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Pitout JDD, Church DL, Gregson DB, Chow BL, McCracken M, Mulvey M, Laupland KB (2007). Molecular epidemiology of CTXM-producing Escherichia coli in the Calgary Health Region: emergence of CTX-M-15-producing isolates. Antimicrob. Agents Chemother. 51: 1281-1286.

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*Full Length Research Paper*

# Treatment test of oil mill effluents by a *Pistia stratiotes* L., 1753 (water lettuce) pond based system, in Maroua (Far-North, Cameroon)

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**In the developing countries in general, industrial effluents are discharged into the rainwater evacuation channels, on the street, or in nature, without treatment, causing immense environmental damages. This work aimed to propose, at a pilot scale, a test treatment, based on a *Pistia stratiotes* L., 1753 pond system, to purify wastewater from the Cotton Development Company of Cameroon (CDCC) oil mill, in Maroua (Cameroon). The system consisted of two pools containing, respectively, microphytes and macrophytes constituted of *Pistia stratiotes* (water lettuce) plants. The physico-chemical characterization of the liquid waste showed that the oil mill generated, at a rate of 324 $m^3$/day, highly alkaline (pH = 9.77 ± 0.51), very low oxygenated (dissolved oxygen = 0.45 ± 0.09 mg/l), highly organic matter ($BOD_5$ = 16000 ± 6850 mg/l), nitrates (510 ± 84.50 mg/l N) and orthophosphates (5560 ± 1550 mg/l) loaded effluents. Total dissolved solids, electrical conductivity, turbidity, ammonium and nitrites presented respective mean values of 475 ± 70 ppm, 989 ± 98 µS/cm, 825 ± 94 NTU, 12 ± 2.60 mg/l and 6.50 ± 1.30 mg/l N. At the end of the test treatment, the mean reduction rates were of 26, 6, 3, 20, 94, 80, 56, 68, and 51%, respectively, for pH, electrical conductivity, total dissolved solids, turbidity, ammonium, nitrites, nitrates, orthophosphates and $BOD_5$, in the microphytes lagoon. These values were of 27, 48, 100, 93, 76, 71 and 57%, respectively, for pH, turbidity, ammonium, nitrites, nitrates, orthophosphates and $BOD_5$, in the macrophytes lagoon. Dissolved oxygen had respective increasing rates of 60 and 156%, in microphytes and macrophytes tanks.**

**Key words:** Oil mill, effluent, lagoon, *Pistia stratiotes*, treatment.

## INTRODUCTION

On the 2030 horizon, world population will increase by 3 billion people and this growth is expected, at 95%, in developing countries. Population growth will result in increased consumption needs, which will quadruple the production of wastes and effluents in cities (Farinet et al., 2004). The amount of waste will increase by 40% worldwide,

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between 2014 and 2020 (Planetoscope, 2014). It is also estimated that, each year, worldwide manufacturers dump 300 to 500 million tons of heavy metals, toxic sludge, solvents and other hazardous wastes into the sea. There are several types of wastes, including liquid waste comprising wastewater, whose release is estimated at 2000 billion litres by day (Planetoscope, 2014). However, more than 3 billion people do not have wastewater evacuation facilities (Farinet et al., 2004).

Vegetable oil mills effluents are considered among the most pollutants liquid wastes from agro-food industries (Sifoun, 2008; Ouabou et al., 2014). When released into nature or directly reused in agriculture, regardless of their quality, without treatment, they cause serious health and environmental damages (Aissam, 2003; El Hajjouji, 2007; Sifoun, 2008; Dongo et al., 2013).

In the town of Maroua (Cameroon) the solid wastes average collection, between 2008 and 2009 was estimated at 31,917 tonnes (CSRT-MUC, 2010). Similarly, the average production of plastic wastes by the population of the district of Maroua II is 337 Kg, in two weeks (Bakari et al., 2010). There are, unfortunately, very little or no statistical data on liquid wastes. Wastewater is discharged haphazardly and/or canalized into the rivers and this can have adverse effects on the environment and on the health of populations. CDCC (Cotton Development Company of Cameroon), in Maroua, in its food component, produces a cottonseed oil. The liquid waste resulting from the manufacturing process of the oil, mixed with other wastewaters, is channelled to the Mayo Tsanaga River, without any treatment.

Oil mill effluents treatment is a problem, given their chemicals quality and quantity contain (Fiestas and Borja, 1992). Indeed, the application of a single treatment is often inadequate and incomplete. Several purification systems of these effluents were tested, notably in the Mediterranean producer of olive oil basin. Treatment methods are numerous and can be classified into three categories: physical (Achak et al., 2009, 2011; Ouabou et al., 2014), chemical (El Hajjouji, 2007; Sifoun, 2008) and biological (Aissam, 2003; Achak et al., 2009, 2011; Lakhtar, 2009; Yaakoubi et al., 2009).

Water lettuce (*Pistia stratiotes*) is a plant of the Araceae family. It is native from tropical and subtropical regions, is an aquatic plant, floating in rivers, ponds, irrigation ditches, rice fields and pond systems, with long and fibrous roots suspended in the water (Iketuonye, 1987; Koné, 2002). It has, among others, the ability to purify water it colonizes (Morel and Kane, 1998; Bodo et al., 2006). Its roots capture directly their nutrients in the water.

Water lettuce has shown great potential for natural water treatment because of its rapid and easiness growth, its high nutritional value, its high capacity for assimilation of organic compounds and metals (Iketuonye, 1987; Bodo et al., 2006). The scientific basis for the treatment of wastewater by a system of aquatic plants is the growing, in cooperation, of the plants and the associated microorganisms. When microorganisms are established in the roots of plants, there is created a synergistic relationship between the two parties that results in better degradation and removal of organic compounds (Koné, 2002). *P. stratiotes* eats nitrates, phosphates and other nutrients to grow; this has the effect of removing these items from the aqueous phase (Aina et al., 2012). These characteristics lead to the use of *P. stratiotes* in the lagoon system for wastewater treating, especially of domestic origin (Fonkou et al., 2002; Koné et al., 2002; Nya et al., 2002; Kpondjo et al., 2012).

There are very few works on the purification of cotton oil mill effluents by a lagooning system and, *a fortiori*, with a *P. stratiotes* based lagoon. Therefore, this combination seems to us useful to be initiated.

The objective of this study was to develop a strategy for purifying the CDCC oil mill effluents in Maroua, by the use of a dual lagoon pools, one with microphytes and the other with macrophytes.

## MATERIALS AND METHODS

### Study Site

The study was conducted in the city of Maroua, the regional capital of the Far-North Cameroon. This town is located between 10°35 and 14°19 North latitude and 10°58 and 14° 32 East longitudes. The climate is characterized by the alternation of two seasons: a long dry season from October to May and a short rainy season, which extends from June to September. The rainfall amount is between 600 and 900 mm, on average. The average temperature is about 28°C; it may reach a maximum of 45 °C, during the month of April, and a minimum of 18°C, in December. The vegetation is characterized by arboreous and shrub savannah and steppes (MINADER, 2003). The city is crossed by two major rivers, with seasonal flow, generally referred to as Mayo, namely the Tsanaga and Kaliao Mayos. Soil types are essentially fersialitic soils, encountered in the foothills and ferruginous soils in the plains (MINADER, 2003).

Maroua CDCC oil mill is located in the industrial area of the Maroua I district. This district has about 450 inhabitants and is crossed by the Mayo Tsanaga River. The activities of oil, compost and animal feed production generate residues. These residues are removed in a network of liquid effluents, which converges to a collecting channel (opening outside of the plant) and flows into the Mayo Tsanaga River.

