EVIDENCE OF CONTAMINATION CAUSED BY SUGAR–CANE MONOCULTURE AND ASSOCIATED INDUSTRIAL ACTIVITIES IN WATER BODIES OF THE STATE OF PARAIBA, NORTHEAST BRAZIL

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ABSTRACT

Analyses of inorganic nutrients, dissolved oxygen, Biochemical Oxygen Demand (BOD), faecal coliforms, and total and fermentative yeasts were carried out in different sectors of representative aquatic ecosystems of the sugar-cane agricultural zone of the State of Paraíba's littoral region. High concentrations of yeasts, low values of dissolved oxygen, and high levels of BOD, observed in the vicinity of a distillery, and a constant presence at high concentrations of fermentative yeasts along the Paraíba do Norte River estuary provide direct evidence of contamination of this environment by vinasse and/or wastewaters. High values of nitrate at the head of the Açu River and at the reservoirs of the Gramame and Mamuaba rivers provide indirect evidence of the contamination of these ecosystems by chemical fertilizers used on adjacent sugar-cane plantations. The presence of fermentative yeasts along the Açu River, usually in relatively high concentrations, also suggests the influence of these crops.

INTRODUCTION

Until 1970, sugar-cane plantations were concentrated mainly in the fertile valleys of the State of Paraíba's littoral and "brejo" regions.

In that year, these two regions jointly accounted for 96.3% of the sugar-cane production, and for approximately 90% of the area under sugar-cane cultivation in the state (MOREIRA, 1990). In 1975, the Federal Government provided incentives through the Alcohol National Program (Pró-alcool) for the expansion of sugar-cane farming to the coastal "tabuleiros" and the slopes of the "brejos", formerly considered inadequate. The "tabuleiros" were formerly regarded as a natural limit to the expansion of sugar-cane crops either due to their low soil fertility, or because the slopes were too steep (MOREIRA, 1990).

"Tabuleiro" is a regional term defining a savanna-type vegetation similar to the "cerrado" of central Brazil, generally showing a poor, sandy, lixiviated and poorly drained soil, "extending for almost all the plain surface of the low coastal tablelands' top of the Barreiras formation" (FERNANDES DE CARVALHO & CARVALHO, *in press*). "Brejo" is a regional term defining areas of evergreen forest subjected to humid Atlantic winds occurring in uplands of the semi-arid region. Their evergreen forest vegetation is similar to that of the coastal Atlantic Forest.

Soil correctives and pesticides were necessary for the cultivation of sugar-cane on the "tabuleiros". This contributed substantially to the degradation of the streams draining the region (Brazil, SUDEMA, 1992). Allethrin, carbamate, diuron, glyphosate, tebuthioron, terbacil, 2,4-D paraquat, and paraquat+ diuron were the major pesticides used. The last two are the most lethal, a couple of drops being lethal to man (GESTAR, unpublished data).

The importance of vinasse as a fertilizer is well known, and although Brazilian legislation prohibits the disposal of vinasse and wastewaters of distilleries and sugar mills in water bodies, river contamination from this kind of pollution is still frequent throughout the northeast of Brazil. However, the scarcity of studies on the effects of vinasse on the soils of this region, together with the high cost of its aspersion over uneven ground and the inefficiency of the environmental agencies concerning inspection and control of the disposal of these effluents, provides no stimulus for entrepreneurs to act differently.

Estuaries and public reservoirs for drinking water are the major aquatic ecosystems of Paraiba's littoral zone which are affected by sugar-cane plantations and/or industrialization. The hydrographic basins of these ecosystems include the "tabuleiros", and pass through the low coastal tablelands. Notable in this context are the estuaries of the River Mamanguape, in the north of the state, and the River Paraiba do Norte, along with the reservoirs of the Rivers Gramame and Mamuaba in the vicinity of João Pessoa, the state capital.

The Mamanguape River estuary, the second largest estuarine area in the state, is apparently still relatively well preserved, being bordered by intact mangrove swamps. It is located within an Indian Reserve controlled by the National Indian Foundation (FUNAI), and is protected by the Brazilian Environment Institute (Ibama). However, the headwaters and upper and middle reaches of some of its tributaries, for example the River Açu, are bordered by extensive sugar-cane plantations.

The Paraíba do Norte River estuary, the largest of the state, receives untreated sewage from many coastal municipalities, among which João Pessoa is the most populous. Moreover, it also receives the discharge of agricultural and industrial residues, mainly those coming from sugar-cane monocultures and the sugar and alcohol industries. Consequently, this ecosystem is subjected to a continuous process of contamination and eutrophication, even showing anoxic areas (SASSI & WATANABE, 1980a, b; SASSI et al, 1985) and high concentrations of bacteria and yeasts (OLIVEIRA, 1990).

The Gramame and Mamuaba rivers were dammed in September, 1988 and March, 1989, respectively, in order to store water for public supply. Together the reservoirs store approximately 70 million m^3, with depths of 17 m during most of the rainy season. They are interconnected through a channel approximately 800 meters in length, the objective of which is maintain the stability of the water level in the Gramame reservoir during prolonged dry periods. Both reservoirs were filled without any previous removal of the vegetation. This caused a change in the water colour, a depletion of dissolved oxygen, and an intense release of hydrogen sulphide, evidencing the influence of the decomposition of the vegetation on the water quality. The area influenced by the reservoirs is surrounded, to a great extent, by sugar-cane crops.

