is actually abundant, has been confirmed by the work of Jones *et al.* (1977) for the Ewaso Ngiro River and the Rift Valley rim streams (Fig. 1). These authors have attributed the apparently low values obtained

Table 1. Hydrochemical data for natural waters of the Kerio Valley area, recorded during July 1992 and July 1993

Parameter	1992		1993			
	Range	Arithmetic mean	Range	Arithmetic mean	International average for freshwater*	Maximum permissible level in drinking water*
T (°C)	18-30	26	17-25	23	NS	NS
pH	6.0-7.9	7.2	7.1-9.5	8.7	6.5-8.5 (R)	6.5-8.5 (R)
Turbidity (NTU)	8-620	255	5-620	94	NS	5
EC ($\mu S\ cm^{-1}$)	76-812	217	42-336	141	10-1000 (R)	NS
Hardness ($mg\ l^{-1}\ CaCO_3$)	8-46	21	10-126	45	NS	500
Alkalinity $mg\ l^{-1}\ CaCO_3$)	26-414	109	26-262	96	NS	NS
TDS ($mg\ l^{-1}$)	110-760	253	180-335	274	<100	1000
TSS ($mg\ l^{-1}$)	5-280	134	0-220	48	150	NS
BOD ($mg\ l^{-1}\ O_2$)	0-66	14	0-66	9	2.0	3.0
COD ($mg\ l^{-1}\ O_2$)	0-80	20	0-80	14	<200	44
F^- ($mg\ l^{-1}$)	1.6-305.5	33.0	0.8-212.6	26.6	0.1	1.5
Cl^- ($mg\ l^{-1}$)	11-48	19	11-27	14	3.9	250
SiO_2 ($mg\ l^{-1}$)	16.4-64.8	43.0	32.6-67.4	43.9	10.8	NS
NO_3^- ($mg\ l^{-1}$)	0.01-0.07	0.04	0.01-0.30	0.06	0.10	50
SO_4^{2-} ($mg\ l^{-1}$)	22.8-55.0	39.5	29.4-66.0	40.7	4.8	400
PO_4^{3-} ($mg\ l^{-1}$)	0.02-0.36	0.11	0.01-0.36	0.12	0.01	5
Fe ($mg\ l^{-1}$)	0.2-0.8	0.4	0.1-0.4	0.3	0.05	0.3
Mn ($mg\ l^{-1}$)	-	<0.2	-	<0.2	0.01	0.5
Cr ($mg\ l^{-1}$)	0.02-0.84	0.11	0.01-0.12	0.03	0.0001	0.05
Cu ($mg\ l^{-1}$)	0.01-0.08	0.03	0.01-0.04	0.02	0.0014	2.0

R=range. NS=not specified. *: WHO (1984, 1992), CCREM (1987), CEC (1980), Sayre (1988), Meybeck (1988), Schiller and Boyle (1985, 1987), Meybeck and Helmer (1989), Chapman and Kimstach (1992), Davies (1994).

Table 2. Selected hydrochemical data for surface waters of the Thika area recorded during the period October 1990 to August 1992

Parameter	Range	Arithmetic mean	International average for freshwater*	Maximum permissible level in drinking water*
pH	5.5-9.5	7.6	6.5-8.5 (R)	6.5-8.5 (R)
EC	70-4420	526	10-1000 (R)	-
Hardness	20-48	32	-	500
TDS	105-390	205	<100	1000
TSS	1-46	22	150	-
BOD	5-990	177	2.0	3.0
COD	8-1088	0.194	<200	44
Cd	0.001-0.004	0.002	0.000001	0.003
Cr	0.001-0.265	0.020	0.0001	0.050
Cu	0.001-0.057	0.010	0.0014	2.0
Fe	0.400-2.500	0.883	0.050	0.300
Mn	0.001-2.976	0.442	0.010	0.500
Pb	0.001-0.026	0.007	0.00004	0.01
Zn	0.010-0.163	0.056	0.0002	3.0

Cd, Pb and Zn in $mg\ l^{-1}$. *Sources as for Table 1. R=range.

