# Nutrient Load of the Sakumo Lagoon at the Sakumo Ramsar Site in Tema, Ghana

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**Abstract**

Water samples were collected from three sections (South, Centre and North) of the Sakumo lagoon for a period of 6 months and analyzed for $NO_2$-N, $PO_4$-P, $NO_3$-N and $NH_3$-N, and the results were compared with the Environmental Protection Agency (EPA)-Ghana permissible guideline values for effluents discharged into water bodies and values from similar studies on the lagoon in 1995 and 2003. Observations showed that, of all the nutrients studied, phosphates were the highest in the Sakumo lagoon. The decreasing order of nutrient concentrations in the lagoon were $PO_4$-P > $NH_3$-N > $NO_3$-N > $NO_2$-N. The nutrient levels in the lagoon have also shown significant increase over the years.

## Introduction

Nutrients are naturally occurring substances which are found in low concentrations in aquatic ecosystems. Compounds such as phosphates serve as source of nutrient for some aquatic plant species, and reduction in their supply affect the spawning and growth cycles of marine fish and prawn species, as well as fisheries further offshore (UNEP, 1997). However, availability of excessive nutrients may result in pollution. In Ghana, the coastal towns and cities, such as Takoradi, Tema and Accra, are heavily populated due to the ease with which a diverse collection of natural resources can be obtained (Biney, 1985).

The Sakumo Ramsar site is one of the six Ramsar sites designated in Ghana in 1999 by Legislative Instrument (LI) 1659 after the Convention on Wetlands, signed in Ramsar, Iran, in 1971 for the conservation and wise use of wetlands and resources *(www.ramsar.org)*. Despite the efforts by government to conserve and protect the site through enactment of framework, establishment of institutions and enforcement of regulations, the Sakumo site is found to be bedeviled with the problem of nutrient pollution.

The catchment of the Sakumo lagoon is found to be an area with a high concentration of human activities, such as industrialization, arable farming, livestock rearing and disposal of solid wastes and municipal sewage (Amatekpor, 1998). Most of the farmers rely on inorganic fertilizers, pesticides and other chemicals to boost the yield of their farm produce (Dadson, 1995). Social survey during the study revealed that inorganic fertilizers such as NPK 15-15-15 and 20-10-10 are used on their farm crops. Other organophosphate pesticides are, however, applied at regular intervals as well.

The unfortunate thing is that during the rainy season, the run-offs from the non-point sources and point sources are channeled into the streams that drain the catchment area, and these eventually end up in the coastal lagoon.

Municipal sewage that is channeled into the sea may also serve as a source of nutrients entering the Sakumo lagoon. Pollution of the lagoon with nutrients can affect biodiversity of plant and animal species, especially water fowls and birds ecology, since the site is noted for its large number of birds (Ntiamoa-Baidu & Gordon, 1991). Other workers on the lagoon including Ansa-Asare *et al.* (2008), used nutrient and the trophic status to assess the impact of human activities on the lagoon.

The Sakumo Ramsar site is drained by a number of streams that eventually flow into the lagoon. Knowledge about the nutrient load of the lagoon can give a fair idea about the level of nutrient pollution of the Ramsar site.

## Materials and methods

*Study area*

The Sakumo Ramsar site is a coastal lagoon situated 3 km west of Tema. The site has total area of 1,364 ha, and located within latitudes 5°36' N and 5°38' N and longitudes 1°30' W and 2°30' W. The lagoon is separated from the sea by a narrow sand dune on which the Accra-Tema coastal road is built. The coastal brackish/saline lagoon is connected to the sea by an old sluice which no longer functions properly. A flood regulation channel is also available, with direction of flow depending on the tide.

*Hydrology*

The catchment of the Sakumo Ramsar site is drained by a number of streams, which flow into the brackish water of the Sakumo lagoon. A number of freshwater marshes are found along most of the river courses within the Ramsar site. Four principal sub-drainage basins have been identified in the catchment area. The major ones are the Mamahuma-Onukpawahe (at the western side) and the Dzorwulu-Gbagbla-Ankonu (situated at the northern end) sub-basins. The eastern and southern sub-basins constitute the minor ones. The catchment area has limited groundwater potentials because of the low rainfall and impermeability of the underlying rocks (Agyepong, 1999).