The present study aimed to characterize sectors from the above mentioned ecosystems, according to select hydrological and microbiological parameters, in order to determine the influences of sugar-cane monocultures and of the residues originating from alcohol distilleries and sugar mills in these locations.

METHODS

Five sampling sites were established in the Açu River (FIG. 1). They were sampled during low tides, from April 1989 to July 1990. Site 0 was located at the head of the river, which is bordered by an extensive sugar-cane plantation site 1, approximately 1.0 km downstream, was also influenced by sugar-cane crops, although other subsistence crops were present; sites 2, 3, and 4 were located in typical estuarine areas, thus being influenced by tidal fluctuations and were bordered by mangrove vegetation.

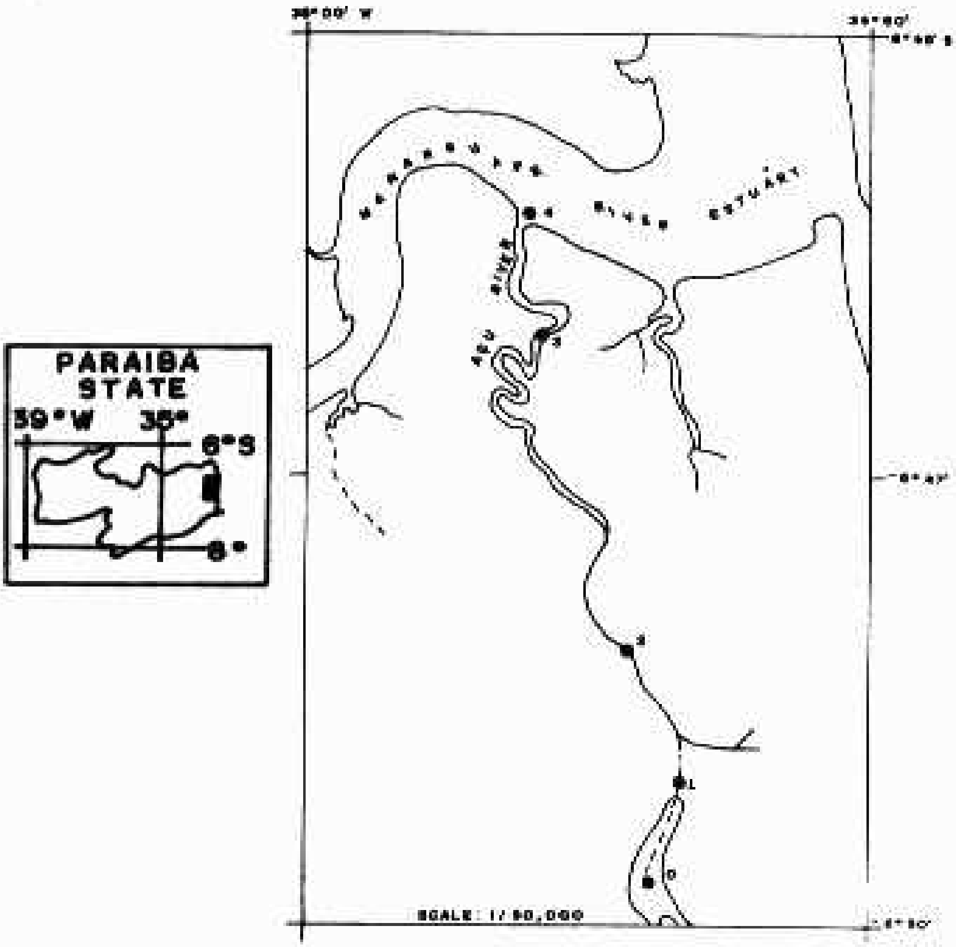

Fig. 1. Collection sites at Açû River.

Sampling of the Paraíba do Norte River estuary was carried out at eight sites (FIG. 2), from November 1984 to July 1985. Except for sites 21A, 21B and 21C, which reflect freshwater characteristics, the remainder were located in a typical estuarine area. Among those three sites 21B was close to an ethanol–producing plant, and 21C was surrounded by an extensive sugar-cane plantation. Site 24 was located in the upper part of the estuary, close to the Ilha do Bispo slum district, and subject to sewage discharge.