Table 3. Mean values of water quality parameters of the Nyando River

Parameter	Arithmetic Mean	International average for freshwater*	Maximum permissible level in drinking water*
pH	7.7	6.5-8.5	6.5-8.5
TDS	142	<100	1000
EC	463	10-1000	-
NO_3^-	1.2	0.10	10
SO_4^{2-}	2.1	4.8	400
Cl^-	4.9	3.9	250
F^-	1.0	0.1	1.5
Fe	4.4	0.05	0.3
Mn	1.5	0.01	0.5

*Sources and units as for Table 1.

Table 4. Mean values of water quality parameters of the Migori/Gucha River

Parameter	Arithmetic mean	International average for freshwater*	Maximum permissible level in drinking water*
pH	7.6	6.5-8.5	6.5-8.5
TDS	137	<100	1000
EC	119	10-1000	NS
NO_3^-	0.02	0.1	10
SO_4^{2-}	30.8	4.8	400
Cl^-	21	3.9	250
F^-	1.02	0.1	1.5
Fe	0.4	0.05	0.3
Mn	0	0.01	0.1
Cr	0.04	0.0001	0.05
Cu	0.04	0.0014	1.0
TSS	64	150	NS
BOD	26.3	2.0	3.0

*Sources and units as for Table 1. NS = not specified.

by others to processes such as sorption and sulphate reduction causing a high loss of sulphate from solution.

ORGANIC POLLUTANTS

Some indication of the level of organic acid anions, humic acids and fulvic acids can be given by typical biochemical oxygen demand (BOD), chemical oxygen demands (COD) and NO_3 levels obtained in recent surveys (Tables 1 to 5). BOD values are nearly always several times higher than the averages for freshwater and maximum permissible drinking water levels. However, COD and NO_3 levels are often low and well within drinking water levels. The balance of evidence appears to favour a relatively low but significant level of organic pollution overall. It is known that water bodies in the region receive high loads of organic matter from domestic and industrial wastes. For example, wastewater from the wet processing of coffee is characterised by BOD values of between 5000 and 9000 mg l^{-1} (WHO/UNEP, 1991).

There is a noticeable absence in the literature of measurements of variables (DDT [dichloro-diphenyl-trichloroethane], PAH [polyaromatic hydrocarbons], etc.) indicating organic pollution from synthetic organic chemicals in western Kenya; these, however, will presumably be present in trace amounts in contrast to bulk organics.

Faecal contamination of surface waters, shallow wells and boreholes is an ever present problem over much of the subregion, which is largely due to a lack of proper sewage disposal facilities. Sewage, land and urban run-off and domestic waste waters are widely discharged into water bodies, particularly rivers, but very few analytical data exist for micro-organisms in water samples of the subregion in relation to human health.

Table 5. Hydrochemical data for River Nzoia, recorded during June and July, 1993

Parameter	Range	Arithmetic mean	International average for freshwater*	Maximum permissible level in drinking water*
pH	6.63-8.81	7.7	6.5-8.5 (R)	6.5-8.5 (R)
Turbidity	7-66	31.9	NS	5
EC	85-3232	879.4	10-1000 (R)	NS
Hardness	6-98	45.1	NS	500
Alkalinity	30-236	74.9	NS	NS
TDS	115-1500	556.7	<100	1000
TSS	5-1100	225.3	150	NS
BOD	0-320	46.5	2.0	3.0
COD	0-400	60.3	<200	44
F^-	0.68-1.20	0.90	0.1	1.5
Cl^-	11-786	185	3.9	250
SiO_2	30.8-63.4	47.3	10.8	NS
NO_3^-	0.01-0.13	0.05	0.10	10
SO_4^{2-}	29.9-66.7	47.9	4.8	400
PO_4	0.01-0.43	0.13	0.01	5
Fe	0.2-0.4	0.25	0.05	0.3
Cr	0.01-0.19	0.07	0.0001	0.05
Cu	0.01-0.20	0.06	0.0014	2.0

*Sources and units as for Table 1. R=range. NS=not specified.