### Survey

A survey was undertaken to evaluate the impact of the use of the oil mill wastewater by and on the population. To gather the views of people, we prepared a set of questions, with six issues divided into five titles: the identification of the resident (respondent), the knowledge of the CDCC outfall sewage, the mode of wastewater use, the impact on the population and the prevention and awareness. In the surrounding areas of the CDCC plant and near the discharge effluents canal, 100 people were interrogated, according to the questions set.

### Characterization of the wastewater

The flow rate of the effluents was determined by evaluating the time

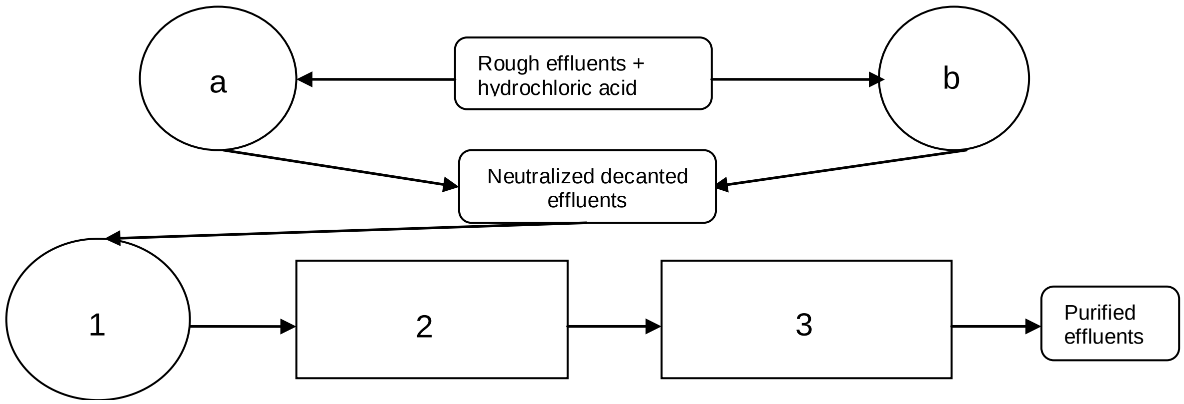


**Figure 1.** Lagooning system diagram. a, b, Decantation-neutralization tanks; 1, Neutralized and decanted effluents tank; 2, Microphytes basin; 3, Macrophytes basin.

needed to full a 15 l bucket by the wastewater collector canal. Elsewhere, samples were taken from manifold channel, using three sample tubes (1 l each). For general characterization, these tubes were placed in a refrigerated icebox and sent to the Hydrobiology Laboratory of the University of Yaounde I, where the following parameters were analyzed, according to the Rodier (2009) methods: $BOD_5$, (mg/l $O_2$) $NO_3^-$ (mg/l N) and dissolved oxygen (mg/l).

pH, electrical conductivity (EC, µS/cm), total dissolved solids (TDS, mg/l)), turbidity (NTU), $NO_2^-$ (mg/l N), $NH_4^+$ (mg/l N) and $PO_4^{3-}$ (mg/l) were analyzed, *in situ*, by a Wagtech International POTALAB kit, composed of a pHmeter (Wagtech Wag-WE391655), a conductimeter (Wagtech Wag-WE393740), a turbidimeter (Wagtech Wag-WE399976) and a photometer (Wagtech Wag-WE10441).

All the measures were made in triplicate, for each parameter and in each basin, at the beginning of the treatment and after a hydraulic retention time of 5 days.

#### Lagooning

The CDCC oil mill wastewaters constitute a vast network of effluents of different origin (refinery, swimming pool, septic tanks and household).

The water lettuce samples were collected from the municipal lake of Yaounde (Cameroon). The samples were kept in a pool of water near a septic tank, within the plant. Before their transfer to the macrophytes basin, they were acclimated to the pre-treated effluent during 3 days.

The microphytes are constituted of local phyto (seaweed)-zooplankton witch developed in the wastewater.

To assess the purifying capacity of the water lettuce based lagoon, we used a pilot installation to simulate a reduced size lagoon system (Figure 1).

Decantation and neutralizing are the pre-treatment process in this lagooning system. Indeed, each operation has a specific role. Decantation separates the insoluble fat matter from the liquid phase. To achieve this, two half-barrels of 100 litres each are used. The rough effluents are poured in each of them and stay there for 3 days. During their stay, floating fats are removed manually, using a small container.

Neutralization is a chemical process witch importance is to make the environment favourable to the development of water lettuce (pH between 6.5 and 7.5). The effluent being basic (pH between 9 and 11), concentrated hydrochloric acid was used to neutralize the caustic effluents. After neutralization, the effluents are poured into the tank. At this level, they are ready to supply the microphytes lake, which, in turn, feeds the macrophytes basin. After the wastewaters have reached the macrophytes basin, water lettuces are introduced.

The pilot system was fed, at its input, with decanted and neutralized effluent of the oil mill, contained in a 200 L metallic cylindrical barrel, with a diameter of 60 cm and a depth of 90 cm.

Two others cylindrical metal barrels of 200 L each were cleaned, drilled and varnished. They were cut, in the length direction (depth of 30 cm) and connected, to each other, by PVC pipe (50 mm of Ø). Wastewater pass from one (microphytes basin) to the other (water lettuce macrophytes basin), by gravity. Two taps were installed, one between the tank and the microphytes basin and the other at the macrophytes basin output.

The 200 L tank is lightly raised (6% of slope) above the ground and connected to the microphytes basin. When the wastewaters reach the pipe communication in the latter, it is poured into the macrophytes basin. The excess water is removed by opening the macrophytes basin tap. The installation was carried out in the oil mill, not far from the discharge channel.

#### Data analysis

Data were recorded and analyzed, using SPSS 19.0 software. Comparison between the parameters amounts in the raw effluent and those in the microphytes and macrophytes ponds was made by variances analysis (One-way ANOVA), at the 0.05 level. The abatement rates of the parameters, in the ponds, were compared by the Z test, at the 0.05 level.

## RESULTS AND DISCUSSION

### Survey

From the questions asked to the 100 nearby residents of the study site, we obtained the following information: Concerning the knowledge of the outlet of the oil mill, of the 100 respondents, 94 argued that the outflow of wastewater from the oil mill is a river (Mayo Tsanaga), 3 thought that this outlet is a pit while the remaining, 3 people, said that, these waters are discharged into the fields and open spaces. Seas, rivers, pools and soils are

**Table 1.** Physico-chemical characteristics of crude oil mill effluent.

| Parameter | Amounts |
|---|---|
| pH | 9.77 ± 0.51 |
| CE (µS/cm) | 989 ± 98 |
| TDS (ppm) | 475 ± 70 |
| Turbidity(NTU) | 825 ± 94 |
| $NH_4$+ ( mg/l N) | 12 ± 2.60 |
| $NO_2$- (mg/l N) | 6.50 ± 1.30 |
| $NO_3$- (mg/l N) | 510 ± 84.50 |
| $PO_4^{3-}$ (mg/l) | 5560 ± 1550 |
| *$BOD_5$ (mg/l $O_2$) | 16000 ± 6850 |
| *Dissolved $O_2$ (mg/l) | 0.45 ± 0.09 |

*Parameters were measured after settling neutralization because the basic pH of the raw effluent is unfavourable to the activities of purifier microorganisms.