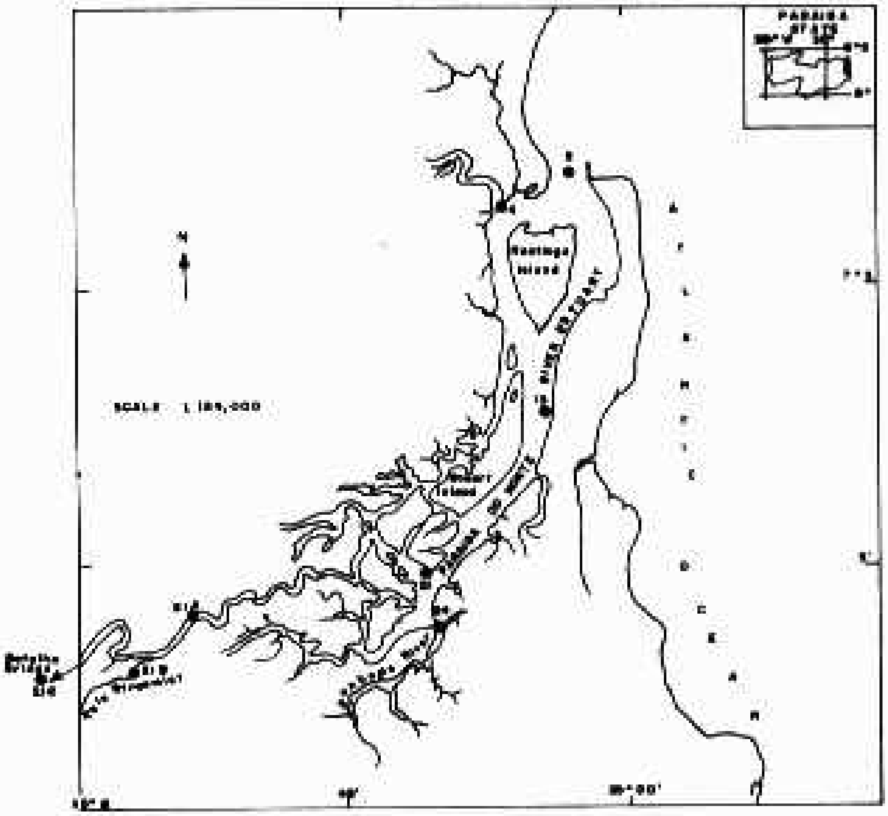

Fig. 2. Collection sites at Paraiba do Norte River Estuary.

Sampling at the Gramame and Mamuaba reservoirs (between 07°12'S and 07°17'S, and between 34°50'W and 34°58'W) was carried out from February 1989 to February 1991 at six sites (3,4 and 5 along the Gramame River; 6, 7 and 8 along the Mamuaba River). Sites 3 and 8 were located immediately downstream of the dam, where the water is taken from the lower portion of the water column. Sites 4 and 7 were located at the deepest parts of the reservoirs, and sites 5 and 6 were close to the mouth of the channel which connects the two reservoirs. In all the areas studied, sampling was monthly and at surface level only.

In the Açu River and the Paraíba do Norte River estuary, concentrations of nitrate and nitrite (following GRASSHOFF, 1976) were determined, as well as orthophosphate (STRICKLAND & PARSONS, 1960), dissolved oxygen (STRICKLAND & PARSONS, 1965), faecal coliforms (APHA–AWWA–WPCF, 1981), and total and fermentative yeast concentrations (HAGLER, 1978; SANTOS, 1980; SCHRANK, 1982). In the Paraíba do Norte River estuary, BOD analyses (following APHA–AWWA–WPCF, 1981) were also carried out. For the Gramame and Mamuaba reservoirs, nitrate was determined by the sodium salicylate method described in RODIER (1975); nitrite, ammonia, and orthophosphate were determined by the colorimetric method according to MACKERETH et al. (1978), and sulphate according to the turbidimetric method described in GOLTERMAN et al. (1978).

RESULTS

THE AÇU RIVER

The highest values of dissolved inorganic nutrients were recorded for the sampling sites close to the Açu River mouth, and occurred between April and September (rainy season). However, high concentrations of nitrate were also recorded between September and December in site 0, which is located at the headwaters (FIG. 3, 4, 5).

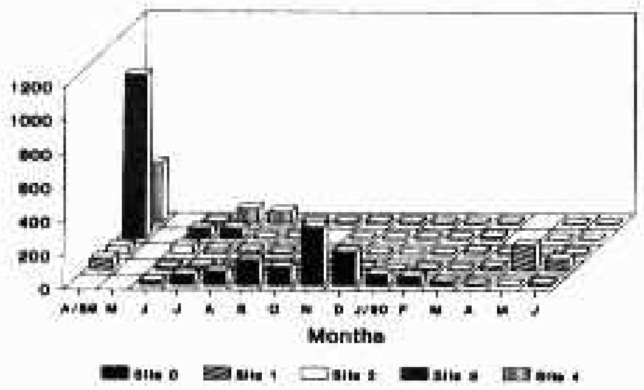

Fig.3. Nitrate (µg/L–NO3) values from Açu River.

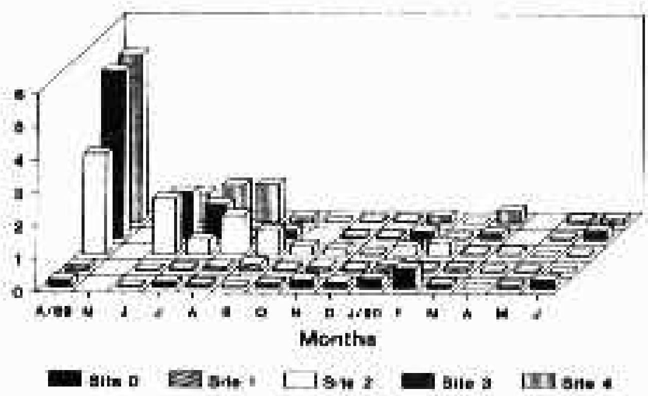

Fig.4. Nitrite (µg/L –NO2) values from Açu River.