The main feeder streams, the Dzorwulu and Mamahuma, have been re-channeled for irrigation. The Dzorwulu stream has a dam on it and this is situated north of Ashaiman town near Santeo. The Mamahuma stream also has a dam on its upper catchment. This normally resulted in very little flow of freshwater into the lagoon during the dry season (Amatekpor, 1998). The drainage system of the Sakumo Ramsar site is shown in Fig. 1.

*Location of sampling points and sample collection*

Determination of the nutrient load of the lagoon was carried out by sampling from three designated zones of the lagoon. These zones were designated A, B and C, and described as: Zone A- southern part of the lagoon (nearest area adjacent to the sea); Zone B- central stretch of the lagoon; Zone C- northern section of the lagoon. The zones were located at intervals of 100 m from each other. By the help of Geographic Positioning System (GPS) - GARMIN GPS 72 the real locations of the sampling points were known.

In assessing the nutrient load, water samples of the lagoon were collected in pre-clean 500-ml polythene bottles, and placed in ice chest packed with ice (Keith, 1988). The contents were transported to the laboratory of

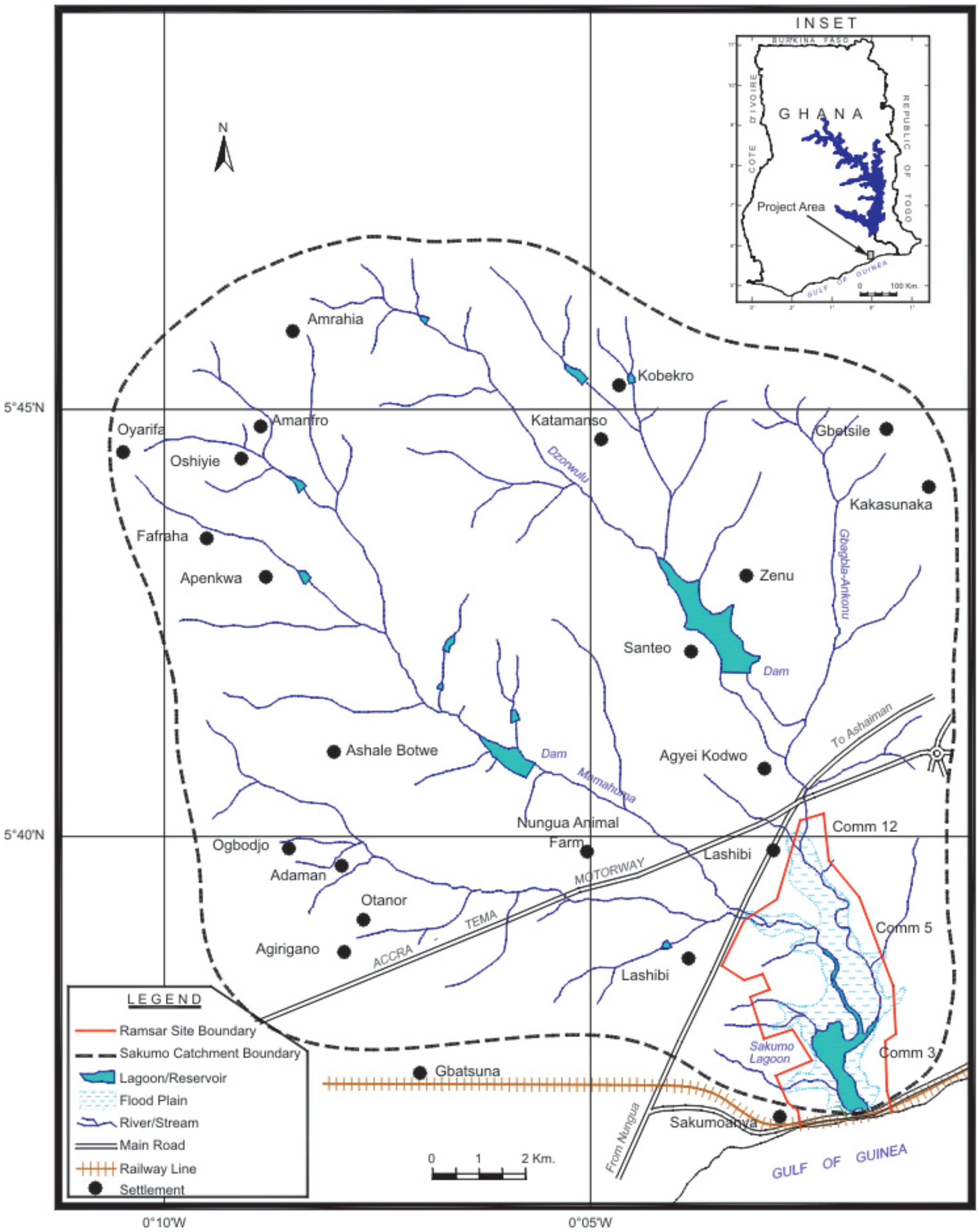


Fig. 1. Map showing the catchment area of Sakumo lagoon

Water Research Institute (WRI) of the Council for Scientific and Industrial Research (CSIR) in Accra for the analyses.

*Sample preparation*

*Nitrite-nitrogen ($NO_2$-N).* This method is based on the measurement of the optical density of the reddish colour produced when nitrite reacts with sulphanilic acid and alpha naphthylamine. The method is sufficiently sensitive to determine small amounts of nitrite (usually less than 1 p.p.m.) present in water and soil extracts (Chapman & Pratt, 1961).

Series of standard $NO_2$-N solutions were prepared by serial dilution of 0.20 *M* nitrite solution. 0.4 ml of buffer-colour reagent was added to each standard solution and allowed to stand for 15 mins for colour to develop. The absorbances of the solutions were measured at 540 nm. A standard curve was prepared by plotting absorbance of the standards against the concentration of $NO_2$-N. The test solutions were also treated the same way as the standard. The nitrite nitrogen concentration of the test samples were determined using the relation:

Nitrite-nitrogen (mg/l)

$$= \frac{\text{mg/1 for standard curve}}{\text{ml sample}} \times 50$$

(UNEP/ WHO, 1996)

*Nitrate-nitrogen ($NO_3$-N).* 10 ml of the sample was pipetted into a test-tube and 1.0 ml of 0.3 *M* NaOH was added and mixed gently, followed by addition of 1.0 ml of reducing mixture (20 m1 copper sulphate solution, l6 ml hydrazine sulphate and 20 m1 0.3 *M* sodium hydroxide mixtures) and mixed gently. The resulting solution was heated at 60 °C for 10 min in a water bath. It was then cooled to room temperature and 1.0 ml colour developing reagent (conc. $H_3P0_4$ acid, sulphanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride mixtures) was added. The solution was shaken to mix and the absorbance was read using UV/VIS spectrophotometer at a wavelength of 520 nm.

*Calculation.* The sample concentration was computed directly from calibration curve. Sample concentration is equal to the sum of $NO_3$-N and $NO_2$-N. To obtain the concentration of $NO_3$-N, the $NO_2$-N concentration was determined separately and subtracted (APHA-AWWA-WEF, 1998).

*Ammonia-nitrogen ($NH_3$-N).* The Nessler method, which was used, is based on the measurement of the optical density of the colour produced by the reaction of ammonium ions with mercuric potassium iodide reagent (Chapman & Pratt, 1961). 10.0 ml of sample was pipetted into a test-tube and one drop of Rochell salt solution was added.

The resulting solution was mixed well and 2 ml of Nessler's reagent was added. A blank (l0 ml ammonia-free water plus one drop Rochelle salt and 2 ml Nessler's reagent) was prepared. The samples were allowed to stand for 10 min for colour development and their absorbance were determined using a UV/VIS spectrophotometer at a wavelength of 4l0 nm (400–425 nm), using a 1-cm light path cuvette. The spectrophotometer was zeroed with the blank solution.

