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Open Access Water chemistry and quality of the Blue Nile at Khartoum

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Abstract

Measurements of physical and chemical variables were made fortnightly on the Blue Nile near Khartoum, from May 2000 to February 2002. The variables analysed were: temperature, pH, and concentrations of total residue, dissolved oxygen, alkalinity, phosphate-phosphorus, nitrate-nitrogen, silica-silicon, calcium, magnesium, sodium, potassium, and oxidizable organic matter. The seasonal variations of these factors in the Blue Nile are compared, and the interrelationships existing between some of them are discussed. Comparisons are made with earlier studies carried out on the same site in the Blue Nile and with some tropical rivers. In the Blue Nile, the amounts of suspended matter and nutrients are largely dependent upon the flood regime. Nitrate, phosphate, silicate, oxidizable organic matter and total residue increase considerably in the Blue Nile when the river is in flood. Silicate-silicon as silica was reduced at certain times of the year, yet the relatively high concentrations, which were maintained throughout the year, were not expected to limit the growth of diatoms. Drops in silicon concentrations, unlike those in nitrate and phosphate, were always followed by a rapid restoration of a higher level. Compared with pre 1970 data, the Blue Nile at Khartoum did not show any sign of unwelcome enrichment. The river at Khartoum is far from being polluted by heavy metals; no cadmium, lead, or nickel was detected in the surface waters.

Keywords: Sudan, Blue Nile, water quality, chemical composition, tropical rivers.

1. Introduction

During the last century, several papers dealt with the water quality of the Blue Nile in an attempt to relate any shifts to changes in the hydrological regimes of the river. In the early 1950s, modern limnological work was launched by members and collaborators of the Hydrobiological Research Unit (HRU, 1953-1980 Annual Reports). Brook (1954), Rzóska *et al.* (1955) and Talling and Rzóska (1967) presented baseline information on the biology and chemistry of the Blue Nile near Khartoum before the construction of the Roseires dam across the Blue Nile in 1966. This dam, as expected had its influence upon the ecology of this river by creating a reservoir in which current velocity was considerably reduced, and lake conditions were initiated. Sinada and Abdel Karim (1984) presented a detailed work on the water characteristics of the Blue Nile at Khartoum which was started in 1968 two years after the completion of the Roseires dam. Sinada and Abdel Karim (1984) did not detect any signs of eutrophication. They concluded that the water quality of the river did not show any sign of unwelcome enrichment. However, the present authors reiterate the concerns of Hammerton (1972) and Sinada and Abdel Karim (1984), who believed "even a mild degree of eutrophication from industrial development could have a serious effect on the Nile because of the high temperatures and high radiation inputs". Contamination of the Blue Nile water is inevitable unless certain measures are undertaken before it is too late. Possible sources of contamination of the Blue Nile water are numerous, and include industrial effluents and surface runoff from urbanization and agricultural land. Within the Sudan, the Blue Nile is exposed to pollution and cultural eutrophication from many factories, which were built along the Blue Nile during the last century and those which will be built in the future. Existing factories include textile, sugar, tanneries, food, soap, and oil mills. Waste waters from some of these factories with their impurities, nutrients, and toxic materials may find their way directly or indirectly into the Blue Nile. Moreover, agrochemicals which are constantly and extensively applied in *Gazira*, *Managil*, *Rahad* and other agricultural schemes, are expected to reach the Nile from diffuse sources during wet seasons.

The purpose of the present study was to assess the existing water characteristics and relate the cause of deterioration in water quality of the Blue Nile at Khartoum, if any, to agricultural, industrial, and urban progress which took place during the 1970s-1990s. Also, the present data will serve as baseline information upon which future changes can be assessed, particularly the impact of heightening the Roseires dam. The heightening works, which are currently in progress, are intended to increase the storage capacity of the dam from 3 $\times 10^9$ m^3 to 7.4 $\times 10^9$ m^3. No doubt the heightening of Roseires dam will have a profound influence on the biological productivity and ecology of the Blue Nile.

Qualitative and quantitative analyses of the seasonal distribution of phytoplankton in the Blue Nile are dealt with in a separate paper.

For comprehensive descriptions of the Nile system, see Hurst (1957) and the monographs edited by Rzóska (1976) and Dumont (2009). The latter books contain a review of chemical information on the Blue Nile obtained before 1970 (Talling 1976, 2009).