considered by industry as the best dumps (Kramkimel et al., 2004). The studied oil mill does not make exception, as it channels the effluents to a river; About the different uses made of sewage, priority goes to the recycling of fat, with 85 opinions. Dishes and laundry represented 29 views. Spreading and spraying had, respectively, 8 and 3 views. Bath, watering and drinking displayed, respectively, 4, 3 and 0 notices. Finally, other uses, including the treatment of latrines had 9 advices. The lack of water in the region is such that the residents do not hesitate to use the effluents as a source of raw material for artisanal cotton oil and soap named Garlacka production. Fortunately, they are not going to use them as a beverage, aware of their danger; Regarding the impacts of the wastewater, the proportion of people thinking that these effluents are an embarrassment is 80%. Only individuals claiming harm these waters were asked about the diseases caused by them. There were 34 respondents who believed that the use of oil mill wastewater cause skin diseases; 11, typhoid fever; 13, dysentery; 8, diarrhoea; 6, cholera; 5, Malaria and 1, diseases such as schistosomiasis and other intestinal parasites; In the area of awareness of local residents on the dangerousness of the oil mill effluent, 60 of those surveyed said they had been warned of the nuisances that may cause the use of these effluents by the competent authorities (Municipality, Regional Delegation of Environment and Protection of Nature, Administrative Division, CDCC...).

## Physico-chemical characterization of effluents

Mean values of physico-chemical parameters of raw wastewater are summarized in Table 1.

The flow of wastewater from the oil mill was of 324 ± 6.51 $m^3$/day, which is 7 times greater than the rate of 48 $m^3$/day found in a cotton oil mill, in Burkina Faso (Nguématio, 1991). This flow is high and waters thus thrown out, without treatment, are destined to cause immense environmental damages.

According to Cameroonian standards of effluents discharges from industrial sources, which state, among other things, that the pH must be of 6-9, $BOD_5$ of 50 mg/l and total nitrogen of 10 mg/l (MINEP, 2008), the values of the parameters are very high and make these effluents extremely polluting. With a pH of 9.77 ± 0.51, these waters are very basic, probably due to the sodium hydroxide used for oil extraction. Nguématio (1991) also find a basic pH, ranging between 11 and 13, at the characterization of a cotton oil mill effluent, in Burkina Faso. A dissolved oxygen level of 0.45 ± 0.09 mg/l make these effluents very low oxygenated. The concentrations of nitrites (510 ± 84.50 mg/l) and phosphates (5560 ± 1550 mg/l) were very high and might be explained, probably, by the use of nitrogen and phosphorus fertilizers and organophosphorous insecticides in cotton cultivation (Achak et al., 2009; Gomgnimbou et al., 2009; Cotton Guide, 2014).

## Treatment essay

### *Decantation-neutralization*

Decantation separated the insoluble fatty matter from the liquid phase. The floating fats are removed manually then, using a small container.

Neutralization is a chemical process witch importance is to make the environment favourable to the development of water lettuce (pH betweens 6.5 and 7.5). During this phenomenon, the effluent pH was reduced from 9.77 ± 0.51 to 7.21 ± 0.24. Throughout the neutralization, the insoluble fatty matter separation from liquid stage is improved (Nguématio 1991).

## Lagooning

Analysis of variance (one-way ANOVA) shows that, except for EC and TDS, there is a statistically significant difference between the mean values of the studied parameters in the raw effluent and those of each basin ($p < 0.05$ in each case), reflecting, a real decrease in the levels of these parameters in the lagoons.

pH varied from 9.77 ± 0.51, in the raw effluent to 7.21 ± 0.24, in the microphytes basin and to 7.09 ± 0.17, in the macrophytes pond (Figure 2A). The abatement rates obtained were, respectively, 26 and 27% for microphytes and macrophytes (Figure 5). Less than 5 or greater than 8.5, pH directly afflicts purifier organisms growth (Belghyti et al., 2009). The pH values thus obtained are acceptable to the growth of microorganisms and water lettuce, which require, generally, a pH range of 5.5 to 7.5 (Belghyti et al., 2009).

EC and TDS are related parameters. Most of the dissolved solids in the water are as electrically charged

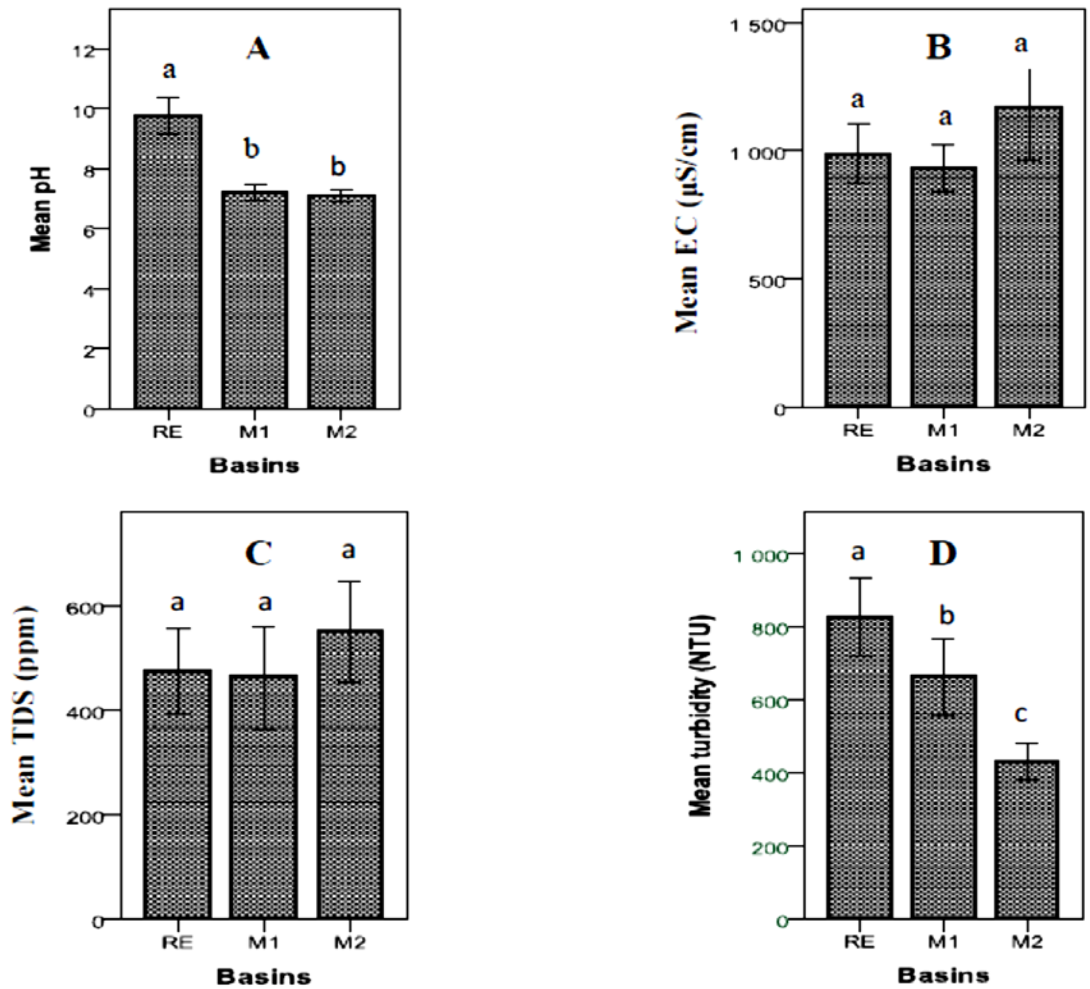


**Figure 2.** Mean pH (A), EC (B), TDS (c) and turbidity (D) amounts evolution, in the basins. RE: rough effluent, M1: microphytes basin, M2: macrophytes basin. In each histogram, rectangles with the same letter belong to the same group of means within which there are no statistically significant differences (Duncan test), at the 0.05 level.