*Calculation*. The sample concentration was computed from calibration curve by the use of the measured absorbance (APHA-AWWA-WEF, 1998).

*Phosphate-phosphorus ($PO_4$-P).* 10 ml of sample was pipetted into a test-tube and 0.4 m1 molybdate reagent was added followed by 0.5 m1 stannous chloride reagent with thorough mixing. After 10 min, the absorbance at a wavelength of 690 nm was measured on UV/VIS spectrophotometer. The spectrophotometer was zeroed with the blank solution.

*Calculation*. From the calibration curve, the concentrations of the samples were found using measured absorbance (APHA-AWWA-WEF, 1998).

## Results and discussions

The results of nitrite-nitrogen ($NO_2$-N), nitrate-nitrogen ($NO_3$-N), ammonia-nitrogen ($NH_3$-N) and phosphate-phosphorus ($PO_4$-P) are presented in Tables 1, 2, 3 and 4.

TABLE 1

*Levels of nitrite nitrogen of the Sakumo lagoon.*

| | *Sampling locations (zones)* | | | |
|---|---|---|---|---|
| | *A* | *B* | *C* | |
| *Month of sampling* | | *Nitrite levels (mg/l)* | | *Mean nitrite levels (mg/l)* |
| | | *Rainy season* | | |
| Sept | 0.112 | 0.076 | 0.070 | 0.086 |
| Oct | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Nov | 0.012 | 0.026 | 0.003 | 0.014 |
| Mean ± Std dev. | 0.042 ± 0.061 | 0.034 ± 0.038 | 0.025 ± 0.039 | 0.034 |
| | | *Dry season* | | |
| Dec | 0.027 | 0.043 | 0.045 | 0.038 |
| Jan | 0.035 | 0.030 | 0.022 | 0.029 |
| Feb | 0.031 | 0.069 | 0.055 | 0.052 |
| Mean ± Std dev. | 0.031 ± 0.004 | 0.047 ± 0.020 | 0.041 ± 0.017 | 0.040 |

TABLE 2

*Levels of nitrate nitrogen of the Sakumo lagoon*

| | *Sampling locations(zones)* | | | |
|---|---|---|---|---|
| | *A* | *B* | *C* | |
| *Month of sampling* | | *Nitrate levels (mg/l)* | | *Mean nitrate levels (mg/l)* |
| | | *Rainy season* | | |
| Sept | 3.650 | 3.950 | 0.802 | 2.800 |
| Oct | 0.217 | 1.220 | 5.030 | 2.156 |
| Nov | 0.431 | 1.060 | 2.280 | 1.257 |
| Mean ± Std dev. | 1.433 ± 1.923 | 2.077 ± 1.624 | 2.704 ± 2.146 | 2.071 |
| | | *Dry season* | | |
| Dec | 0.964 | 0.804 | 1.440 | 1.069 |
| Jan | 1.460 | 1.160 | 1.140 | 1.250 |
| Feb | 0.580 | 2.648 | 2.009 | 1.746 |
| Mean ± Std dev. | 1.001 ± 0.441 | 1.537 ± 0.978 | 1.530 ± 0.441 | 1.355 |

TABLE 3
*Levels of ammonia nitrogen of the Sakumo lagoon*

| Month of sampling | Sampling locations (zones) A<br>Ammonia levels (mg/l) | B | C | Mean ammonia levels (mg/l) |
|---|---|---|---|---|
| *Rainy season* | | | | |
| Sept | 1.110 | 2.290 | 0.346 | 1.249 |
| Oct | 2.370 | 2.690 | 1.420 | 2.160 |
| Nov | 0.575 | 2.380 | 1.210 | 1.388 |
| Mean ± Std dev | 1.352 ± 0.922 | 2.453 ± 0.210 | 0.992 ± 0.569 | 1.599 |
| *Dry season* | | | | |
| Dec | 1.300 | 1.650 | 1.290 | 1.413 |
| Jan | 1.490 | 3.540 | 13.200 | 6.077 |
| Feb | 0.734 | 0.514 | 2.470 | 1.239 |
| Mean ± Std dev. | 1.175 ± 0.393 | 1.901 ± 1.529 | 5.653 ± 6.562 | 2.910 |

