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Nutrients in a Freshwater Lagoon, Lagos, Nigeria

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Abstract. Water samples were taken from a freshwater lagoon of Nigeria, for determination of inorganic nutrients and other water constituents at different sampling points of Owo river and Ologe lagoon at bimonthly intervals for a period of two years from January, 1997 to December, 1998. Indications of the pristine nature of the environment were considerable lower concentrations of dissolved phosphate, nitrate and ammonia than the global averages for unpolluted freshwater. Less significant differences were observed between spatial and seasonal variations in NO_3^- - N and NH_3 -N concentration. PO_4^{3-} - P concentrations on the other hand showed no significant difference. Phosphorus level was below 0.1 mg/l throughout the study period which signal eutrophy in lotic systems. Nitrogen/phosphorus ratios in Owo river and lagoon system (3.0 - 3.2) were lower than expected in P-limited freshwater systems, where molar ratio of N/P is generally >10 to 15. Hence, the nutrient limiting aquatic primary productivity and the most critical to control in the entire study area was nitrogen.

Keywords: nutrients, freshwater lagoon, nitrogen/phosphorus ratio, Nigeria

Introduction

Nutrients, like nitrogen and phosphorus, occur naturally in water, soil and air. Nutrient enrichment seriously degrades aquatic ecosystems and impairs the use of freshwater for drinking, industrial, agricultural, recreational and other purposes. Increased use of nitrogen and phosphorus fertilizers during the last half century has led to increased potential of nutrients for contamination of freshwater. These nutrients occur naturally in soil, animal waste, plant material etc; even atmospheric deposition from diverse sources can add significant amounts of nitrogen to surface water (Howarth *et al.*, 1996). In addition to these natural sources, sewage treatment plants, industries, vehicle exhaust, acid rain, and run-off from agricultural, residential and urban activities contribute nutrients to aquatic ecosystems (Diaz, 2001; Novotny and Olem, 1994; Sharpley *et al.*, 1994). In aquatic ecosystems, these nutrients, cause diverse problems such as toxic algal blooms (Anderson and Garrison, 1997) which pose serious health hazard to humans (Kotak *et al.*, 1993) and contribute to trihalomethane formation in water during chlorination (Palmstrom *et al.*, 1988), loss of oxygen, fish kill, loss of aquatic biodiversity including species important for commerce and recreation (Seehausen *et al.*, 1997) and loss of aquatic plant beds (Jeppesen *et al.*, 1998; NRC, 1993).

Contamination of surface water by nitrate, which is commonly found in it, poses direct health hazard to all living beings. Ingestion of nitrate in drinking water by infants can cause low oxygen level in the blood (methemoglobinemia), a potential fatal condition (Sandstedt, 1990). Hence Federal Environmental Protection Agency now Federal Ministry of Environment has established a maximum contaminant level (MCL) of 10 mg/l nitrate as nitrogen in drinking water (FMEnv, 1991). Higher concentrations in water presents significant health risk. Other adverse health effects of nitrate have been described in the recent literature. A case study in Indiana indicated that nitrate concentrations of 19-29 mg/l in rural drinking water caused eight spontaneous abortions in four women during 1991-1994. Ammonia occurs naturally in water bodies as a result of the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by microorganisms and gas exchange with the atmosphere. It may be discharged into the water bodies by industrial processes (e.g. ammonia based pulp and paper production) and also as a component of municipal or community waste. At certain pH levels (8-9), high concentrations of ammonia are toxic to aquatic life and, therefore, detrimental to the ecological balance of water bodies. Unpolluted waters contain small amounts of ammonia and ammonia compounds, usually less than 0.1 mg/l as nitrogen. Higher concentrations could be an indication of organic pollution such as by domestic sewage, industrial waste and fertilizer run-off.