2. Materials and methods

Water samples were collected in 2 L polythene bottles between 10.00 and 11.00 a.m. at two-week intervals from May 2000 to February 2002. During the period May–November 2000 the *Research Vessel Malakal* which belonged to the Institute of Environmental Studies, University of Khartoum, was used for sample collection from a fixed midstream station located 3 km upstream of the confluence with the White Nile. Water samples from 0.5, 2, 4 and 7 metres were collected using a Friedinger sampler, but no appreciable difference between them was found. From December 2000 onwards, only sub-surface samples (0.1-0.5 m), which were considered to be representative of the water column, were taken by direct dip from a fixed point 8 m off the bank of the river from the side of a barge permanently anchored 3 km upstream of the confluence.

Except for pH, oxygen, alkalinity, and total residue (largely particulate matter, silt or seston), analyses were made on filtered samples run through Whatman GF/C filters immediately on return to the laboratory. The chemical measurements were usually performed within a few hours of collection or stored at -20°C for a maximum of four weeks before analysis. The following variables were determined as described in American Public Health Association (APHA 1965): nitrate-nitrogen (phenoldisulphonic acid method), phosphate-phosphorus (stannous chloride reduction method), and silica-silicon (molybdosilicate method). Alkalinity (titration finally to approximately pH 4.5 with 0.02N HCl in the field using phenolphthalein and bromcresol green-methyl red mixed indicators), and dissolved oxygen (Winkler method) were determined as described by Mackereth *et al*. (1978). Dissolved oxidizable organic matter (permanganate method) was determined as described by Mackereth (1963). Sodium, potassium, calcium, magnesium, cadmium, lead, and nickel were measured using a Perkin Elmer 2380 atomic absorption spectrophotometer following the methods described in its manual. Total residue was estimated by weight after evaporating unfiltered water, followed by drying overnight in an oven at 105°C. Water temperature was measured with mercury, thermometer and pH with a Lovibond Comparator in the field pH using phenol red and universal indicators and checked with Hach EC 10 pH meter in the laboratory.

The data presented in this paper are the means of two replicas. Colorimetric determinations for PO_4-P, NO_3-N, and SiO_2 were carried out using Jenway Model 6300 spectrophotometer fitted with a 1-cm pathlength cuvette.

3. Results and discussion

The maximum and minimum values water characteristics recorded in the Blue Nile during this study compared with those obtained by Talling and Rzoska (1967), Hammerton (1972), and Sinada and Abdel Karim (1984) are shown in Table 1. The seasonal variations of the variables which were monitored throughout the sampling period are presented in Figs. 1-4 and discussed separately below.

Current flow

The flow of the Blue Nile showed marked seasonal changes. According to Sinada and Abdel Karim (1984) during the flood season (end of June-October) the rate of flow increased considerably, recording a maximum of 1.8 m s^{-1} in August. From November onwards, the rate of flow remained low in the range of 0.1-0.4 m s^{-1} until late June when it began to increase again. During the flood season, the Blue Nile at Khartoum usually rises more than 5 m above the lowest level in May. The current velocity during the latter period is negligible due to minimal discharge and also due to a natural damming which is exerted by the White Nile at the confluence when maximal amounts of water are released from the Gebel Aulia dam on the White Nile, 45 km upstream from the confluence.

Table 1. Summarized physical and chemical data. Range of each characteristic recorded in the Blue Nile at Khartoum during the period May 2000-February 2002 compared with values obtained by Talling and Rzóska (1967), Hammerton (1972), and Sinada and Abdel Karim (1984)

		Present study Rzóska	Talling & (1967)	Hammerton (1972)	Sinada & Abdel Karim (1984)
Characteristic	Units	2000-2002 1956 10.iv.64	1954- and	1965-67	1968-1970
Conductivity	µScm^2	165-256	238 (10 .iv.64)	140-390	-
pH	(units)	7.2-8.6	8.0-9.2 (1954-1956)	8.2-9.1	7.6-9.5
Oxygen	(mg L^{-1})	5.4-10.2	€ -	-	6.2-9.6
Alkalinity	(meq L^{-1})	1.40-3.90	2.57 (10 .iv.64)	1.63-2.66	1.35-2.68
NO_3-N	(µg L^{-1})	31-630	<20-.500 (1954-1956)	1-100	29-1880
PO_4-P	(µg L^{-1})	<5-108	<10-100 (1954-1956)	2-120	0-92
Si (x2.1=SiO_2)	(mg L^{-1})	1.9-14.1	8.6-11 (1954-1956)	7.5-11	2.4-10.7
Ca^{2+}	(meq L^{-1})	0.51-1.16	1.50 (10 i.v.64)	0.98-1.41	0.86-1.80
Mg^{2+}	(meq L^{-1})	0.12-0.66	0.72 (10 .iv.64)	0.41-0.54	0.23-0.84
Na^+	(meq L^{-1})	0.20-0.62	0.47 (10 .iv.64)	0.20-0.39	0.17-0.67
K^+	(meq L^{-1})	0.02-0.07	0.06 (10 .iv.64)	0.04-0.07	0.03-0.12
Organic matter	(as mg O_2 L^{-1})	1.2-5.9	-	-	1.1-6.0
Total residue	(mg L^{-1})	40-5980	-	-	112-3842