ions, that determinate the EC. The behaviours of these parameters were similar. Their average values remained approximately the same, between the raw and the microphytes effluents, while they rose in the basin of macrophytes (Figure 2B and C). Likewise, Finlayson and Chick (1983), Abissy and Mandi (1999) and Tiglyene et al. (2005) show that the EC of the wastewater treated by planting Typha, Phragmites and Roseau, increases. This behaviour, with a decrease, in the microphytes basin and an increase, in the macrophytes pool (Table 2) is mitigated and is explained in different ways. This increase is, for some authors, related to evapotranspiration of vegetation, which tends to concentrate more the effluents (Finlayson and Chick, 1983; Koné et al., 2011). Ranjani et al. (1996) have linked this increase to the leaching of soil minerals and mineralization of organic matter. In our case, evapotranspiration, ions exchange between the barrel and the water and mineralization may be involved so, as well as chemical and physical mechanisms are concerned.

Turbidity translated visual presence of suspended particles, finely divided in water, clays and microscopic organisms (Menduga, 2002). Its averages significantly decreased from 825 ± 94, in the rough effluent to 662 ± 89 NTU, in the microphytes pond and to 430.33 ± 45.06 NTU, in the macrophytes lagoon (Figure 2D). Despite a reduction of 48% (Figure 5), turbidity remains high, probably because of the presence of microorganisms suspended in the macrophytes lake and the short hydraulic retention time, which would not have allowed the deposition and trapping of suspended solids by plants floating roots. Longer retention hydraulic time, may lower, the level of this parameter.

The $NH_4^+$ initial average grade of effluent was 12 ± 2.60 mg/l N. This decreased, in the microphytes lagoon, down to 0.67 ± 0.46 mg/l N and was reduced to zero, among

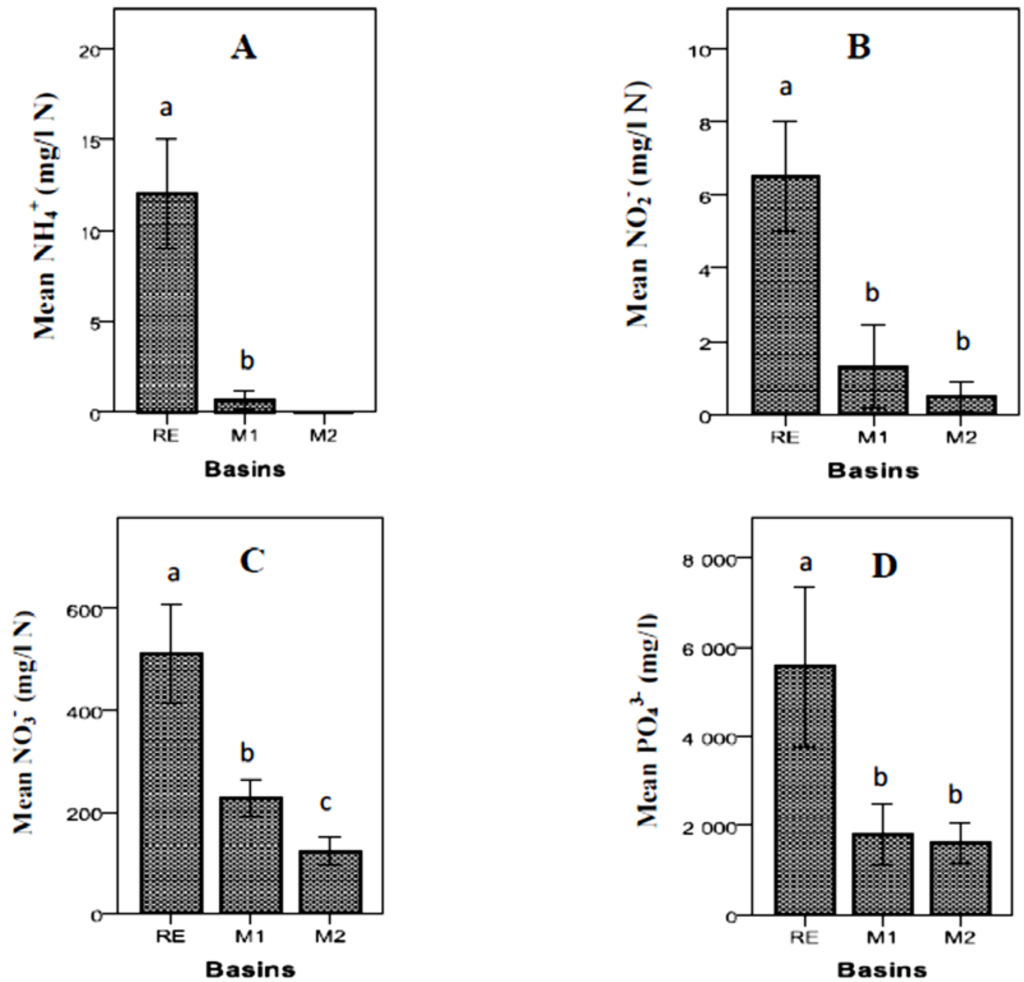


**Figure 3.** Mean $NH_4^+$ (A), $NO_2^-$ (B), $NO_3^-$ (C) and $PO_4^{3-}$ (D) amounts evolution, in the basins. RE, rough effluent; M1, microphytes basin; M2, macrophytes basin. In each histogram, rectangles with the same letter belong to the same group of means within which there are no statistically significant differences (Duncan test), at the 0.05 level.

macrophytes (Figure 3A). The abatement rates were, respectively, 94 and 100%, for microphytes and macrophytes (Figure 5).

Nitrites, generally, proceed from incomplete degradation of the ammonium ions, or from nitrates reduction. Their mean concentration of the raw effluent was 6.50 ± 1.30 mg/l N, then it dropped down to 1.30 ± 0.99, in the microphytes tray and to 0.47 ± 0.34 mg/l N, in the macrophytes one (Figure 3B), inducting respective reduction rates of 80 and 93% (Figure 5).

The nitrates, relatively high average grade of raw effluent (510 ± 84.50 mg/l N), decreased to 226.70 ± 30, in the presence of microphytes and to 122.40 ± 24.50 mg/l N, in the presence of macrophytes (Figure 3C), corresponding to respective abatement of 56 and 76% (Figure 5).

The various reactions, which lead to the elimination of nitrogen in an aquatic environment, are ammonification (conversion of organic nitrogen to ammonium), nitrification (oxidation of ammonium to nitrate), volatilization (transformation of ammonium to ammonia) and denitrification (reduction of nitrate to nitrogen gas, $N_2$).