TABLE 4
*Levels of phosphate phosphorus of the Sakumo lagoon*

| Month of sampling | Sampling locations (zones) A<br>Phosphate levels (mg/l) | B | C | Mean phosphate levels (mg/l) |
|---|---|---|---|---|
| *Rainy season* | | | | |
| Sept | 0.465 | 0.451 | 0.008 | 0.308 |
| Oct | < 0.001 | 2.190 | 1.070 | 1.087 |
| Nov | 1.950 | 2.050 | 1.940 | 1.980 |
| Mean ± Std dev. | 0.805 ± 1.018 | 1.564 ± 0.966 | 1.006 ± 0.968 | 1.125 |
| *Dry season* | | | | |
| Dec | 0.429 | 0.804 | 1.440 | 0.891 |
| Jan | 14.300 | 10.700 | 14.200 | 13.070 |
| Feb | 0.647 | 4.809 | 7.690 | 4.379 |
| Mean±Std dev. | 5.125 ± 7.946 | 5.438 ± 4.978 | 7.777 ± 6.380 | 6.113 |

*Correlation studies*.

Correlation coefficients among the various nutrients are presented below, and this was done to determine how the levels of the four nutrients are inter-dependent. Table 5 shows that there was positive correlation ($r$ = 0.509) between nitrate and nitrite. Similarly, a strong positive correlation of 0.924 occurred between phosphate and ammonia. These are indications that ammonia, nitrate and phosphate may be coming from the same point source of pollution, which is likely to be of anthropogenic activities.

TABLE 5
*Pearson correlation among the nutrients*

| | $NO_2^-$ | $NO_3^-$ | $NH_3$ | $PO_4^{3-}$ |
|---|---|---|---|---|
| $No_2^-$ | 1 | | | |
| $No_3^-$ | 0.509 | 1 | | |
| $NH_3$ | -0.253 | -0.316 | 1 | |
| $Po_4^{3-}$ | -0.136 | -0.409 | 0.924** | 1 |

** Correlation is significant at the 0.01 level.

*Nitrite*. The nitrite ($NO_2^-$) level in the Sakumo lagoon ranged from 0.003–0.112 mg/l. The concentrations of $NO_2^-$ in the lagoon were generally low and varied at all sampling points throughout the entire period of the study. The month of September recorded the highest level of the nutrient at all sampling points for the study period. It is equally interesting to note that for the same month, September, nitrite levels decreased from the southern to the northern part of the lagoon.

The observed seasonal variations in the nutrient concentrations may be mainly due to the biological cycles of organic matter in the wetland (Vollenweider *et al.*, 1992). Meanwhile, in the dry season of the month of December, an increasing trend in the concentration of nitrite has been recorded from the south of the lagoon to the north, an observation which was contrary to the trend established in the rainy season of September. All the sampling sites have nitrite levels below 0.001 mg/l, the detection limit of the UV/VIS spectrophotometer. There were variations in mean concentration of the nutrient at all the sites, with sampling point B recording the highest mean value of 0.047 mg/l in the dry season, followed by the north with 0.041 mg/l, and then site A with the lowest mean concentration of 0.031 mg/l (Table 1). The rainy season, trends follow the order, 0.042, 0.034 and 0.025 mg/l for the sites A, B and C, respectively.

It is obvious that the rainy season month of September recorded concentrations that showed decreasing trend from the southern to the northern part of the lagoon. The established trend may, therefore, be as a result of anthropogenic pollutants that were carried in the run-offs during the rainy season. It is equally likely the influence of tidal waves resulting in sea water intrusion may account for the established levels of nutrients in September.

*Nitrate*. The rainy season nitrate ($NO_3^-$) levels in the study area spanned from 0.217 mg/l as the lowest which occurred in October at zone A to 5.030 mg/l in the same month at zone C of the lagoon, the north of the wetland. The monthly rainy season mean concentration of the nutrient for the entire lagoon ranged between 1.257 mg/l and 2.800 mg/l (Table 2). The dry season monthly mean values span 1.069 to 1.746 mg/l, and are observed to be lower than values recorded for the rainy season where run-offs influence nutrient levels.