Total residue (Fig. 1a)

The fluctuations of this material (originally dissolved plus particulate) in the Blue Nile showed a marked seasonality. The water of the Blue Nile descending from the Ethiopian highlands where it received numerous tributaries, is always laden during the flood season with enormous quantities of silt, clay, and fine sand with maximum levels in the range of 1720-5980 mg L^{-1}. However, during low water flow between November-May, only a little material in the range of 40-270 mg L^{-1} was carried in the water of the Blue Nile. The turbid flood water reduced the Secchi disc transparency during peaks of total residues in August to < 1 cm. The post-flood period is characterized by relatively high Secchi disc transparency which fluctuated between 32 and 56 cm. During low river flow, Secchi disc readings closely followed the densities of the phytoplankton.

Temperature (Fig. 1b)

The water temperature of the river fluctuated in the range 15.0-30.2°C. Samples taken from different depths (0.5-7.0 m) indicated that the river was not thermally stratified. Homothermal conditions at Khartoum during low river flow may be attributable to complete mixing of the water column at various shallow stretches of the river upstream of Khartoum.

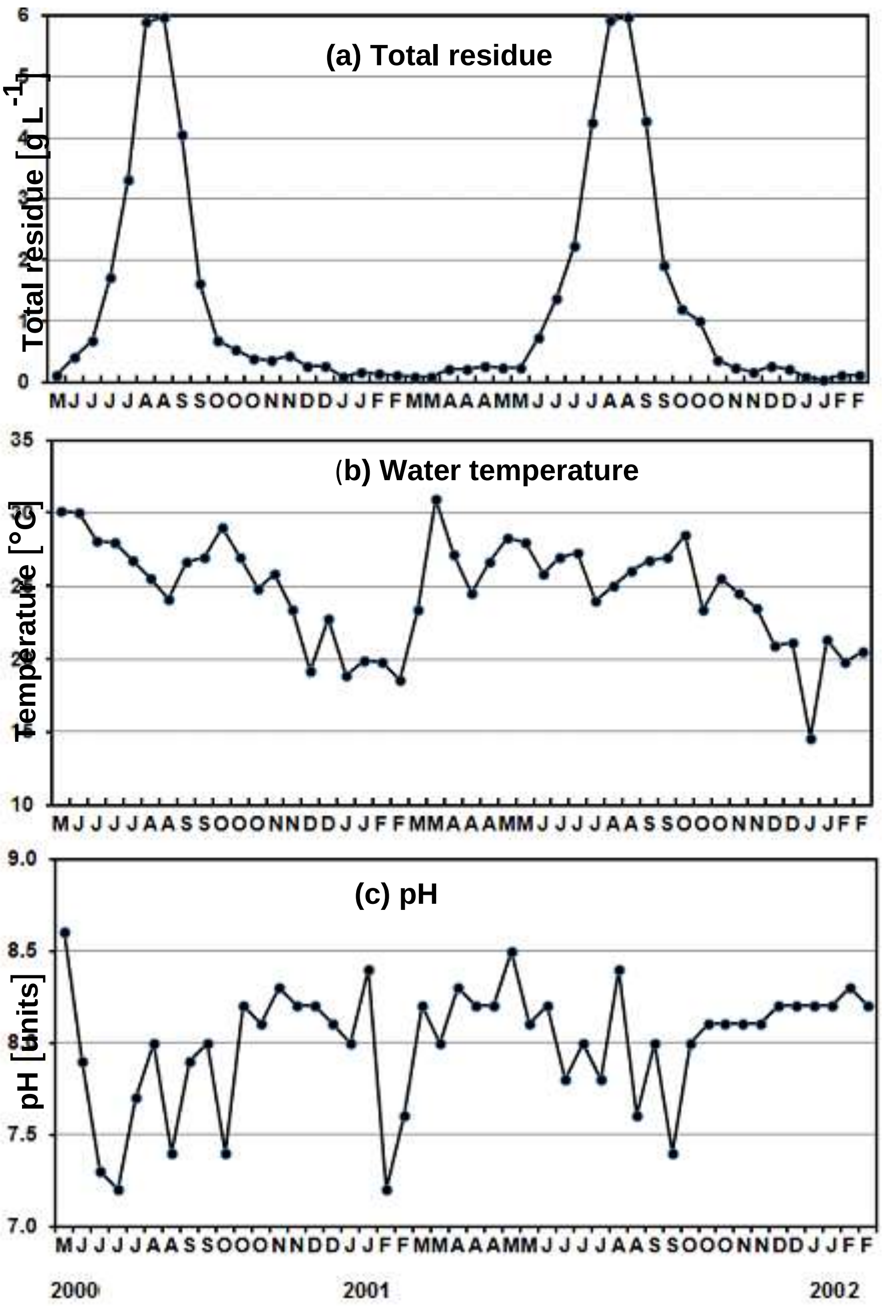

Fig. 1 Seasonal variations in (a) total residue, (b) water temperature and (c) pH in the surface water of the Blue Nile at Khartoum during May 2000-February 2002

pH (*Fig. 3c* measured at 10 am)

The pH in the Blue Nile was neither acidic nor highly alkaline. It fluctuated in the range 7.2 and 8.6, indicating that the river possesses a relatively high buffering capacity which prevents abrupt changes in its pH. The maximum pH values usually coincided with periods of high phytoplankton densities when net CO_2 consumption by photosynthesis was expected. This is in harmony with the findings of Talling and Rzóska (1967) and Sinada and Abdel Karim (1984), and others who worked on different tropical rivers. As expected, low values of pH below 8.0 were always maintained throughout the flood season (late June-October) when phytoplankton growth was negligible.

Dissolved oxygen (Figs. 2a and 2b)