In the presence of aquatic plants, the main reactions of nitrogen removal are nitrification/denitrification and uptake by plants (Brix, 1997; Reddy and D'Angelo, 1997). Several studies have shown that the ammonium nitrogen form is preferably used by aquatic plants (Ower et al., 1981; Aoi and Hayashi, 1996). The presence of plants in the basin provides to the present bacterial communities a fixing support. These form a biofilm, which contributes to the degradation of pollutants. The oxygen released in this medium enables the development of nitrifying bacteria, responsible for the nitrification of ammonium. It is now accepted that nitrification/denitrification contributes largely

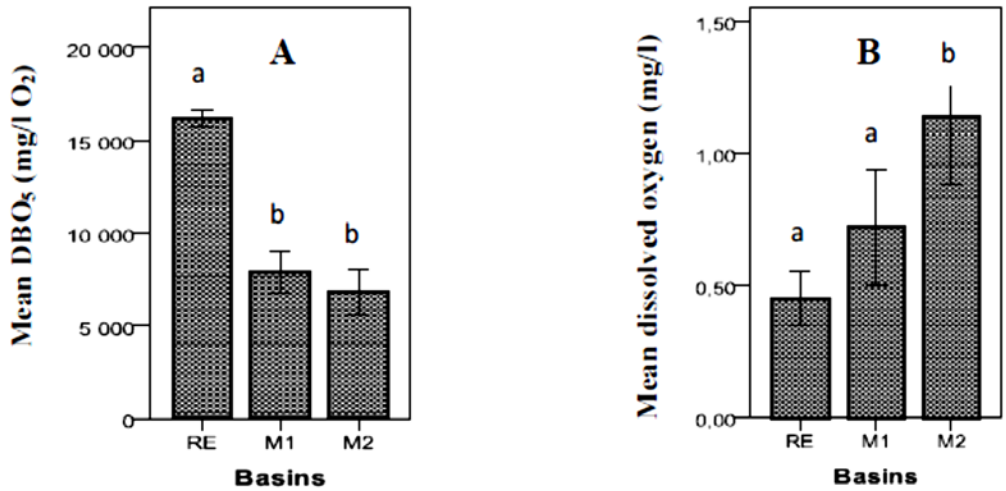


**Figure 4.** Mean $DBO_5$ (A), and dissolved oxygen (B) amounts evolution, in the basins. RE: rough effluent, M1: microphytes basin, M2: macrophytes basin. In each histogram, rectangles with the same letter belong to the same group of means within which there are no statistically significant differences (Duncan test), at the 0.05 level.

to the removal of nitrogen in ponds macrophytes (Koné, 2002). When nitrogen levels are sufficient and that the environmental conditions are favourable, nitrification-/denitrification can represent over 60% of the nitrogen lost in the basins (Bachand and Horne, 1999). The role of aquatic plants in the removal of nitrogen appears to be dominant, whether by storage in tissues or by stimulating nitrification/denitrification (Koné, 2002). From the different phenomena cited above and abatement rates obtained, we can deduce that both microorganisms and macrophytes, by uptake and trapping, are involved in the reduction of nitrogen pollutants in our purifying system.

Regarding phosphates, the average level of the raw effluent concentration was very high (5560 ± 1550 mg/l). Mean concentrations in microphytes and macrophytes lakes were, respectively, 1800 ± 592 and 1610 ± 385 mg/l (Figure 3D), giving abatement rates of 68 and 71% (Figure 5). Like nitrogen, phosphorus is an essential constituent for plant development, its availability have a direct influence on their growth. The presence of plants creates a physico-chemical environment favourable to absorption and complexation of inorganic phosphorus, which is well absorbed from the orthophosphate form in the roots and submerged parts (Koné, 2002).

$BOD_5$ decreased from 16,000 ± 6850 mg/l, in raw effluent to 7904 ± 969, in the presence of microphytes and 6811 ± 1056 in that of macrophytes (Figure 4A), giving respective abatement rates of 51 and 57% (Figure 5). $BOD_5$ is a physico-chemical parameter that estimates biodegradable organic carbon in water. In polluted environment, carbon is used by bacteria as a source of energy and for the synthesis of new cells. The removal of organic matter, in pools with floating macrophytes, is based on a symbiotic relationship between plants and bacteria, in which the bacteria use oxygen provided, to the environment, by plants during photosynthesis, to degrade organic carbon. In return, the by-products of this reaction, such as $NH_4^+$ and $CO_2$, are used by the plant (Polprasert and Khatiwada, 1998). The reactional mechanisms of BOD abatement, in pools with floating plants, are identical, for the rhizosphere, to those of fixed biomass systems and for the lower layers, to those of facultative ponds (Koné, 2002).

Poorly oxygenated, at the beginning, oil mill effluent was oxygenated more and more, as it passed through the purification basins (Figure 4B). The rate of increase in the macrophytes lagoon was 156%, reflecting thus a progressive and efficient purification (Table 2). Dissolved oxygen measured in the pools is a resultant of metabolism of plants and bacteria and of the transfer due to diffusion of air (Koné, 2002). It is also estimated that the floating plants provide 90% of the oxygen necessary for reactions of aerobic degradation in purifying ponds. Furthermore, the production of oxygen by water lettuce has been estimated between 1.4 and 2 $g/m^2/day$ (Jedicke et al., 1989).

## Purifying performance

The different parameters abatement rates, according to the purifying path used, are illustrated in Figure 5. Parameters such as turbidity, nitrates, phosphates and $BOD_5$ showed better purification in macrophytes pond ($|Z| > Z_{0.05} = 1.960$, in each case).

These discoveries contrast, in part, with previous works. Indeed, Nya et al. (2002) find that turbidity and $BOD_5$ have better reduction rates in macrophytes ponds,

**Table 2.** Increasing rates of some effluent physico-chemical parameters, after treatment.

| Parameter | Rough effluent | Microphytes | Increasing (% ) | Macrophytes | Increasing (% ) |
|---|---|---|---|---|---|
| CE (µS/cm) | 989 ± 98 | 934.33 ± 78 | 6* | 1169.60 ± 177 | 18 |
| TDS (ppm) | 475 ± 70 | 463 ± 85 | 3* | 542.66 ± 73,80 | 14 |
| Dissolved $O_2$ (mg/l) | 0.45 ± 0.09 | 0.72 ± 0.19 | 60 | 1.15 ± 0.21 | 156 |

* Reduction rate.