The highest monthly mean level of the nutrient for the entire lagoon was 2.800 mg/l and was recorded in the month of September. Surprisingly, zones A and B recorded 3.65 mg/l and 3.95 mg/l, respectively, in September whereas the level in the same month at zone C was 0.802 mg/l. The high values may be attributed to leaching of nitrate from the soil (Park, 1997) during these times of the year when arable fields are bare, and often coincide with times of heavy rainfall, and may also be attributed to run-offs from rainfall (MES, 2002). Arable farming is a vigorous enterprise in the catchment area of the lagoon. The extensive use of inorganic fertilizer in farming is very likely to leave residues that are transported by run-offs into the lagoon during the rainy season.

The high concentration of $NO_3^-$ may contribute to the problem of eutrophication, since the pollutant enriches the nutrient content of the water body into which it flows. The observed spatial distribution of nitrate in the lagoon may be attributed to the extent of water discharge (Vollenweider *et al.,* 1992) and the different rivers that flow into the lagoon. The values of nitrate at the sampling sites have varied, and exceed the EPA maximum guideline value of 0.1 mg/l for effluents discharged into aquatic ecosystem; a situation which suggests that the Sakumo Ramsar site is polluted with nitrates. These can provide adequate nutrients for aquatic plants to proliferate.

*Ammonia.* The concentrations of ammonia nitrogen ($NH_3$-N) of the lagoon at the sampling sites during the period of the study ranged from 0.346 to 2.690 mg/l for the rainy season and 0.514 to 13.200 mg/l for the dry season. The mean concentration ranges from 0.992 to 2.453 mg/l for the rainy season while the same for the dry season is 1.175 to 5.653 mg/l for the entire lagoon (Table 3). The obtained values of $NH_3$ varied from one sampling zone to another, some of which were above the EPA maximum permissible value of 1.5 mg/l. Ammonia was found to be the second highest nutrient in the lagoon apart from phosphate which was in the highest concentration.

Mean concentration of the nutrient showed a defined trend of increasing concentration from the south to the north. Thus, increasing mean levels at the zone were 1.263, 2.177 and 3.323 mg/l for zones A, B and C, respectively, for the entire study period. Thus, $NH_3$-N was highest at the north where influence of streams would be highest felt. The values were lowest at the south which is more likely to be influenced by sea water intrusion. The month of January recorded the highest value of $NH_3$-N for all the sampling zones during the period of study. The highest concentration of 13.200 mg/l was found at zone C which was at the north of the lagoon. The high value in the dry season may be attributed to domestic pollutants from wastewater from point sources.

A concentration of 0.024 mg/l has been suggested as the highest concentration of unionized ammonia that would not have adverse effect on fishes (NAS, 1979), the value recorded at all the sampling sites were higher than this concentration for fish survival. Similarly, the lethal concentration of $NH_3$ for a variety of fish species is 0.2–2.0 mg/l (NAS, 1979). Unfortunately, the recorded mean values (1.239–6.077 mg/l) for the entire study period have far exceeded the lethal concentration range of $NH_3$. This implied that the water quality of the lagoon was poor in terms of amount of ammonium nutrient, suggesting that waters of the lagoon may pose a threat of ammonia toxicity to fish species found in it.

*Phosphate.* The phosphate ($PO_4^{3-}$) concentrations in the lagoon varied throughout the study period. The range of phosphate was between 0.001 mg/l in October at site A and 2.190 mg/l at site B for the rainy season in November. For the monthly mean concentration, in the rainy season, the recorded value ranges from 0.805 to 1.564 mg/l while the dry season values have been found in the range 5.125–7.777 mg/l. Considering the entire lagoon for the study period, it has been observed that the mean concentration at the sampling sites varied from the south to the north, with the north of the lagoon recording the mean peak value of 4.391 mg/l, followed by 3.499 mg/l at the centre while the lowest value of 2.965 mg/l (Table 4) was recorded at the south. These mean values exceeded the EPA maximum guideline value of 2.0 mg/l for total phosphorus, indicating that the Sakumo lagoon is highly polluted with phosphate. This might be the cause of the wide green vegetation found in some sections of the Ramsar site.