Phosphorus is an essential component of the biological cycle in water bodies; it exists as both dissolved and particulate species. It is the limiting nutrient for algal growth and therefore, controls the primary productivity of water bodies. Natural sources of phosphorus are mainly the weathering of phosphorus bearing rocks and the decomposition of organic

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*Author for correspondence; E-mail: kafyusuf@yahoo.co.uk matter. Domestic wastewaters, particularly those containing detergents, industrial effluents and fertilizer run-off contribute to elevated levels of phosphorus in surface waters. Phosphorus associated with organic and mineral constituents of sediments in water bodies can also be mobilized by bacteria and released to the water. In most natural surface waters, phosphorus occurs as PO_4-P in the range of 0.005 to 0.020 mg/l. High concentrations of phosphorus can indicate pollution and are largely responsible for toxic algal blooms or anoxic conditions.

Knowledge of natural or baseline nitrogen and phosphorus concentrations can thus make valuable contributions to the management of surface waters, particularly for drinking water supply and development of conservation strategies by providing realistic targets for restoration of and enabling an assessment of aquatic ecosystem. The Ologe lagoon system, with a length of about 30 km serves as an important waterway for the transportation of goods and provides rich agricultural flood basins for the cultivation of food and vegetables. Also it is a major source of animal proteins in the form of fishes and other aquatic forms. Above all, the major tributary (Owo river) is the main source of domestic water supply for the Lagos metropolis. Therefore, there is a need to establish the present levels of nitrogen and phosphorus in the lagoon, and the contribution made by the tributary on the gross pollution level. So far no work has been reported on the levels of nitrogen and phosphorus of the Ologe at the place where contribution of the major tributary is significant, and where there are settlements on its banks and the banks of the tributary. This work aims at establishing base-line levels of the nutrients (nitrogen and phosphorus) and their sources.

Description of the study area. Ologe lagoon is a natural semi-enclosed fresh water body situated about 30 km west of Lagos on the Lagos-Badagry express way. The lagoon is broad, shallow and navigable and its outlet is on a section of the coastline which discharges into the sea through Badagry Creek (25 km away) as shown in Fig. 1. Owo river is the major fresh water inlet into the lagoon with a catchment area of approximately 1122 km^2 above Agbara. It is an area of secondary succession of rain forest and/or freshwater swamp and mangrove with vegetation cover at the bank. The river has pronounced seasonal cycle of freshwater discharge, which is high during the months of July and September. The flow decreases considerably after October and is minimal during January to March. The river is under-developed and sparsely populated, it is tapped at Isasi for the Lagos metropolitan water supply and is subjected to threats from human activities at Agbara among which are: (i) the sewage treatment plant