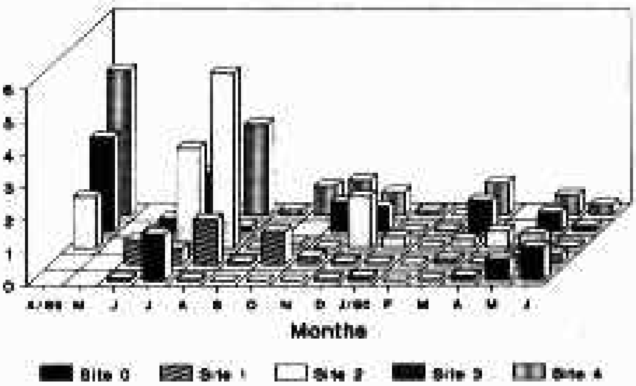

Fig. 5. Orthophosphate (µg/L –PO4) values from Açũ River.

The nitrate values ranged between 2.24 mg/L–NO_3 (January/90, site 1) and 973.68 mg/L–NO_3 (April/89, site 3). At the head waters, the nitrate values reached 346.94 mg/L–NO_3 (November/89). For nitrite, the concentrations varied from 0.0 mg/L–NO_2 to 5.09 mg/L–NO_2 (April/89, sites 3 and 4), and for orthophosphate the values ranged from 0,01 mg/L–PO_4 to 5.37 mg/L–PO_4 (August/89, site 2).

FIG. 6 shows the mean values of dissolved oxygen, faecal coliforms, and total and fermentative yeast concentrations at the sampling sites along the Açu River. An increase in coliform density was detected from site 0 to site 2, and a decrease was observed from the latter site to the river mouth. The results expressed in $\log_{10}$ MPN/dL ranged from 1.50 (±0.82) at site 0 to 2.00 (± 0.64) at site 2.

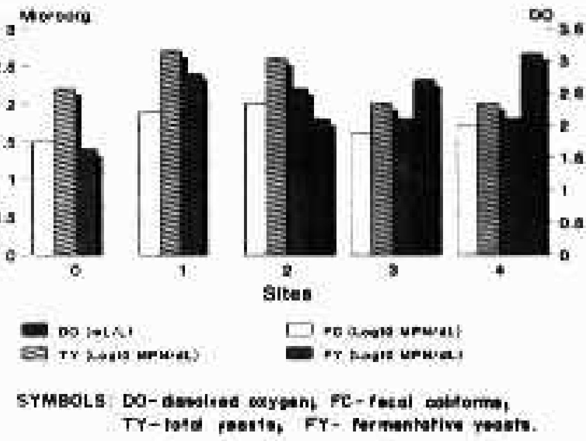

Fig. 6. Microbial counts and dissolved oxygen concentration from Açũ River (mean values).

The concentrations of total and fermentative yeasts followed a pattern similar to that showed by faecal coliforms. The highest value for total yeasts was 2.68 (± 0.49) $\log_{10}$ MPN/dL at site 1, and the lowest was 2.00 (± 0.56) $\log_{10}$ MPN/dL at site 4. These results indicated that the concentrations of total yeasts were always higher than that of faecal coliforms at all sites. Concerning the fermentative yeasts, only site 0 showed lower values compared to those for faecal coliforms.

In contrast to the concentrations of faecal coliforms and total and fermentative yeasts, the concentrations of dissolved oxygen gradually increased from site 2 (2.07 ± 1.18 mL/L) towards site 4 (3.10 ± 1.03 mL/L).

THE PARAÍBA DO NORTE RIVER ESTUARY

The highest levels of nitrate and nitrite were observed at site 24, which showed mean values of 129.08 (± 44.11) mg/L—NO_3 and 9.86 (± 3.98) mg/L—NO_2, respectively. The lowest values were recorded at site 21B, with mean values of 12.58(± 12.42)mg/L—NO_3 and 0.05 (± 0.02) mg/L—NO_2 respectively (FIG. 7).

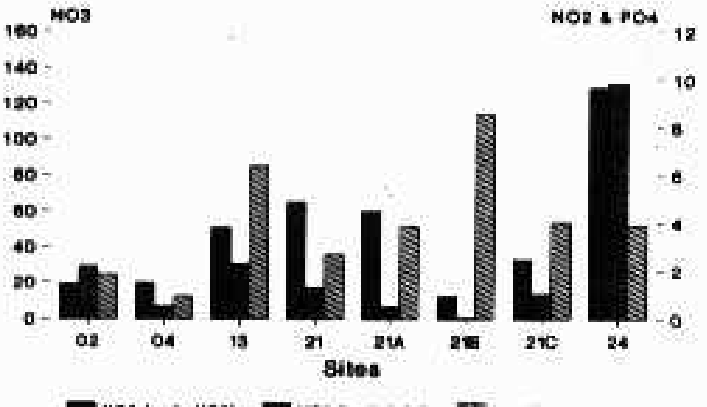

Fig. 7. Nitrate, nitrite and orthophosphate values from Paraiba do Norte River estuary (mean values).

The maximum and minimum average values recorded for orthophosphate were obtained at sites 21B and 4; 8.57 (± 4.77) mg/L—PO_4 and 0.94 (± 1.30) mg/L—PO_4, respectively (FIG. 7).