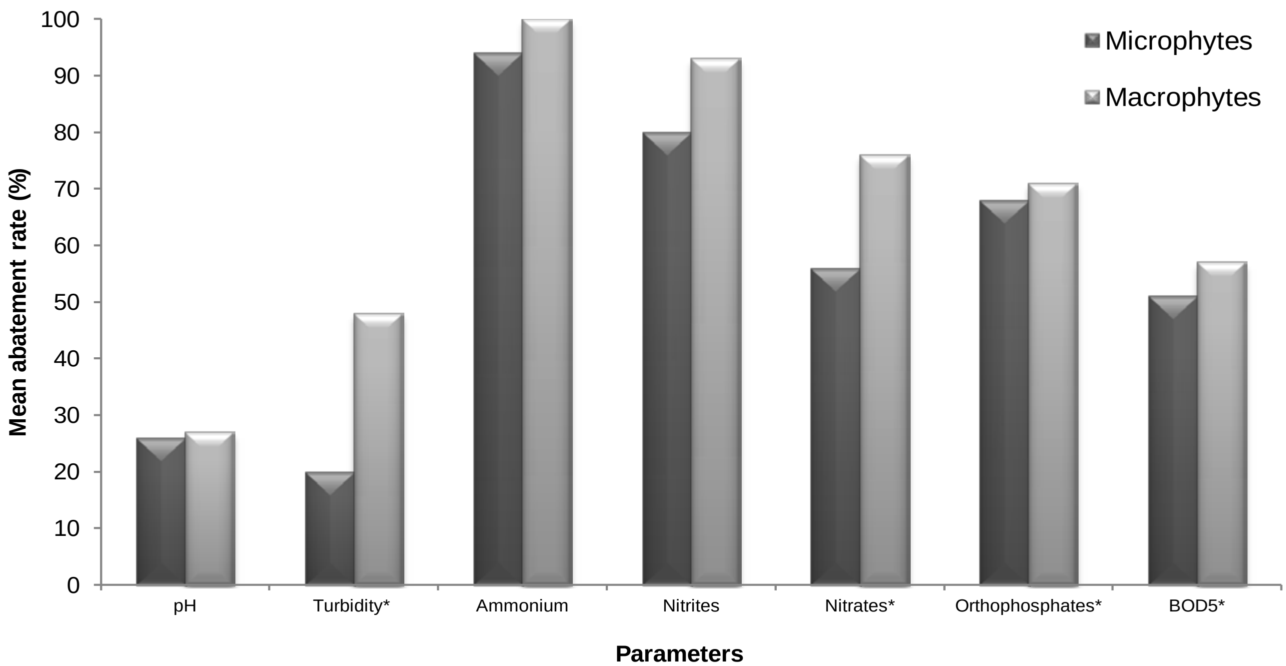


**Figure 5.** Parameters abatement rates, according to the used purifying path. * indicates statistically significant differences (Z test, at the 0.05 level) between the concerning parameter abatement rates.

while phosphates and ammonium are clearly reduced by microphytes lagooning. Similarly, Mandi et al. (1993) and Ouazzani et al. (1995), evaluating the comparative effectiveness of these two lagoons in Morocco, respectively, achieved a reduction of 78 and 50%, of P; 63 and 60% of $NH_4^+$, by the microphytes lagoon against only 26 and 37% of P; 50 and 50% of $NH_4^+$, by the macrophytes pond. On the contrary, Maiga et al. (2002), after a review of the abatement levels of these parameters in wastewater treatment plants by microphytes or macrophytes, in Cameroon, Burkina Faso, Senegal, Ivory Coast, Ghana and Niger, report that it would be unwise to conclude to a superior performance of microphytes or macrophytes lagoon, as the obtained results are so disparate. Koné (2002) relates the purifying performances of the two types of lagoon to their initial pollutants charges and to the order in which the basins are connected.

It was shown that macrophytes showed better performance respect to microphytes. This can proceed from the conjunction of many processes. The scientific basis for the treatment of wastewater by a system of aquatic plants is the growing, in cooperation, of the plants and the associated microorganisms. When microorganisms are established in the roots of plants, there is created a synergistic relationship between the two parties that results in better degradation and removal of organic compounds, in macrophytes system than in a microphytes one, where there are only microorganisms (Koné, 2002). Moreover, polluting particles are trapped by the plants roots and this has the effect of removing them from the aqueous phase (Nya et al., 2002).

## Conclusion

In this work, a survey of one hundred individuals in the nearby of the oil mill study site was used to assess the impact of the use of these effluents by the population. It appears that these wastewaters are used for both economic contributions and agricultural household. However, these emissions are thought to cause health nuisances, like the skin, water and parasitic diseases.

A physico-chemical characterization of wastewater showed that the effluent is highly alkaline and extremely polluting, with high levels of $BOD_5$, TDS, EC, $PO_4^{3-}$, $NO_3^-$ and turbidity.

The treatment essay of the wastewater, by combined stabilization pond (microphytes pool) and water lettuce lagoon, that ensued, allowed to display reduction rates of nitrogen compounds (ammonium, nitrites and nitrates), orthophosphates and $BOD_5$ upper to 50%, in each of the two ponds used, taken separately. These abatements are slightly higher in macrophytes basins. Only the pH decreased, after pre-treatment, in the range of norms required for discharges of oil mills effluents, in Cameroon. For other parameters, their initial charges were so high that, at the macrophytes tray output, their values remained important.

The achieved percentages of reduction, although very encouraging, need to be improved. It would be interesting to add filtration to the pre-treatment mechanisms, microbiological parameters to the studied elements, multiply the basins number and make them work continuously.

## Conflict of Interests

The author(s) have not declared any conflict of interests.

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*Full Length Research Paper*

# Phytoplankton composition and water chemistry of a tidal creek (Ipa-Itako) part of Lagos Lagoon

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**The composition and diversity of planktonic algae in a sluggish tidal freshwater/brackish mangrove dominated creek (Ipa Itako) part of the Lagos lagoon was investigated for twelve months (February 2010 - January 2011). The surface water pH varied between 6.5 (December 2010) and 8.6 (August 2010) indicating a slightly acidic to alkaline nature of the creek. The salinity was higher during the dry months (November- April) and phosphate - phosphorus and nitrate-nitrogen recorded highest values (3.50 and 16.70 mg/L) respectively in June, 2010. Ninety three species belonging to forty nine genera from five classes (Bacillariophyceae, Chlorophyceae, Euglenophyceae, Cyanophyceae and Xanthophyceae) were recorded. Bacillariophyceae constituted the most abundant group making up 72.85% of cells/ml followed by the Chlorophytes (18.02%) then the blue green (7.65%), euglenoids (1.40%) and xanthophytes (0.07%) with only *Vaucheria* sp. recorded as a representative of the group. Higher phytoplankton diversity and cell counts were recorded in the dry months than in the wet months. *Navicula*, *Pinnularia, Cymbella* (Diatoms) and *Closterium* (Chlorophyceae) were more frequently occurring species. Community structure analysis indices used indicated a diverse but stressed environment.**

**Key words:** Diversity, phytoplankton, creek, eutrophication.

## INTRODUCTION

The nine lagoons in south-western Nigeria (Lagos, Kuramo, Yewa, Ologe, Badagry, Iyagbe, Epe, Lekki and Mahin) receive several rivers and creeks that drain into them. Some, like the Ogun River, Majidun, Ogudu and Festac creeks receive maritime influence through the adjoining lagoons in the dry season. While others like Yewa, Owo, Oshun Rivers, Ogbe and Orile creeks remain fresh through the year. The Lagos Lagoon, Nigeria is an open, shallow and tidal lagoon with a surface area of 208 km$^2$. Olaniyan (1969) reported that the rainfall regime in Lagos lagoon system is seasonal, with a wet season from May-November (with a short dry spell in July and August) and a dry season from December-April while Nwankwo (1999) reported two peaks of rainfall linked with excessive flood, a major peak in June and a lesser peak in September, associated with this area. Various ecological studies at the Lagos Lagoon have investigated and highlighted the mixing induced by semi-diurnal tidal dynamics and river flow (Hill and Webb, 1958), the existence of environmental and biota gradients (Sandison, 1966; Nwankwo, 1996),

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**Plate 1.** Part of Ipa-Itako showing the dominant riparian vegetation.

an increase in biodiversity towards the harbour (Nwankwo, 1996) and the phytoplankton (Nwankwo, 1996; Adesalu and Nwankwo, 2005). According to Olaniyan (1957), Hill and Webb (1958) and Nwankwo (1998), two physiographic factors, rainfall and salinity determine the hydro-climatic conditions of the Lagos lagoon. Rainfall dilutes the lagoon water, breaks down any environmental gradient and enriches the environment (Nwankwo et al., 2003). The presence and dominance of diatoms in water bodies in Nigeria has been reported by Nwadiaro (1990) in the chanomi creek system of the Niger Delta, Chindah and Pudo (1991) in Bonny River, Erondu and Chindah (1991) in the new Calabar River, Niger Delta, Adesalu and Nwankwo (2005, 2008) in Olero and Abule Eledu creeks, respectively, Adesalu et al. (2008) in Ogbe creek and Nwankwo (1986, 1991) in the Lagoons of South western Nigeria. Due to seasonal distribution of rainfall, seasonal flooding is experienced within the lagoon system and adjourning creeks. The creeks and lagoons of south-western Nigeria apart from their more ecological and economic significance, serve as sink for the disposal of any increasing array of waste types. Refine oil, waste heat, sewage, wood waste, municipal and industrial effluents among others enter into immediate coastal waters through conduits such as rivers, creeks, storm water channel and lagoons (Akpata et al., 1993; Chukwu and Nwankwo, 2004). Hence, phycologists over the years have attempted to judge the degree and severity of pollution by analyzing changes in biological systems (Nwankwo, 2004). Egborge (1974) suggested that the seasonal variation of the phytoplankton population and abundance in many West African rivers could be related to the physico-chemical parameters of the water which in turn is determined by the distributive rainfall pattern. The interplay between the physical and chemical characteristics of any lagoon determines the spectrums of biota present at any time (Nwankwo, 2004).