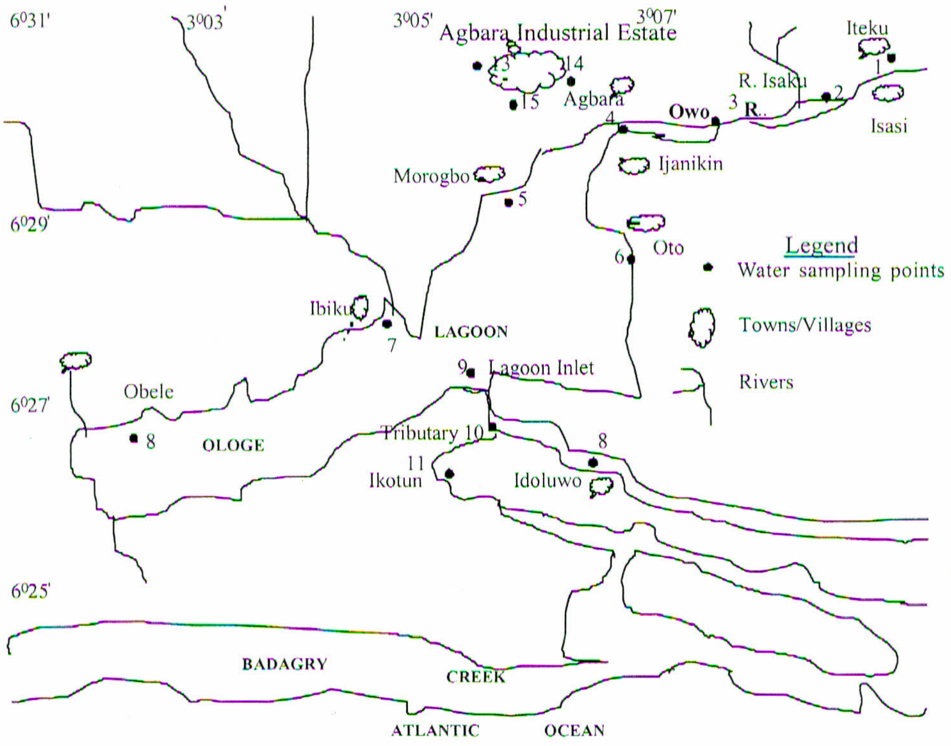

Fig. 1. Map of Ologe Lagoon showing all the sampling points.

(sampling points 13 and 14) fed by combined industrial and domestic wastewater from industries and residential houses located within Agbara industrial estate. The effluents from this plant are released through constructed pipe into an industrial outfall (sampling point 15), and thereafter enters Owo river through natural drain before it is finally discharged into Ologe lagoon (ii) discharges from domestic and untreated sewage from settlements and villages along the study area.

Materials and Methods

The location of the fifteen chosen sites along the Ologe lagoon is shown in Fig. 1. The sampling sites were chosen to reflect different activities in the catchment area, upstream, mid-stream and downstream, which may affect the water quality situation in the lagoon. Water samples for analysis were collected over a period of two years at bimonthly intervals. The samples were collected mid-stream at depths of about 20 cm by dipping the sample containers into the lagoon from an engine boat. Two samples were collected from each sampling point for the determination of anions and for measurements of pH, turbidity, chloride and suspended solids. After collection, water samples were transported to the laboratory and preserved in the refrigerator prior to analysis which was generally undertaken within 2 weeks of collection. Water samples for anion determination, were filtered through 0.45 μm membrane filters and the filtrates were analyzed as described below. Phenoldisulphonic acid method (Taras, 1950) was used for nitrate determination. The absorbance was measured spectrophotometrically at 410 nm. Phosphate was determined by ascorbic acid method according to APHA-AWWA-WPCF (1998). The absorbance was measured spectrophotometrically (Perkin Elmer, Lambda 3B uv/vis spectrophotometer) at 880 nm. Ammonia was determined by Nesslerisation method and measured spectrophotometrically at 420 nm according to APHA-AWWA-WPCF (1998). Suspended solids were determined by filtering a known volume of water through a pre-washed glass fibre filter paper (0.45 μm); the weight of suspended solids on the glass fibre filter was obtained after drying the filter in an oven at 70-80 °C. The pH values were noted using a digital portable pH meter. The chloride content was determined by argentometric method.

In order to avoid contamination during sampling and sample preparation, all bottles, glass filters, test tubes, filtration apparatus and other laboratory tools were cleaned by washing with detergent, rinsed thoroughly with tap water, soaked with 0.1 N HCl then rinsed again with deionized-distilled water. All chemicals used were of reagent grade and all solutions were prepared with deionized-distilled water throughout the study.

Results and Discussion

Results of the analyses of Owo river and Ologe lagoon samples are summarized in Table 1. Mean concentrations of phosphorus and nitrogen in both the cases were lower than the

Table 1. Concentration of nutrients and other water quality parameter (mg/l) in Owo river and Ologe lagoon