In general, the mean concentrations of faecal coliforms and total and fermentative yeasts, recorded for the eight sites surveyed, showed and increase from site 2 (estuary mouth) to site 21B (upper portion). The yeasts decreased numerically from site 21C to 24, while the coliforms increased. The maximum concentration of faecal coliforms was 4.84 (± 1.33) $\log_{10}$ MPN/dL at site 21A, and the minimum concentration was 1.97 (± 0.51) $\log_{10}$ MPN/dL at site 4. The maximum concentrations of total yeasts varied from 2.29 (± 1.26) $\log_{10}$ MPN/dL (site 2) to 5.37 (± 1.46) $\log_{10}$ MPN/dL (site 21B). At site 21B, where the content of dissolved oxygen was lowest, the concentration of total yeasts prevailed over that of faecal coliforms. On average, fermentative yeasts ranged between 1.80 (± 0.49) $\log_{10}$ MPN/dL (site 4) and 5.01 (± 1.84) $\log_{10}$ MPN/dL (site 21B) (FIGS. 8, 9).

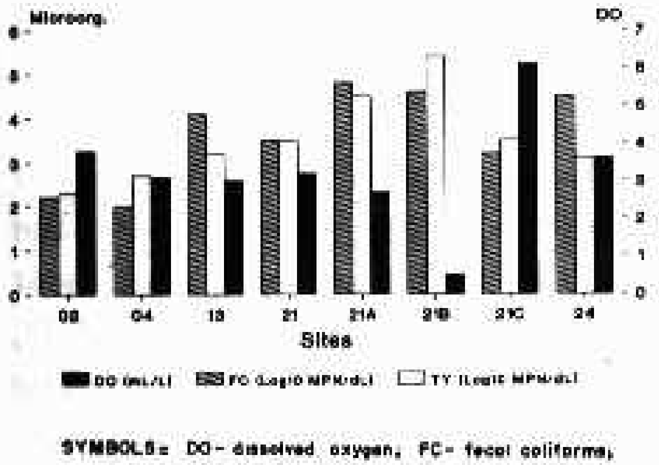

Fig. 8. Microbial counts and dissolved oxygen concentration from Paraiba do Norte River estuary (mean values).

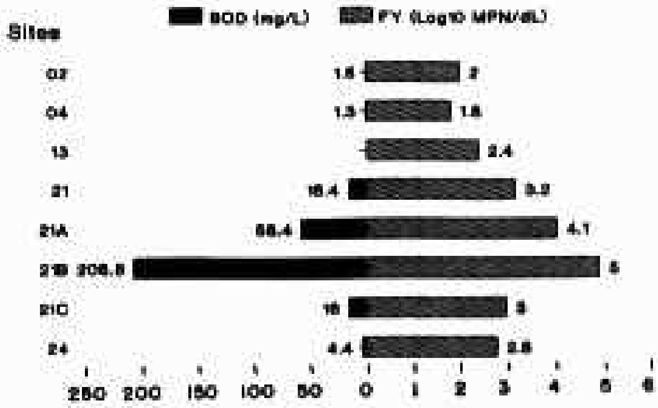

Fig. 9. Biochemical oxygen demand and fermentative yeasts from Paraiba do Norte River estuary (mean values).

The average values of dissolved oxygen showed an opposite pattern to that observed for total and fermentative yeasts and faecal coliforms, decreasing from site 2 with 3.80 (± 0.74) mL/L, to site 21B with 0.50 (± 0.69) mL/L. The latter sampling site was also totally anoxic during the most part of the study period. The highest average value was recorded at site 21C, reaching 6.09 (± 2.16) mL/L.

A direct relationship was observed between BOD and fermentative yeasts (FIG. 8), and an inverse one between BOD and dissolved oxygen (FIG. 8, 9). The maximum average value for BOD was recorded at site 21B, reaching 208.8(± 285.8) mg/L.

THE GRAMAME AND MAMUABA RESERVOIRS

The orthophosphate content in both reservoirs suggests a shortage of this nutrient (FIG. 10, 11). Orthophosphate concentrations were low between February 1989 and March 1990. The highest values recorded for this period were 66.4 mg/L—PO_4 in the Gramame River (site 3) and

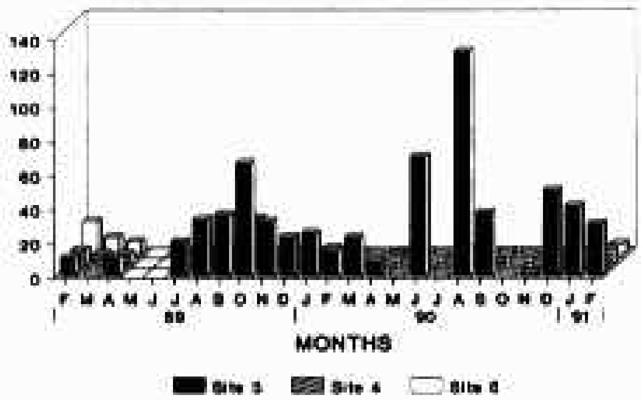

Fig. 10. Orthophosphate (µg/L -PO4) values from Gramame Reservoir.

Fig. 11. Orthophosphate (µg/L -PO4) values from Mamuaba Reservoir.