Table 6. Analyses, in milligrams per litre, of water from some Kenyan lakes

Parameter	A	B	C	D	E	F
HCO_3^- ⊗	180	336	1304	-	35300	12300
SO_4^{2-}	17	40	56	57.6	204	253
Cl^-	10	36	429	320	3450	1375
NO_3^-	Nil	Trace	Trace	-	-	Trace
PO_4^{3-}	0.4	0.96	1.23	0.5	1.29	-
Ca^{2+}	16	22	5	57	26	10
Mg^{2+}	7	2	4	-	Trace	Nil
Li^+	0	0	0	-	0	0
Na^+	41	126	770	-	14360	5550
K^+	19	15	23	-	304	256
Fe, Al	6	36	3	-	Trace	6
SiO_2	20	15.8	4.2	24	-	-
S.G.	1.00024	1.00044	1.00190	-	1.03910	1.01383
TDS	316	630	2600	-	>53600	>19800

⊗Includes carbonate. A: Lake Naivasha; B: Lake Baringo; C: Lake Turkana; D: Lake Turkana, 1953; E: Lake Bogoria; F: Lake Nakuru.
Source: analyses A, B, C, E and F from Beadle (1932, p207); analysis D from Beauchamp (1954, p27).

Pathogens associated with these discharges subsequently become distributed through the water body, presenting a risk to downstream users. Table 8 gives the range of a number of typical faecal organisms in various types of water in Kenya.

Programmes to combat waterborne diseases and epizootics (e.g. onchocerciasis, bilharzia, trypanosomiasis) require an increased use of pesticides. The annual amount of pesticides used in Kenya between 1979 and 1983 was 5728 t (WHO/UNEP, 1991). DDT is widely used, although no data for pesticide contamination is available owing to the lack of monitoring facilities and the sophisticated expertise required to initiate a regional monitoring programme. It is assumed that the higher pesticide use rates in Kenya will have potentially adverse health effects should transfer to humans via water or biota occur.

Table 7. Iodine content of some natural water samples from parts of the Kiambu District, Central Kenya

Locality	Sample description	Depth to water surface (m)	Iodine as I^- ($\mu g\ l^{-1}$)
River Ruiru	(Impact) sample of river water	-	10.0
Gati-igiru[a]	Shallow well	15.5	11.3
Gati-igiru[b]	" "	12.3	10.0
Ndumberi	" "	21.5	7.9
Giathi-ini	" "	23.3	12.5
Tigang'a	" "	17.5	11.3
Miguta	" "	35.3	6.7
Githunguri	" "	23.9	12.0
Kibichoi	" "	27.4	12.7
Ikinu	" "	18.9	10.6
Kagwe	" "	21.9	4.1

a and b: separate wells within the same locality. Source: Davies (*in prep.*).

Table 8. Concentrations of faecal bacteria in drinking water in Kenya

	Faecal organisms per 100 ml	
Type of source	Coliforms	Streptococci
Large rivers	0-100,000	0-10,000
Dams	0-2	0-14
Springs	0	0
Waterholes	11-350	50-90

Source: adapted from WHO/UNEP (1991).

The use of fertilizers, too, is becoming widespread in western Kenya, although as has been noted NO_3^- (generally the main concern in fertilizer use) tends to be low. Other contaminants such as As, Cd, Cr, Cu, Ni, Pb and Se are present in fertilizers (and pesticides) in varying concentrations and these could leach into the groundwater and thus contaminate the sources. However, the role of these cations in degrading water quality is considered to be limited owing to the binding effect of suspended matter.

pH, SALINITY AND EUTROPHICATION

The pH of most natural waters in the subregion falls within the range of 6.0-8.0 in keeping with values of most rivers and lakes in the world. A smaller number of streams located in past or present metalliferous mining areas (Macalder, Migori, etc.) have values of around 6.0 or less. Water with a pH of more than 9.0 is rare and is mainly of the deep well type in the fringes of the Rift Valley.

The high pH of waters would favour the stability of the metal fraction bound onto particulates and sediments. This fraction may be unavailable for systemic absorption unless rendered soluble within the digestive tract of organisms due to a drop in pH.

Salinity presents a problem only for some groundwater sources. In the eastern part of the country, one borehole in seven yields undrinkable water, a condition precipitated by low rainfall, the low recharge of aquifers and high evaporation rates, which together result in the increased salinity of groundwaters (WHO/UNEP, 1991).