The spatial concentration of phosphate in the lagoon may be attributed to the orientation of water flow (Heathwaite, 1999), and the discharge rate of the streams that drained the lagoon. The months of December, January and February generally recorded phosphate concentrations in decreasing order from the north to the south of the lagoon. This observation may be attributed to the water flow in the lagoon which is at its lowest level this time, and as such the phosphorus from different point sources accumulate progressively (Lauga *et al.,* 1986) in the bed of the wetland during the dry season. The dry season also recorded the peak values of phosphate during the study period. A situation which may possibly be due to the lower volume water in the lagoon, resulting in increased concentration of the ion in solution.

Phosphorus is an essential nutrient and can exist in water in both dissolved and particulate forms. It is vital to the production of living organisms in the aquatic environment. High phosphate concentration is responsible for the eutrophication of a water body as phosphorus is a limiting nutrient for algae growth. All poly-phosphates are eventually hydrolysed to produce the ortho form. The rate of hydrolysis is increased by temperature, low *p*H and bacterial enzyme action (Baird, 2000).

The sudden increase in the level of phosphate during the dry season might also be due to nutrient diffusion from sediments (Jorgensen & Loffer, 1990) into the water column. This phosphate accumulation may be from run-offs from cultivated lands where fertilizers are in common use along the banks of streams draining the catchment area of the Sakumo lagoon. The high phosphate level in the lagoon may possibly be the cause of eutrophic nature of the water at the sampling sites during the period of the study. This eutrophication process might probably result into assimilation of excess phosphates by plants and algae. They later died and are decomposed by microorganisms in the aquatic system, a phenomenon that leads to depletion of oxygen in the water. This might certainly be the cause of low or poor dissolved oxygen content of the water at the sampling sites, especially during the dry season.

*Pollution level of nutrients in the Sakumo lagoon*

Table 6 shows the mean nutrients concentration in the waters of the lagoon and Fig. 2 shows the graph of the pollution level. The nutrient concentrations are found to increase in the order: $NO_2$-N < $NO_3$-N < $NH_3$-N < $PO_4$-P. From the graph, it is obvious that phosphate is highly concentrated in the water column of Sakumo lagoon.

*Comparison of pollution levels*

The mean results of nutrients in the water column of the study area are compared with the mean results of 1995 study (Koranteng, 1995) and 2003 study (Yawson, 2003). This would reveal the extent of human influence on the pollution level of the lagoon over the years to ascertain whether there are changes in the human activities in the catchment area of the Ramsar site.

*Pollution levels of nutrients in the lagoon*

The overall mean values of nutrients obtained during the period of study are compared with the previous work done in 1995 and 2003 at the Ramsar site as shown in Table 7.

Fig. 3 shows the variation of the concentration of nutrients in Sakumo lagoon over the years. Comparing the results of this study with those of 1995 and 2003 there has been obvious increases in the levels of the nutrients in the lagoon over the years. The increases have been in the order, $PO_4$-P > $NH_3$-N > $NO_3$-N > $NO_2$-N. The nitrite concentration in the lagoon has shown a significant decrease from 2003 study, 3.910

TABLE 6

*Mean concentration of nutrients in water column*

| *Nutrient* | *Sampling locations(zones)* *A* | *B* | *C* | *Mean levels for entire lagoon (mg/l)* | *EPA guideline values(mg/l)* |
|---|---|---|---|---|---|
| | *Mean nutrient levels at sample sites (mg/l)* | | | | |
| | | | *Rainy season* | | |
| $NO_2$-N | 0.042 | 0.034 | 0.025 | 0.034 | – |
| $PO_4$-P | 0.0805 | 1.564 | 1.006 | 1.125 | 2.000 |
| $NO_3$-N | 1.433 | 2.077 | 2.704 | 2.071 | 0.100 |
| $NH_3$-N | 1.352 | 2.453 | 0.992 | 1.599 | 1.500 |
| | | | *Dry season* | | |
| $NO_2$-N | 0.031‘ | 0.047 | 0.041 | 0.040 | - |
| $PO_4$-P | 5.125 | 5.438 | 7.777 | 6.113 | 2.000 |
| $NO_3$-N | 1.001 | 1.537 | 1.530 | 1.356 | 0.100 |
| $NH_3$-N | 1.175 | 1.901 | 5.653 | 2.910 | 1.500 |