19.7 mg/L—PO_4 in the Mamuaba River (site 8). The release of phosphated compounds resulting from the decomposition of the submerged vegetation, surely contributed to these results. During most of the subsequent period (from March 1990 to February 1991), orthophosphate levels were zero in almost all the sampling sites. The highest values were recorded in August, reaching 132.2 mg/L—PO_4 and 47.2 mg/L—PO_4, in the Gramame and Mamuaba rivers, respectively.

Nitrogen compounds were detected in both reservoirs, mainly as nitrate and ammonia—nitrogen. At the Gramame Reservoir, nitrate—nitrogen concentrations ranged from zero to 563.03 mg/L—NO_3, while at Mamuaba the values varied from zero to 377.6 mg/L—NO_3 (FIGS. 12, 13). A decrease in the nitrate concentrations in both reservoirs was observed from April 1989 to June 1990, but followed by a sharp increase in the subsequent period.

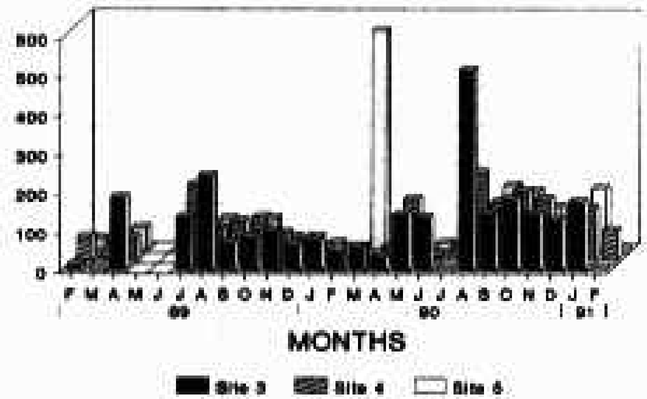

Fig. 12. Nitrate (µg/L-NO3) values from Gramame Reservoir.

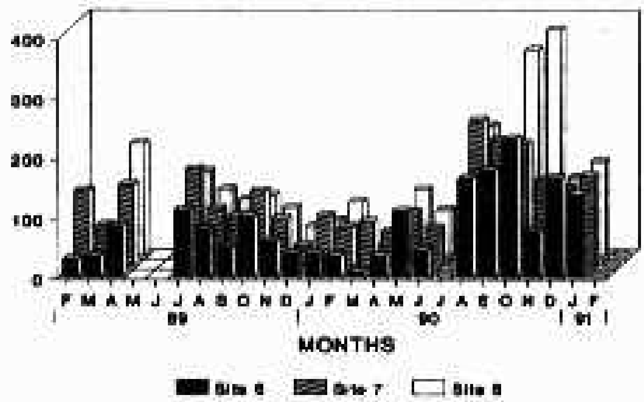

Fig. 13. Nitrate (µg/L-NO3) values from Mamuaba Reservoir.

Nitrite concentrations remained relatively low between February 1989 and June 1990, showing an increase between August and September. A very high concentration was also observed in January 1991 (66.02 mg/L—NO_2) in the Gramame Reservoir. Except for this maximum value, nitrite contents ranged from zero to 19.8 mg/L—NO_2. For the Mamuaba Reservoir the values obtained in August to September, ranged from 33.9 mg/L—NO_2 (site 7) and 36.4 mg/L—NO_2 (site 6). These results are considered to be very high when compared to the normal pattern of monthly variation observed in both reservoirs (FIGS. 14, 15).

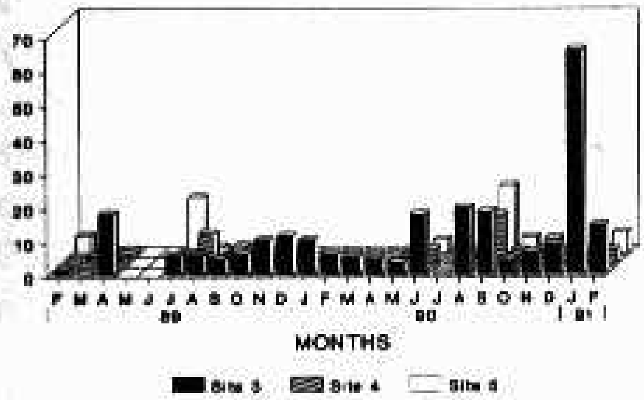

Fig. 14. Nitrite (µg/L -NO2) values from Gramame Reservoir.

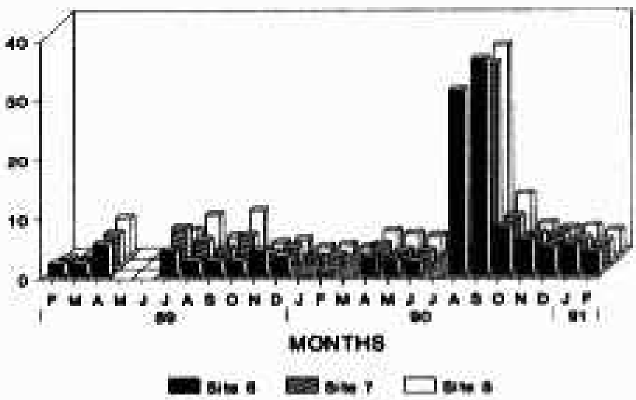

Fig. 15. Nitrite (µg/L -NO2) values from Mamuaba Reservoir.