The Blue Nile was well oxygenated. The percentage saturation did not drop below 74%. Super saturation was observed on several occasions during January-May at times of phytoplankton abundance; values in the range 106-115% were recorded during the winter diatom maximum and the summer phytoplankton peak. During the flood season of the Blue Nile, the undersaturated levels of oxygen tended to fluctuate between 66-86% but never reached 100%. The present findings are reminiscent of those observed in the same river by Talling and Rzóska (1967) who reported a slight super-saturation during phytoplankton maxima and moderate degree of sub-saturation when the river was in flood.

Dissolved oxidizable organic matter (Fig. 2c)

The well oxygenated waters of the Blue Nile at Khartoum indicated that the river was far from being organically polluted.

Oxidizable organic matter remained in the range 1.1-5.9 mg O_2 L^{-1}. However, relatively high concentrations in the range 3.7-5.9 mg O_2 L^{-1} were only recorded during the flood season whereas during low river flow the concentrations fluctuated in the narrow range 1.4-3.6 mg O_2 L^{-1}. The increase in the concentration of oxidizable organic matter in the Blue Nile during the flood may be attributed to appreciable amounts of organic matter (particulate plus dissolved) prone to leaching being washed down the Ethiopian plateau into the course of the river during the torrential rains.

Nitrate-nitrogen (Fig. 3a)

The variation of NO_3-N in the Blue Nile showed a definite annual cycle. Low concentrations in the range 31-70 µg NO_3-N L^{-1} were maintained throughout the dry season (December-May). The maximum concentrations of NO_3-N occurred during the wet season (July-September). With the arrival of the Blue Nile flood water at Khartoum in late June, the concentration of NO_3-N increased sharply, reaching maximum concentrations (480-630 µg NO_3-N L^{-1}). In 1951-3 Talling and Rzoska (1967) found similar results, but Sinada and Abdel Karim (1984) recorded much higher peaks of 1040 and 1880 µg NO_3-N L^{-1} during the flood seasons of 1969/1970 in the Blue Nile at Khartoum. The relatively lower concentrations recorded during the present study when compared to those recorded by Sinada and Abdel Karim

(1984) may be explained by the dilution effect of a higher river discharge experienced during the flood season of the present study. Presumably, the high concentrations of nitrate-nitrogen recorded at Khartoum are contributed by tributaries from Ethiopian soils leached by rain which plays an important role in bringing nitrate