The eutrophication of lakes and reservoirs is not widespread, although the phenomenon is increasing in many of them.

CASE HISTORY

Lake Victoria (Fig. 10) lies within Tanzania, Uganda and Kenya and is one of the African Great Lakes. It is monomictic with a maximum depth of about 80 m, a cross-sectional area of 68,800 km^2 and a volume of 2750 km^3, making it the 7th largest lake in the world in terms of volume.

Like the other African Great Lakes, Lake Victoria is not regularly monitored, largely due to a lack of sampling equipment and political agreement amongst the riparian countries on the

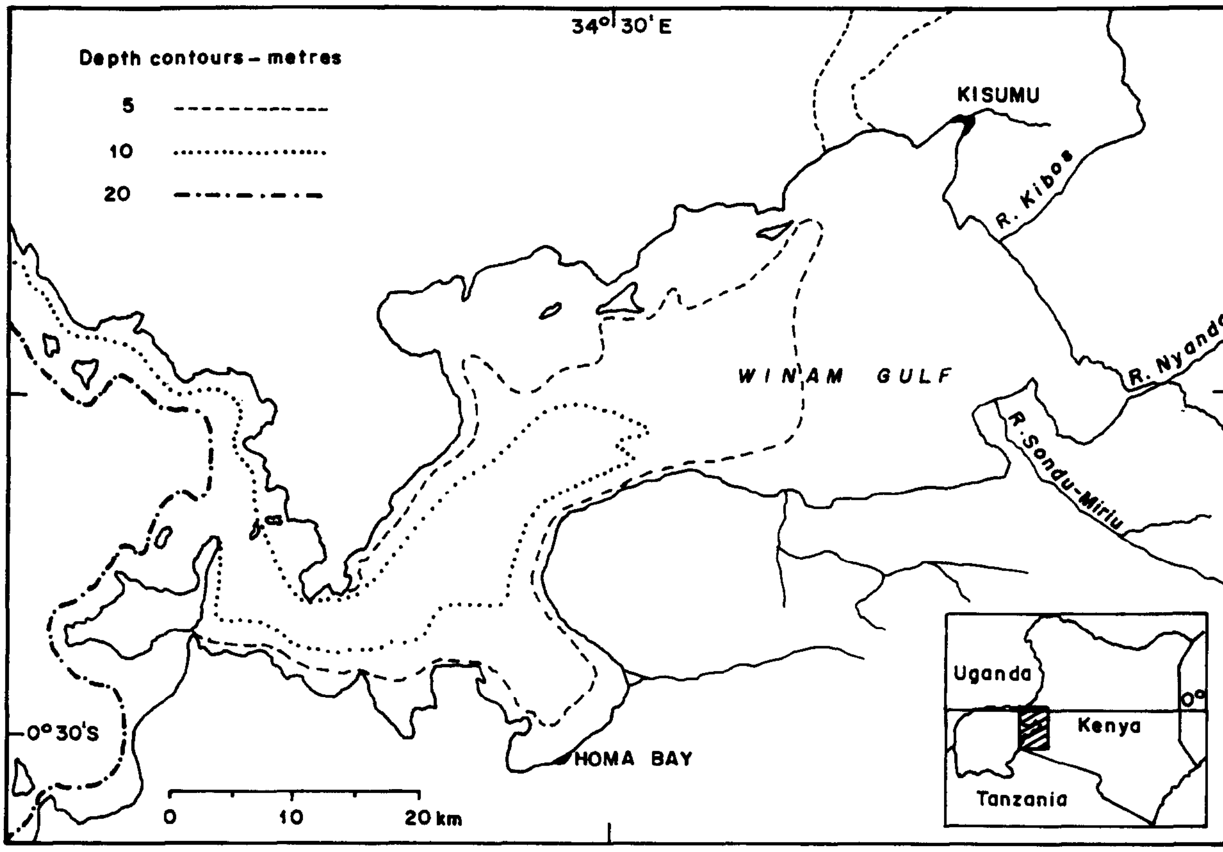

Figure 10. The Winram Gulf and Kenyan waters of Lake Victoria.