Site*	$^{**}NO_3^-$-N	$^{**}NH_3$-N	$^{**}PO_4^{3-}$-P	N/P	SS	Turbidity	Cl^-	pH
1.	15.6	1.5	7.5	2.3	7.3	39.5	7.3	6.3
2.	18.5	2.6	7.8	2.7	7.9	37.1	7.4	6.0
3.	18.1	2.3	6.8	3.0	9.3	38.5	8.3	6.0
4.	22.9	2.3	7.6	3.3	9.5	40.5	11.6	5.7
5.	24.6	2.3	6.0	4.5	10.3	38.8	43.2	6.6
6.	29.7	2.4	6.2	5.2	11.3	41.6	41.5	5.8
7.	26.8	2.6	5.3	5.5	16.1	66.6	100.6	6.4
8.	22.4	2.6	5.5	4.5	12.3	48.8	110.4	6.3
9.	26.4	2.5	9.3	3.1	12.75	47.8	90.4	6.7
10.	22.9	2.6	5.6	4.5	13.1	43.9	94.7	6.7
11.	21.3	2.7	6.3	3.8	19.7	51.6	441.4	6.7
12.	32.1	2.4	13.7	2.5	12.8	46.2	93.9	6.4
Mean	23.4	2.4	7.3	3.75	11.9	45.1	87.56	6.3
SD	4.83	0.32	2.33	0.75	3.49	8.20	118.71	0.35
Range	15.6-32.1	1.5-2.7	5.3-13.7	2.3-4.8	7.3-19.7	37.1-66.6	7.3-441.4	5.7-6.7

* = Owo river before (sites 1 and 2) and after (sites 3 and 4) receiving industrial effluent; Ologe lagoon upstream (sites 5 and 6) and downstream (sites 7and 8) after receiving Owo river; Lagoon outlet (sites 9-12); ** = concentration in μg/l

Table 2. Nutrient concentrations in Owo river, and Ologe lagoon water in comparison with global nutrient concentrations (μg/l) for unpolluted inland waters

Region	PO_4^{3-}-P	NO_3^--N	NH_4^+-N	N/P	Reference
Owo River/Ologe lagoon	7.3	23.4	2.4**	3.5	This study
Loch Linnhe, Scotland	46	551	-	11.9	Hall *et al.* (1996)
English coastal	^{w}66-114 ^{s}9.5-38	^{w}2169 ^{s}62-248	-	^{w}19.0 ^{s}6.5	Hall *et al.* (1996)
Continental coast	^{w}190-285 ^{s}9.5-38	^{w}2789 ^{s}610-1240	-	^{w}9.7 32.6	Hall *et al.* (1996)
German coastal	^{w}76-199	-	-	-	Paris & Oslo Commission (1992)
Arctic rivers					
Kazan & black river Canada, 1969-1973	16	-	2	8.0	Maybeck, (1982)
Subartic rivers					
Nelson (1972-1976)	126	-	4	31.5	Maybeck, (1982)
Iceland	23	25	20	2.4	
Tropical rivers					
Niger	100	14	13	8.8	Maybeck, (1982)
Zaire	90	17	24	4.5	Maybeck, (1982)
Purari (Papua Guinea)	40	40	1.5	53.3	Maybeck, (1982)
Amazon	40	35	12	6.3	Maybeck, (1982)
*Nigeria	6.01	13.7	3.98**	4.95	Udousoro, (1997)

* = concentration in mg/l; ** = NH_3-N determined; ^{w} = winter; ^{s} = summer

global average for unpolluted inland waters (Table 2). Low levels of nitrogen and phosphorus found in the present work reflect low agricultural activity and low population density in the drainage basin of the lagoon. Low phosphate-phosphorus concentrations could probably be due to precipitation of phosphate by trivalent iron, which is in relatively high concentrations in the study area. Considerable high phosphate concentration was noted in effluents of sewage treatment plant at Agbara (Table 3) as a result of domestic sewage and decaying plant and animal materials. The phosphate-phosphorus in effluent was, in the present study, above the recommended maximum limit (100 μg/l) for prevention of nuisance plant growth in lotic systems. Phosphorus in water is not considered to be directly toxic to humans and animals (Amdur *et al.*, 1991). Any toxicity due to phosphorus in fresh water is indirect. Increased levels of phosphate-phosphorus may cause toxic algal blooms or anoxic conditions resulting in increase in aquatic weeds that interfere with use of water for