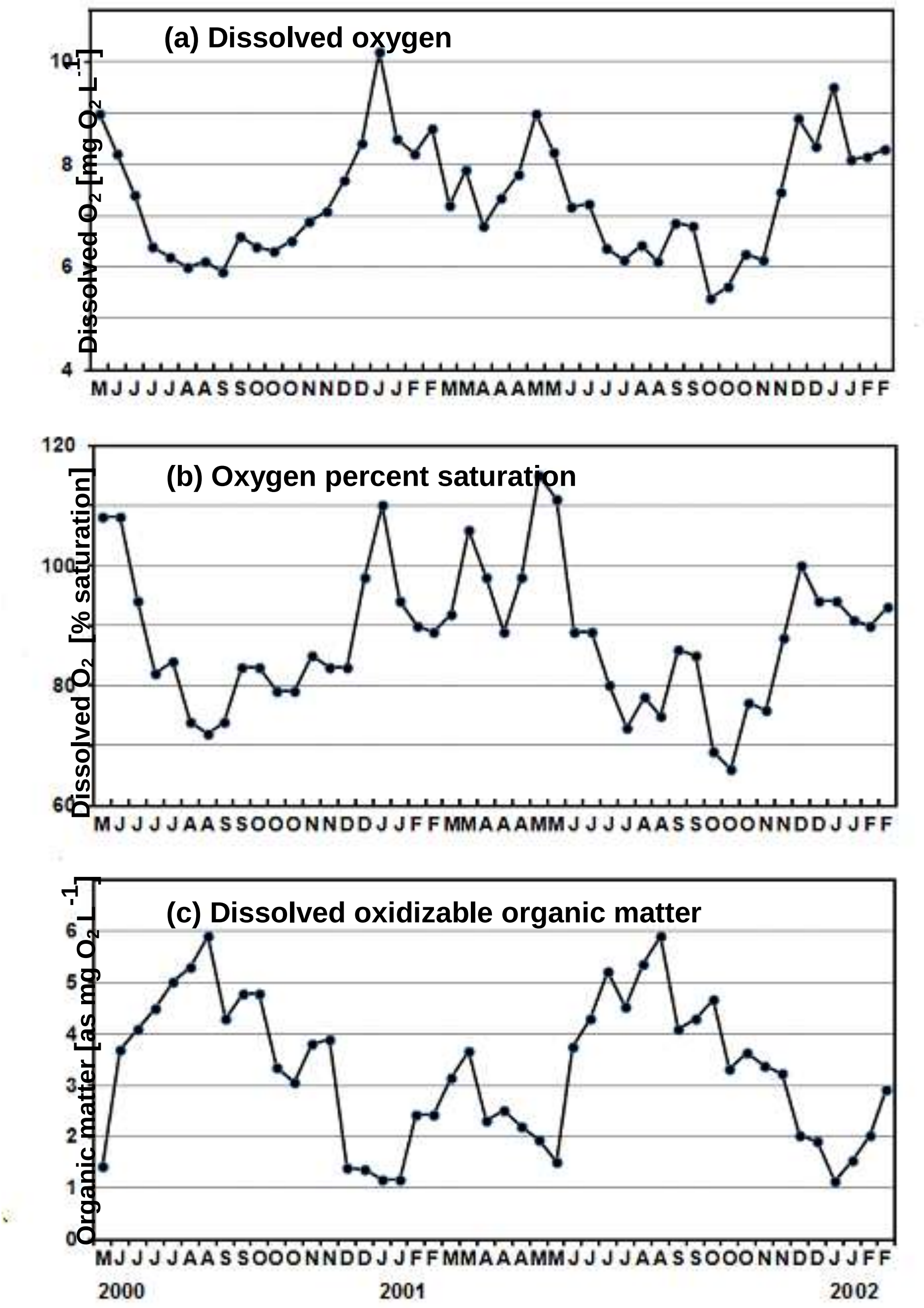

Fig. 2 Seasonal variations in (a) dissolved oxygen, (b) oxygen percent saturation and (c) dissolved oxidizable organic matter in the surface water of the Blue Nile at Khartoum during May 2000-February 2002

into the Blue Nile. In addition to weathering of rocks in the drainage basin, Talling and Lemoalle (1998, p. 46) reviewed other sources of nutrient inputs in tropical waters, such as atmospheric precipitation, breakdown of organic matter, and chemical exchange at the water-sediment interface.