Table 9. Hydrochemical parameters of the Winam Gulf and Kenyan waters of Lake Victoria (July/August, 1984)

	Temp. (T°C)	EC ($\mu S\ cm^{-1}$)	Secchi (cm)	Turbidity (NTU)	DO($mg\ l^{-1}$)	Alkalinity ($mg\ l^{-1}\ CaCO_3$)	pH
Winam Gulf (Nearshore)	25.6±1.0	137±4	75.3±13	10.1±3.9	8.1±1.1	64±11	8.5±0.5
Winam Gulf (Offshore)	24.6±1.1	132±7	118±28	4.3±1.2	6.9±0.8	55±4	8.0±0.3
Main Lake	24.5±0.5	86.0±0	283±67	1.9±0.6	5.8±0.9	37±2	7.5 ± 0.2

Source: adapted from Foxall *et al.* (1985).

use of the Great Lakes. The current level of understanding of the lake is therefore insufficient for recognising and harnessing its full potential. The following summary, drawn largely from the work of WHO/UNEP (1991) and Foxall *et al.* (1985), provides some examples of the information available, as well as some of the gaps.

Lake Victoria is much more sensitive to pollution than the other Great Lakes due to its relatively short water residence time of 23 years. Foxall *et al.* (1985) determined various physicochemical parameters (Table 9) in attempting to establish the quality of the Winam Gulf of the lake. Their study indicates that the present quality of the water appears to pose an immediate threat to the viability of the gulf ecosystem and its utility as a resource. They further noted that the high proportion of algal biomass and the preponderance of the bloom-causing blue-green algae present problems in the region, including eutrophication.

Evidence of pesticide contamination has been found in some fish and decreases in the dissolved oxygen in bottom waters of some sheltered bays have been reported. These decreases may be the result of the reported increasing algal production associated with increased nutrient inputs, although complete biological studies are still lacking. Lake Victoria's catchment has some of the highest population densities in Africa and sewage treatment is largely inadequate. The Winam Gulf catchment alone has a mean of 170 people per km^2 and supports 0.75 million units of livestock.

The lake provides an essential fish protein for the surrounding population and, if properly fished with modern techniques, could be the main source for the whole region. It is essential to recognise that Lake Victoria is a highly valuable water body of global significance and should be managed in a similar way to the other major lakes.

SUMMARY AND CONCLUSIONS

The major objective of this compilation has been to provide assessments to those concerned in the water and health sectors on the state of the natural waters of western Kenya by looking at the levels of critical water quality indicators pertinent to potential human health problems, aquatic ecosystem changes and environmental degradation.

The water quality of most surface water bodies in western Kenya is considered to be still relatively unimpaired, in spite of continuous discharges of largely untreated effluents from industrial activities, sewage and agricultural runoffs. However, current trends indicate that this unimpaired state may not be sustained, particularly in the absence of consistent and reliable data on the water quality.

Programmes for the supply of safe drinking water to increased proportions of the rural and urban population should be closely tied to programmes which control domestic wastes and protect water resources. Proper excreta disposal and domestic waste water treatment should be made priorities.

Agro-industrial effluents are the most important individual waste sources. These require the application of specially designed waste water treatment and disposal schemes. Similarly in mining areas, special measures for the treatment and disposal of mine wastes have to be taken.

In places where intensive agricultural development and/or pest control are taking place,specific pesticide monitoring programmes should be established as part of the operation.

The role of suspended matter and sediments as major carriers for heavy and trace metals, as well as organic micropollutants, should be thoroughly investigated. Integral models for the behaviour of these compounds, which are often used as predictive tools in water quality management, should contain accurate descriptions of adsorption, chemisorption, complexation and other relevant mechanisms and processes valid for realistic conditions.

Prior to substantial agricultural, industrial or natural resource developments, environmental impact assessments should be performed, including specific reference to water quality.

Continuous monitoring of the water quality of Lake Victoria (the Kenya waters) is essential because of the importance of this body of water to the surrounding population. Current evidence indicates a strong impact by land-based human activities which is causing a degeneration of water quality and leading to eutrophication and fish poisoning.

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