Table 3. Nutrient concentrations (μg/l) and other water quality parameter (mg/l) of effluent / outfall from Agbara industrial estate

Site	NO_3^--N	PO_4^{3-}-P	NH_3-N	N/P	SS	Turbidity	Cl^-	pH
Effluent/Outfall								
13**	121.9	141.9	66.5	1.3	295.1	304.3	19.9	6.6
14**	83.2	167.2	54.0	0.82	135.3	308.4	23.7	6.8
15***	86.0	176.6	44.4	0.74	100.8	221.8	25.0	7.0
Mean*	97.0	161.9	55.0	0.94	177.1	278.1	22.9	6.8
Range	83-122	142-177	44-67	0.74-1.3	101-295	222-308	20-25	6.6-7.0

* = mean of 12 replications; ** = effluent; *** = industrial outfall

fish culture, recreational, industrial, agricultural and drinking purposes. Oxygen shortages caused by decomposition of nuisance plants cause fish kills. Eutrophication which is excessive enrichment of water body with nutrients causes the loss of habitats, including aquatic plant beds in fresh water and coral reefs of tropical coasts (Jeppesen *et al.*, 1998). Eutrophication is also a factor in the loss of aquatic biodiversity (Seehausen *et al.*, 1997).

Ammonia is a product of microbial activity, and may promote the growth of aquatic weeds (Maybeck, 1982); its occurrence in surface water is sometimes accepted as chemical evidence of sanitary pollution (FAO, 1975). Concentration of ammonia nitrogen was lower than values obtained for nitrate nitrogen in the river as well as the lagoon (Table 1); ammonia concentration was also still much lower than what is normally found in the natural environment. It has been reported (Environment Canada, 1979) that natural water contains ammonia nitrogen values less than 100 μg/l. Concentration of ammonia in the present work was lower than the values reported for natural water (< 100 μg/l).

The principal form of soluble inorganic nitrogen found in the present study was nitrate-nitrogen whose levels showed little significant spatial pattern. Mean nitrate concentration was considerably greater in Ologe lagoon than in Owo river. A seasonal trend in the nitrate nitrogen concentration was observed with maximum concentration in wet season and minimum in dry season (Table 4). The decrease in nitrate-nitrogen concentration during the period of low flow could be the result of loss by denitrification coupled with lack of nitrification by plants or accumulation in sediment, (Howes and Teal, 1995; Wulf *et al.*, 1990; Maybeck, 1982). The increase in nitrate concentration during the period of high flow indicates the influence of surface runoff and precipitation as sources of nitrate to the lagoon.

Nitrate pollution poses direct health threat to humans and other mammals. Nitrate in water is toxic at high concentrations and has been linked to methemoglobinemia in infants and toxic effects on livestock (Amdur *et al.*, 1991; Sandstedt, 1990).

Although nitrogen is the major factor in eutrophication of most estuaries and coastal seas, phosphorus is also an essential element that contributes to coastal eutrophication. It has dominant control of primary production in some coastal ecosystems.

Urban nonpoint sources, such as erosion from agriculture, construction sites, and inputs from unsewered developments may contribute to phosphorus and nitrogen in the study area. Eroded material from construction sites may cause siltation of water bodies as well as surface-water degradation. Urban point sources of water pollution, such as sewage and industrial

Table 4. Seasonal variation of nutrients (μg/l) and other water quality parameters (mg/l) for the year 1997/1998