The Gramame and Mamuaba Reservoirs showed different patterns of monthly variation in ammonia.

Site 3 (Gramame River) presented relatively high concentrations during almost the entire study period. This pattern was not observed at site 8 (Mamuaba River), although both sampling sites were located downstream from the dams in similar locations. The site 3 varied from zero to 710.4 mg/L—NH_4, with an average at 357.29 mg/L—NH_4. Although extremely high values were recorded for the remaining sampling sites (1,276.60 mg/L—NH_4 at site 6 and 984.04 mg/L—NH_4 at site 5), the average values ranged from 58.2 mg/L—NH_4 (site 7) to 119.6 mg/L—NH_4 (site 8); much lower than that found for site 3 (FIGS. 16, 17).

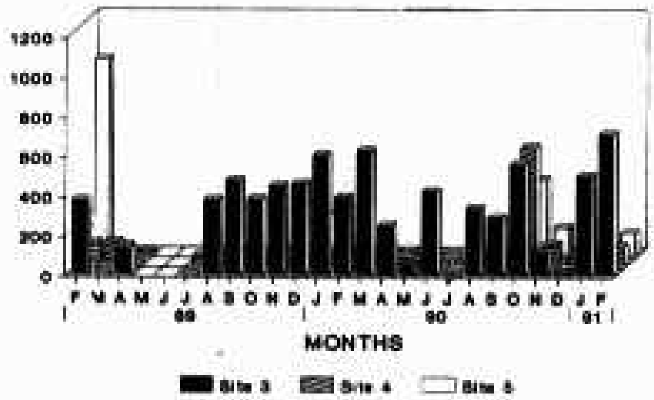

Fig. 16. Ammonium-nitrogen (µg/L-NH4) values from Gramame Reservoir.

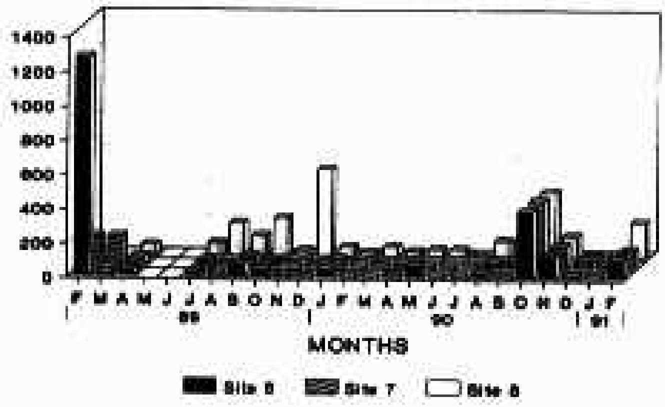

Fig. 17. Ammonium-nitrogen (µg/L-NH4) values from Mumbaba Reservoir.

Dissolved sulphate showed a very similar monthly variation among the different sampling sites and in both reservoirs. Between February 1989 and June 1990 the concentrations of dissolved sulphate were low, and the highest values were 11.81 mg/L–SO_4 in Gramame River (site 3) and 11.07 mg/L–SO_4 in Mamuaba River (site 8). There was a sharp increase in the levels of sulphate from August on, reaching 36.59 mg/L–SO_4 in the Gramame River (site 3) and 51.76 mg/L–SO_4 in the Mamuaba River (site 7) (FIGS. 18, 19).

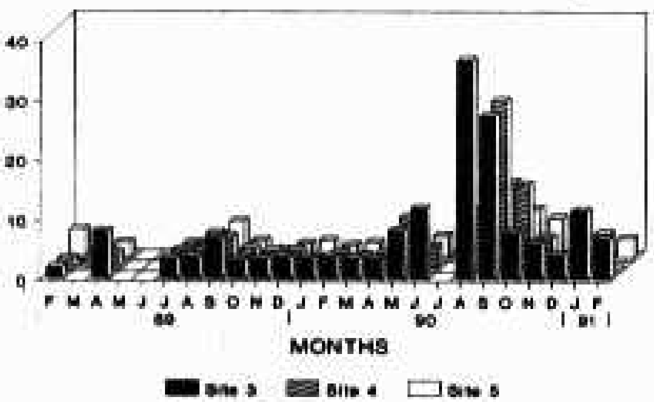

Fig. 18. Sulphate (µg/L-SO4) values from Gramame Reservoir.

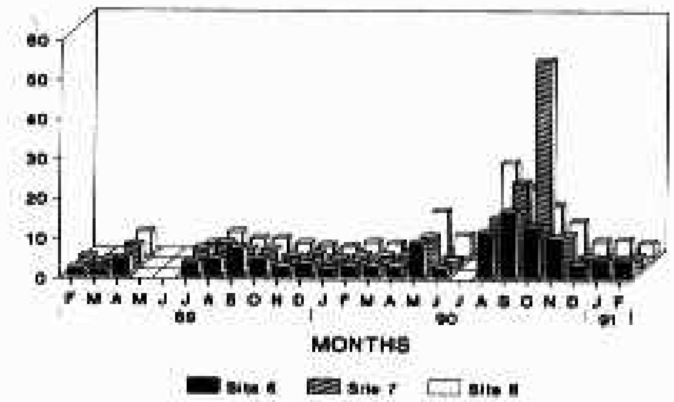

Fig. 19. Sulphate (µg/L-SO4) values from Mamuaba Reservoir.