After the light, the most important factor in phytoplankton productivity seems to be the concentration of inorganic salts, primarily nitrates and phosphates (Reynolds, 1984). The productivity of phytoplankton is strongly constrained by the need for light, which is only available in the upper layers and the need for mineral nutrients available only in the deeper layers. Nwankwo (1990) reported that the Lagos lagoon is primarily characterized by seasonal salinity variations. In wet season, there are obvious discontinuities in the salinity gradient which coincide with the periods of fresh water discharge (Nwankwo, 1990). The dry season however, imposes an increased tidal sea water incursion, which raises the salinity appreciably (Nwankwo, 1990). Olaniyan (1969) grouped the Lagos lagoon into three distinct environments with regards to salinity. They are: fresh, low brackish and high brackish. These features have impact on the lagoon floristic and faunanistic spectral changes in the temporal and seasonal terms (Nwankwo et al., 2003). Nwankwo and Amuda (1993) reported that information on the creeks of South-western Nigeria as well as their possible value in biological water quality assessment is either scanty or non-existent but more recently, Adesalu and Nwankwo (2006, 2008a), Adesalu and Olayokun (2011) and Adesalu et al. (2008b, 2010) worked on Olero, Ogbe, Agboyi, Ajegunle and Tomaro creeks, respectively. Since no study has been specifically carried out on this water body (Ipa-Itako), it is then necessary to investigate the phytoplankton composition interaction with the water chemistry.

## MATERIALS AND METHODS

### Description of the study site

Ipa-Itako creek (Figure 1) is one of the water bodies in Ikorodu area of Lagos State that empties into the Lagos lagoon. Three sampling stations were created, Station 1 (Latitude 06° 473′ 35N, Longitude 003° 570′ 26E), Station 2 (Latitude 06° 735′ 35N, Longitude 003° 324′ 26E) and Station 3 (Latitude 06° 804′ 35N, Longitude 003° 352′ 26E). Ipa-Itako creek is slow flowing and the shore is characterized by mangrove plants including *Rhizophora racemosa*, *Avicennia germinans* and very few *Eichorrnia crassipes* Solms on the surface of the water along the edges with *Rhizophora racemosa* being the dominant riparian vegetation (Plate 1). The creek is quite narrow as compared to some other creeks in the Lagos lagoon and this is probably due to the spread of mangrove plants in the area. The area experiences tidal influences from the sea via the Lagos Lagoon. Dredging often occurs at these stations which is probably the cause of the regular change in colour of the water body. The study area is quite far from human settlement and industries; the water has unpleasant odour and fishing is not common in this area.

### Collection of samples

Samples were collected on every second saturday of the month for twelve months (February, 2010 – January, 2011) to spread across the dry months (December – April) and wet months (May-November). Phytoplankton samples were collected using 55 µm mesh size standard plankton net tied unto a motorized boat and towed horizontally at low speed (< 4 knots) for five minutes. The samples were transferred into 500 ml plastic containers and preserved with 4% unbuffered formalin. Water samples for the analysis of physico-chemical parameters were collected in 750 ml plastic containers with screw caps just below the water surface. All samples were transferred to the laboratory for further analysis.