Season	*NO_3^--N	*PO_4^{3-}-P	*NH_3-N	SS	Turbidity	Cl^-	pH
Owo river before receiving effluent							
Dry	13.4	7.5	2.15	7.4	33.5	6.7	6.5
Wet	20.7	7.9	2.0	8.0	42.5	8.6	5.6
Owo river after receiving effluent							
Dry	16.6	6.7	2.7	7.8	44.3	9.0	6.1
Wet	24.6	7.7	1.95	10.9	44.3	10.7	6.1
Lagoon upstream before receiving Owo river							
Dry	21.4	6.4	2.85	7.4	30.7	62.8	6.3
Wet	38.0	5.8	1.95	13.8	49.0	21.9	6.1
Lagoon downstream before receiving Owo river							
Dry	18.1	5.4	2.8	10.0	44.4	162.9	6.45
Wet	31.1	5.5	2.35	18.1	71.0	48.2	6.2
Lagoon outlet							
Dry	20.8	5.9	2.95	8.0	34.5	305.0	6.8
Wet	31.1	11.9	2.15	19.7	59.8	53.8	6.4

* = µg/l

discharge, are also significant. The results of nutrients obtained from industrial effluents (Table 3) were higher than those obtained from average global values for unpolluted inland waters. This showed that the effluent from industries discharged into Ologe lagoon via Owo river is the source of pollution and can cause explosive growth of nuisance algae. These algae are harmful to livestock, humans, and other organisms. In marine ecosystems, algal blooms (red or brown tides) cause widespread problems by releasing toxins and by causing anoxia due to consumption of oxygen in decomposition of dead algae. The blooms have severe negative impact on aquaculture and shellfisheries (Shumway, 1990), causing shellfish poisoning in humans and significant mortality in marine mammals (Anderson and Garrison, 1997). In freshwater, blooms of cyano-bacteria (blue-green algae) contribute to a wide range of water-related problems including summer fish kills, foul odours, unpalatability of drinking water and formation of trihalo-methane during chlorination in treatment plants (Kotak *et al.*, 1994). Water-soluble neuro and hepatoxins are released when cyanobacterial blooms die or are ingested, which can kill livestock and may pose a serious health hazard to humans (Martin and Cooke, 1994).

Excess fertilization and manure production on agricultural lands create surplus nitrogen, which is mobile in many soils. It often leaches to downstream aquatic ecosystems and can volatilize to the atmosphere, redepositing elsewhere and eventually reaching aquatic ecosystems thus contributing to increase in the nitrogen content.

The importance of readily available atmospheric nitrogen to the nonpoint pollution of surface waters should not be underestimated. High temperature, high-pressure combustion from industries may release significant quantities of fixed nitrogen into the atmosphere through oxidation of organic nitrogen stored in the fossil fuels combustion (Table 3). Microbial generation of dinitrogen oxygen is also important. Numerous studies have shown that dinitrogen oxygen contributes to global warming and can catalyze the destruction of ozone (Vitousek *et al.*, 1997; Schlesinger and Hartley, 1992; Eichner, 1990). Much of the nitrogen volatilized to the atmosphere is redeposited on land and in water and eventually enters aquatic ecosystems (Howarth *et al.*, 1996).

The potential eutrophication of the water environment is dependent not only on nutrient concentrations but also on the ratios of various nutrients (Smith and Hitchcock, 1994). Nitrogen/phosphorus ratio is often used in water quality analysis to determine which nutrient is limiting to aquatic primary productivity. This limiting nutrient often poses greatest threat to cultural eutrophication; stricter control of its loading is often justified by nitrogen/phosphorus ratio. Generally, phosphorus is considered the limiting nutrient in freshwater system at nitrogen/phosphorus ratios of 10 to 15. When the ratio is lower than 10, nitrogen concentration becomes the potential limitation (Smith and Hitchcock, 1994; Childers and Gosselink, 1990). The mean nitrogen/phosphorus ratio for the present study (Table 1) was below 10 indicating that nitrogen and not phosphorus is the critical nutrient for water quality control in Ologe lagoon. In the present study, NO_3-N, NH_3-N and PO_4^{3-} -P were not related with turbidity, SS, perhaps because of differential surface and subsurface loading of nitrogen and phosphorus. NO_3-N + NH_3-N concentrations were 77.9% of nutrient concentration while PO_4^{3-}-P concentration was 22.1% of nutrient. The nitrogen/phosphorus ratio increased during the wet season (Table 4) as a result of increase in nitrogen content which probably reflects constant phosphorus content.