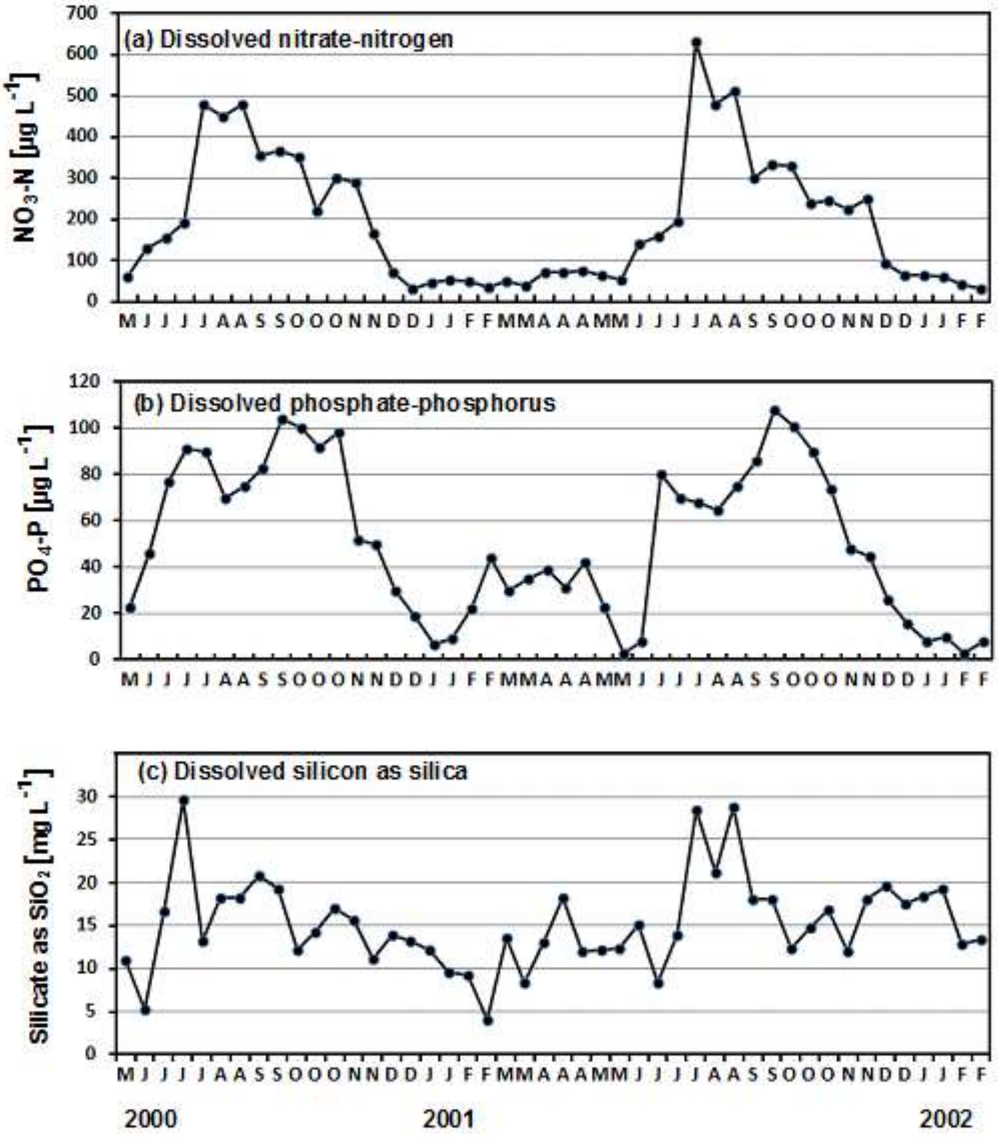

Fig. 3 Seasonal variations in the concentrations of (a) dissolved nitrate-nitrogen, (b) dissolved phosphate-phosphorus and (c) dissolved silicon in the surface water of the Blue Nile at Khartoum during May 2000-February 2002

Phosphate-phosphorus (Fig. 3b)

The concentrations of PO_4-P showed a well-developed seasonal cycle. Periods of high phosphate content in the Blue Nile coincided with the flood season. A sudden increase occurred with the arrival of the brown flood water at Khartoum in late June. As reported by previous workers (Talling and Rzóska 1967; Sinada and Abdel Karim 1984) higher levels in the range 74-108 µg PO_4-P L^{-1} were maintained throughout the flood season until November when the concentration started to decline gradually. During low river flow between February and early May 2001, the concentrations of PO_4-P (22-44 µg L^{-1} , Fig. 3b) were higher than those reported by Talling and Rzóska (1967) and Sinada and Abdel Karim (1984), who found that the concentrations of PO_4-P between February and May, were below or near the limit of detection (<5-10 µg PO_4-P L^{-1}).