DISCUSSION

The expansion of sugar-cane cultivation to non-fertile areas has induced planters to use large amounts of fertilizers and herbicides. This has directly affected the water bodies of the region. The increasing transfer of land occupation to the cultivation of sugar-cane in the state of Paraíba led to the harvesting of 178,000 hectares in 1986, although the harvested area decreased in the following years to 160,000 hectares in 1988 (MOREIRA, 1990). During 1990-1991 the total cultivated area was not more than 130,000 hectares according to the Associação dos Plantadores de Cana-de-Açúcar do Estado da Paraíba (ASPLAN).

Despite the retraction of the cultivated area and the reduction of the use of pesticides on sugar-cane plantations due to the application of biological pest control, the use of herbicides is still very intense, being a means to minimize labour costs and the preparation of the soil (GESTAR, unpublished).

The increase of sugar-cane production for distilleries also implies a higher vinasse production. Approximately 13 litres of vinasse are produced for each litre of alcohol. The extremely high reducing action (BOD between 20,000 and 30,000 mg/L) associated with its very acid pH, makes this effluent one of the major polluting agents of aquatic systems (MONTEIRO, 1984). In this context, it should be stressed that in the state of Paraíba, which ranks sixth in national sugar-cane production, between 70% and 80% of the crop is reserved for the production of alcohol, and only 20% to 30% is destined for sugar mills.

According to the Associação dos Plantadores de Cana-de-Açúcar do Estado da Paraíba (ASPLAN), alcohol production in this Brazilian state amounted to 265 million litres in the 1990/1991 harvest. Strong evidences of contamination caused by the activities of the sugar-cane industry were observed in the Paraíba do Norte River estuary, starting especially at site 21B, where high levels of BOD and orthophosphate, low values of dissolved oxygen, and significant concentrations of total and fermentative yeasts were observed. It should be stressed that this sampling site is located close to a sugar-cane processing plant.

Among the yeasts, *Cryptococcus* and *Rhodotorula* prevail in unpolluted and lightly polluted waters, whereas *Saccharomyces* predominates in sites close to distilleries. *Candida* and *Rhodotorula* are typical of waters polluted by sewage (AHEARN et al., 1968; WOLLET & HEDRICK, 1970; MEYERS et al., 1970; SANTOS, 1980). The presence of *Saccharomyces cerevisiae* in almost all the estuarine area of the Paraíba do Norte River detected by OLIVEIRA (1990), is undoubtedly a strong indication of the contamination caused by the residues originating from sugar-cane plantations and/or the sugar and alcohol industries.

In the other two ecosystems studied, the evidence is indirect, and may not be attributed exclusively to sugar-cane cultivation. Nevertheless, it seems unquestionable that the expansion of sugar-cane monoculture to less fertile soils, and the consequent use of chemical fertilizers, have substantially contributed to the contamination of the water bodies of the region. This evidence is clear enough in the Açu River, particularly at the headwaters where high contents of nitrate were observed. The evidence is strengthened by the constant presence of total and fermentative yeasts throughout this environment, consistently in higher concentrations than faecal coliforms.

High contents of inorganic nutrients were also observed in the Gramame and Mamuaba reservoirs; particularly nitrate, just after the building of the dams. However, it must be stressed that the damming was carried out with no previous deforestation of the area, which suggests that the processes of mineralization of submerged organic matter could have been responsible for the initial increases in the nutrient levels observed in these reservoirs. Soon after the damming, a dense bloom of chlorophytes, mainly represented by the genera *Spirogyra, Mougeotia,* and *Oedogonium* was observed, although after this phenomenon the concentrations of inorganic nutrients, orthophosphate in particular, showed a sharp decrease.

According to the Sindicato dos Trabalhadores Rurais do Município de Caaporã (State of Paraíba) the harvesting of sugar-cane starts between late August and early September, and extends until March/April in the following year. The period between May and September is dedicated to planting. The process of preparing the soil, manuring, and herbicide application may occur throughout the year, although during the planting period the use of herbicides may be intensified.

The increase in nutrient levels in the water of the Gramame and Mamuaba reservoirs between August and September seems to be, therefore, connected with agricultural practices in the sugar-cane crops that surround their collecting basins.

Although nitrates are not considered to be of high risk to human health, they are the precursors of the reaction for nitrite production through their reduction in an anaerobic medium, or even in the human intestine when swallowed (ARAÚJO & MIDIO, 1989). One of the most well-known effects of nitrites on man is the oxidation of hemoglobin, which is converted to methemoglobin, a pigment that does not transport oxygen (FERNÍCOLA & AZEVEDO, 1981). Nitrites can also lead to the formation of carcinogenic compounds (e.g., nitrosamines) through reactions with certain aromatic amines found in the intestine (OTTAWAY, 1982; ARAÚJO & MIDIO, 1989). It can be clearly seen, therefore, that high levels of nitrate in waters destined for human consumption (including groundwater) constitute a potential risk to public health.

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