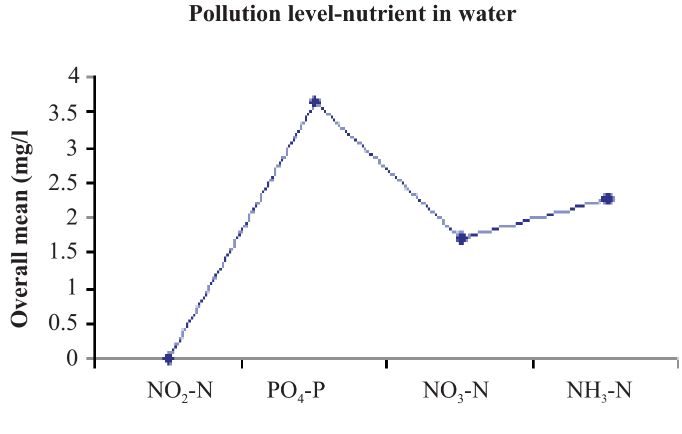


Fig. 2. Variation in nutrient at study area

TABLE 7
*Nutrients comparison in Sakumo Ramsar site*

| *Nutrient* | *Sakumo*[a]*/mgl*$^{-1}$ | *Sakumo*[b]*/mgl*$^{-1}$ | *Sakumo*[c]*/mgl*$^{-1}$ |
|---|---|---|---|
| $NO_2$-N | 0.250 | 3.910 | 0.037 |
| $PO_4$-P | 0.644 | 0.000 | 3.618 |
| $NO_3$-N | 0.134 | 1.440 | 1.713 |
| $NH_3$-N | 0.390 | 1.650 | 2.254 |

[a:] mean results from 1995 study (Koranteng, 1995).
[b:] mean results from 2003 study (Yawson, 2003).
[c:] this study

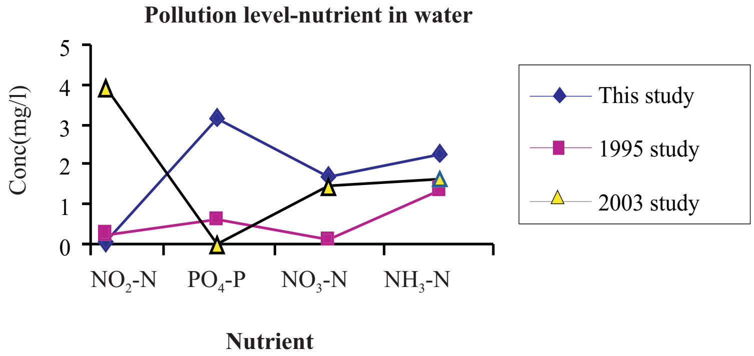


Fig. 3. Variation of various nutrient concentrations in the study area over the years

mg/l to as low as 0.037 mg/l in 2008. The decrease may be attributed to the thermodynamic instability of nitrite (Commonwealth Science Council, 2001). It is likely that prevailing conditions of the lagoon between 1995 and 2003 favoured the build-up of the compound, or the rate of its decomposition could not match the rate of formation.

## Conclusion

The Sakumo lagoon is polluted with nutrients from diffuse and direct sources of agricultural, urban and industrial pollutants. This leads to algae bloom and growth of water weeds in the lagoon. The high level of phosphate in the lagoon also contributes to eutrophication, resulting in a decline in dissolved oxygen content of the water. This may, consequently, affect aquatic life in the lagoon. There would, therefore, be the need to look at the decline in the level of aquatic life of the lagoon.

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