Post flood decline was followed by the first diatom maximum which occurred during November- December. Presumably, the phytoplankton is responsible, in part, for the removal of PO_4-P from the surface waters of the Blue Nile during the cold season. Although PO_4-P dropped to levels approaching limits of detection (7 µg PO_4-P L^{-1}) during January and May 2001, a cyanobacterium (*Anabaena flos-aquae* f. *spiroides*) then showed profuse growth. It is not unreasonable to assume that phosphorus transfer in the Blue Nile is rapid in that phosphate is absorbed by *Anabaena* as rapidly as it comes in solution. According to Stewart and Alexander (1971), excess phosphorus is stored in the vegetative cells of blue-green algae as polyphosphate bodies, which may form within 60 min of adding phosphorus to phosphorus starved cells. The internal phosphorus reserves are stored in the cyanobacterium in sufficient amounts to sustain two or three doublings when external concentrations of phosphorus appear to be limiting (Reynolds and Walsby 1975).

Silica-silicon (Fig. 3c)

The concentrations of dissolved silicon in the Blue Nile varied between 4.0 and 29.7 mg SiO_2 L^{-1} (1.9-14.0 mg Si L^{-1}). High concentrations of silicon occurred during the flood season when values between 12.0-29.7 mg SiO_2 L^{-1} (5.6-14.0 mg Si L^{-1}) were maintained in the absence of diatoms. The increase in silicon during the flood season can be explained as Hall *et al.* (1977) suggested that the seasonal variation of silicon is due to the product of rock weathering of large Si reserves whose dissolution is helped by the rain, by the tropical temperature and the increased turbulence of the river in flood. The decrease in silicon which occurred during November 2000-February 2001 is apparently due to removal by diatoms which preponderate during these months. The depletion of silicon by diatoms in tropical waters is well documented as reviewed by Talling and Lemoalle (1998). However, Talling and Rzóska (1967) did not observe any correlation between depletion of silicon and diatoms increase in this very river during 1954-1956. Sinada and Abdel Karim (1984) pointed out that the decline in silicon concentration in the Blue Nile was gradual, but the restoration of higher levels after the dispersal of diatom maxima, was always rapid. This probably indicates that the dissolved silicon, which is depleted by diatoms, has large reserves in the particulate fraction which go rapidly in solution.

Alkalinity (Fig. 4a)

Phenolphthalein alkalinity was not detected at any time in the Blue Nile; the total alkalinity was due primarily to bicarbonate ions. The maximum value of