Suspended solids and turbidity represent the best analytical measure of particulate load in a water body. Turbidity and suspended solid levels at Ologe lagoon is shown in Table 1. The two are highly significant ($P = 0.05$). Suspended solids and turbidity concentrations depend on rainfall patterns, streamflow partitioning and flow pathways, geology, soils and cultural and land-use practices of the area. The general or characteristic response of suspended solid concentrations in the study area can be seen by examining the seasonal means (Table 4). The period with greatest suspended solid concentration was the wet season. During the low flow or dry period, suspended solid concentrations were the lowest. When runoff started, suspended solid concentrations were elevated during the first run-off month, indicating entrainment of loose solids in the alluvial zone following a no-flow period. Numerous studies (Udousoro, 1997; Hubbard *et al.*, 1990; Irvine and Drake, 1987) have shown that suspended solid concentration increases with discharge rate due to increased energy available for particle entrainment and transport. Mean suspended solid concentrations during high-flow storm events were also compared with the overall means at various sites. The mean suspended solid concentrations for high storm events were 8.0, 10.9, 13.8, 18.1 and 19.7 mg/l for Owo river before receiving effluents, Owo river after receiving effluents, lagoon upstream before receiving Owo river, lagoon downstream after receiving Owo river and lagoon outlet, respectively. At various sites the mean suspended solid concentrations were 7.6, 9.4, 10.8, 14.2 and 13.8 mg/l, respectively. The greater mean concentrations from the high flow storm events were due to discharge rates carrying a greater load of suspended solids.

The chloride concentrations of Owo river before and after receiving effluents ranged between 7.3 mg/l and 11.6 mg/l for sites 1 to 4 (Table 1). This value is typical of unpolluted surface water. At sites 5 to 12, the concentration increased to a maximum of 441.4 mg/l, thus indicating weak waste water pollution. Since sites 5 to 11 are affected tidally, it seems reasonable to assume that the chloride concentrations determined at sites 5 to 11 may reflect not only pollution load, but also intrusion from the sea.

It is of great practical importance that most of the chemical and biochemical reactions are influenced by the pH. Adverse effects of most of the acids appear below pH 5 and of the alkalis above pH 9.5. The average pH of the study area was slightly acidic (6.3) and close to WHO recommendation of 6.5 to 8.5 for drinking water. Water supports aquatic life and many fishing activities take place in lagoon and its tributaries.

Conclusion

All the sites in the Ologe lagoon study area are oligotrophic with respect to N and P; N/P ratios indicate N to be more critical than P for cultural eutrophication, throughout the entire study area. The suspended solid concentrations are low. The riparian (shoreline) vegetation has improved the water quality significantly and reduced non-point nutrients of Ologe lagoon landscape. One consequence of a land scape-scale drainage basin with adequate forested riparian zones to filter runoff is that major waterways are likely to be continually oligotrophic.

Management practices for maintaining good water quality in this area include:

(i) returning river hydrology to natural flow patterns, to the extent possible, by reducing or removing unnecessary control structures,

(ii) improving farm practices to decrease sediment and nutrient inputs, including less fertilizer use and no-till farming,

(iii) creating wetlands, retention ponds, and greenways as integrated components of urban stormwater management systems; litter control; street sweeping; and reduction of erosion, especially from construction sites; reduction in fossil fuel combustion and improved interception of nitrate therefrom,

(iv) protecting existing forested corridors along streams and reforesting streamside buffer zones where agricultural fields and urban development are continuous with river-banks.

A management plan to accomplish the last measure would also alleviate hydrological problems and conserve and restore the indigenous biota. Such a plan would permit regulation of future development in the context of the entire Ologe lagoon landscape.

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