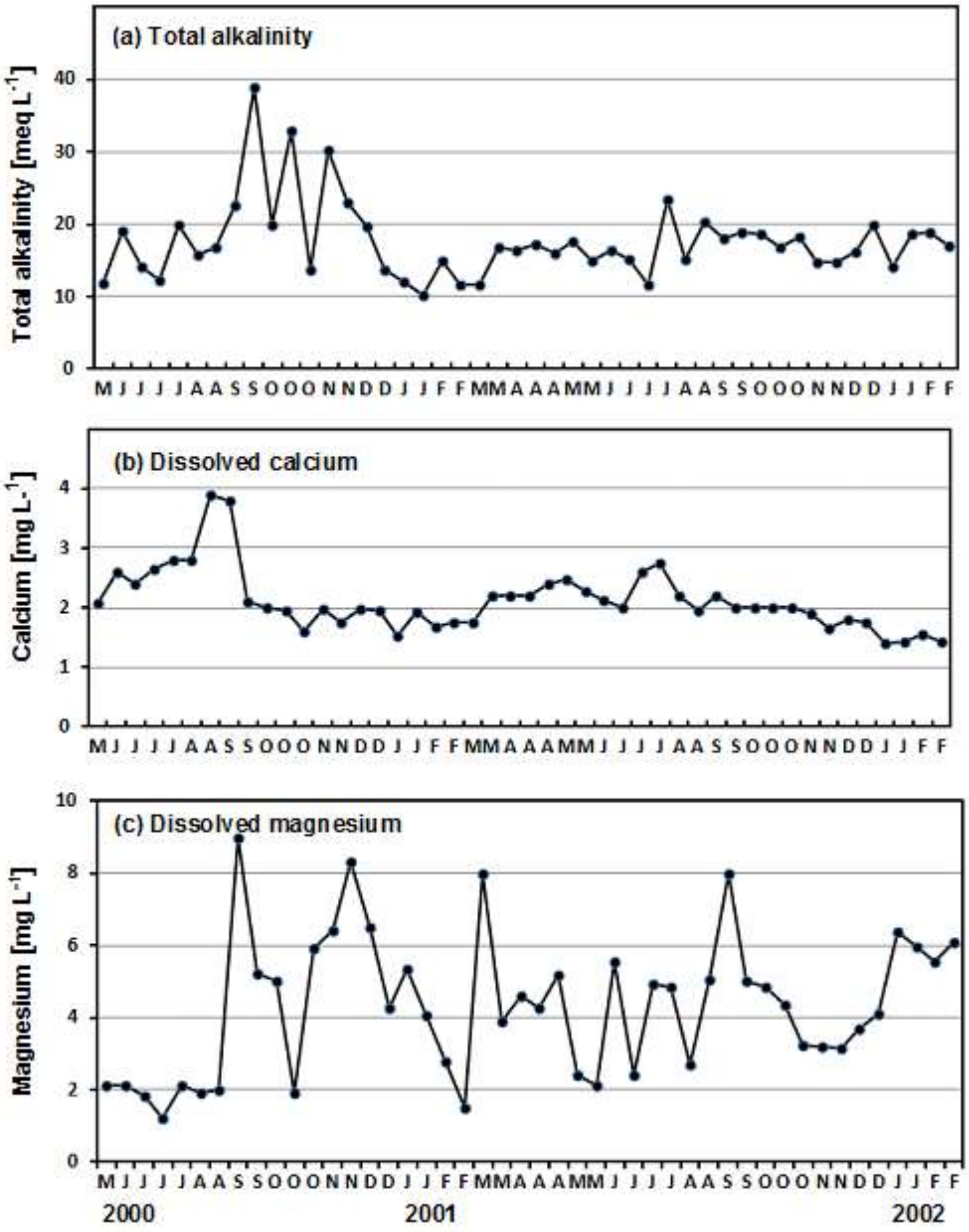

Fig. 4 Seasonal variations in (a) total alkalinity, (b) concentrations of dissolved calcium and (c) concentrations of dissolved magnesium in the surface water of the Blue Nile at Khartoum during May 2000-February 2002

alkalinity recorded during the present survey was 3.90, and the minimum value was 1.40 meq L^{-1} These high values of alkalinity imply a large reserve of total CO_2 which reflects an adequate supply of inorganic carbon for the support of algal populations unless uptake is limited to free CO_2 that declines with rise of pH.

Alkalinity values increased gradually and steadily during the flood season in the Blue Nile but decreased during the dry season. The highest values 2.80-3.90 meq L^{-1} observed during July-August 2000 can be attributed to introduction of bicarbonates into the river from the catchment area during the rainy season on the Ethiopian plateau. Previous workers did not observe increase of alkalinity during the flood season of the Blue Nile (Talling and Rzóska 1967; Sinada and Abdel Karim 1984).

Calcium and magnesium (Fig. 4b, c)

Sufficient quantities of Ca^{2+} and Mg^{2+} in excess of the requirements of the algae were maintained throughout the study in the waters of the Blue Nile. The average, maximum and minimum values of calcium and magnesium in the Blue Nile during 2001 are shown in Table 1. The seasonal variations of calcium and magnesium were irregular and without any definite pattern. The concentrations of calcium were always greater than those of magnesium.

Sodium and potassium (Table 1)

Sodium (Na^{+}) and potassium (K^{+}) were measured for eight months only from May to December 2000. The average, maximum and minimum values of sodium and potassium in the Blue Nile are shown in Table 1. The concentrations of sodium exhibited greater concentrations than potassium. This is in conformity with observations of Talling and Talling (1965) as is typical of most inland waters. The maxima of sodium and potassium occurred during the end of the dry season, as is typical of tropical rivers (Talling and Lemoalle 1998) but contrary to the finding of Hall *et al.* (1977) who found higher contents of sodium and potassium during the flood of the Zambezi River.

Heavy metals (lead, cadmium and nickel)

No attempt has been made before to detect the presence of heavy metals such as cadmium, lead, and nickel in the Blue Nile at Khartoum. None of these heavy metals was detected in any sample during the present study. This indicates that the Blue Nile at Khartoum is far from being polluted by heavy metals.

Conclusion

Comparison of the present data, with those recorded in the 1950s and 1960s, shows that the physical and chemical characteristics of the Blue Nile at Khartoum did not experience any change in its water chemistry (Table 1). The pre 1970 values have remained as they were for nearly 50 years without any significant change, although appreciable concentrations of PO_4-P (22-44 µg PO_4-P L^{-1}) were maintained during low river flow between February and May 2001. Nonetheless, long-term physical, chemical, and biological monitoring programmes are recommended. The detection of unwelcome enrichment, which might occur as a result of introduction of industrial contaminants, or diffusion of agrochemicals into the course of the river, may serve as an early warning of deterioration of the water quality which needs urgent attention.

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