### Physical and chemical parameters analysis

Air and surface water temperatures were measured *in situ* with a

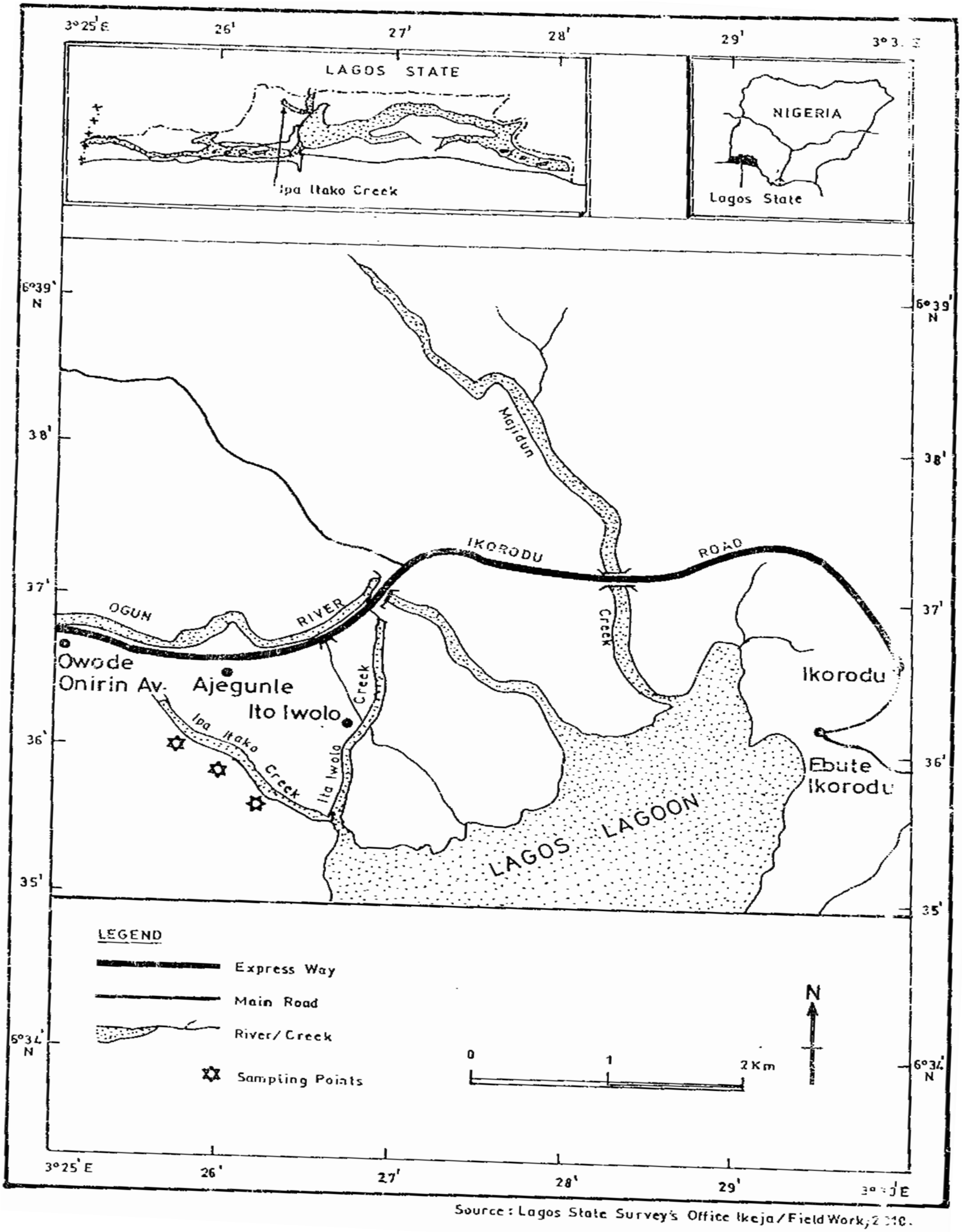


**Figure 1.** Map showing Ipa Itako creek part of Ikorodu area with sampling stations.

nitrate-nitrogen values were estimated using titrimetric method while phosphate-phosphorus and sulphate were determined by ascorbic acid and turbidimetric methods, respectively (APHA, 1998). Silica was determined at 600 nm using a pre-calibrated colorimeter (DR2010). Copper, lead and mercury values were measured using atomic absorption spectrophotometer (AAS) (APHA, 1998). Heavy metals, copper, lead and mercury were determined using Atomic Absorption Spectrophotometer (AAS). Rainfall data were kindly supplied by the Meteorological Services Department, Oshodi, Lagos State.

#### Phytoplankton analysis

Biological samples were analyzed using Olympus XSZ-N107 photo-microscope. In this study, filamentous blue green were counted using 10 µm of filament length representing one unit unicells and solitary cells were tallied as separate individuals, for *Microcystis* sp. the method used for filamentous algae was applied. For further analysis, one unit was equated as one cell. Chlorophyll 'a' was determined using a fluorometer equipped with filters for light emission and excitation. Relevant texts employed in the identification included Nwankwo (1984), Olaniyan (1969, 1975), Wimpenny (1996), Hustedt (1930, 1937, 1942, 1971), Patrick and Reimer (1966, 1975), Prescott (1964, 1973, 1982) and Whittford and Shumacher (1973).

#### Community structure analysis

To obtain the estimate of species diversity, three community structure indices were used: Margalef's diversity index (d) (Margalef, 1970), Shannon-Weaner Index ($H^1$) (Shannon and Weaver, 1963) and Species equitability (J) or evenness (Pielou, 1975).

## RESULTS

### Physico-chemical parameters

Some of the parameters analysed with the results are presented on Table 1. For this study, the highest (31.7°C) and lowest (26.2°C) surface water temperature values were recorded during dry (February 2010) and wet (July 2010) months at station 2, respectively. The pH was essentially neutral (7.0) for the first four months and varied from slightly acidic (6.5) to being alkaline with the highest value (8.6) recorded in August 2010 (wet month) at station 3. Highest transparency (225.6 cm) and conductivity (20.0 µs/cm) values were recorded in dry month (March 2010). Salinity decreased steadily as the rainfall increased, the highest value, 20.0‰ recorded in March 2010 (dry month) at station 1. Nitrate-nitrogen and phosphate-phosphous values varied between 2.0 – 16.7 and 1.58 - 3.50mg/L, respectively while sulphate highest value (23.4 mg/L) was recorded in April 2010 (dry month) at station 2 (Figure 2). Silica content of the water recorded its highest value (0.44 mg/L) in October 2010 (wet month) at station 2. Dissolved oxygen content highest value (5.7mg/L) was recorded during the dry month (April 2010) at station 2.

### Phytoplankton results

93 taxa belonging to 49 genera were recorded for this study, spread across five classes, Bacillariophyceae, Chlorophyceae, Cyanophyceae, Euglenophyceae and Xanthophyceae (Table 2). Diatoms recorded highest percentage composition cells/ml value of 72.85% followed by the green algae (Table 3). *Navicula mutica, Navicula muralis*, *Pinnularia substomatophora, Nitzschia palea* and *Cymbella obtusa* were observed as frequently encountered species. Variations in chlorophyll 'a' value, total phytoplankton and rainfall are depicted on Figure 3.

Community structure analysis followed same trend as highest species divesity (d) value (6.46) corresponded with highest Shannon-Weaner index value (3.16) (Figure 5). Highest species evenness (j) value (0.99) was recorded in February at station 1 (Figure 4). Chlorophyll-a content varied between 0.01 and 0.04 mg/L throughout the sampling period (Figure 4). Numerically, the diatoms outnumbered other algae species, with *Navicula* appearing most throughout the study period. Other diatom species recorded were *Fragilaria construens, Coscinodiscus centralis, Cyclotella meneghiniana, Ulnaria ulna, Bacillaria paradoxa, Perlibellus berkeleya* and *Melosira moniliformis.*

## DISCUSSION

Information on variation in physico-chemical factors of the Ipa Itako creek confirms earlier observations in the Lagos lagoon that two dominant factors, fresh water discharge and tidal sea water incursions governs the physical, chemical and biological characteristics of the areas (Hill and Webb, 1958; Sandison and Hill, 1966; Nwankwo, 1988, 1998b; Brown, 1991). According to Webb (Hill and Webb, 1958), rainfall other than temperature is more important in determining environments in the tropics. Rainfall pattern has been linked to the different ecological factors influencing the abundance and composition of phytoplankton in coastal waters of southwestern Nigeria (Olaniyan, 1969; Nwankwo and Akinsoji, 1992). The highest amount of rainfall recorded at Ipa Itako creek in June and July 2010, probably accounts for decrease in salinity values which is in accordance with observation made by Adesalu and Nwankwo (2008). Increased total suspended solids and lower transparency values recorded at the peak of wet season with high volume of rainfall confirmed the work of Adesalu et al. (2010) who stated that increased total suspended solids and reduced transparency values lower photosynthetic rate of phyto-plankton. According to Nwankwo and Akinsoji (1988), phos-phate-phosphorus alone or in combination with nitrate-nitrogen favoured the growth of *Navicula* and *Nitzschia* which were observed in this study and probably suggests high concentration of organic nitrogenous materials. Similarly, The presence and dominance of diatoms in the sampling areas conform with observation made by Nwadiaro (1990) in the Chanomi creek system of the Niger Delta, Chindah and Pudo (1991) in Bonny

**Table 1.** Physico-chemical analysis results of the surface water at Ipa-Itako through out sampling period (Wet months: May-October Dry month:November-April).

| Parameter | February 2010 | | | March 2010 | | | April 2010 | | | May 2010 | | | June 2010 | | | July 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Surface Water temperature (°C) | 31.5 | 31.7 | 31.2 | 29.8 | 30.1 | 29.9 | 29.0 | 29.4 | 28.5 | 31.5 | 31.4 | 31.5 | 28.3 | 29.0 | 28.7 | 26.5 | 26.2 | 26.4 |
| Transparency (cm) | 118.9 | 128.1 | 137.2 | 214.3 | 225.6 | 146.3 | 29.0 | 36.0 | 31.0 | 182.9 | 134.6 | 152.4 | 50.8 | 48.3 | 38.1 | 26.0 | 29.0 | 34.0 |
| pH | 7.0 | 7.0 | 7.0 | 7.6 | 7.3 | 7.0 | 7.4 | 7.5 | 7.2 | 7.6 | 7.5 | 7.5 | 8.0 | 7.7 | 7.5 | 7.0 | 8.4 | 8.3 |
| Conductivity (us cm) | 20.0 | 20.0 | 20.0 | 13.10 | 20.0 | 20.0 | 15.06 | 20.0 | 20.0 | 19.14 | 19.29 | 17.5 | 2.56 | 2.27 | 1.09 | 0.05 | 0.29 | 0.24 |
| Total Suspend Solids (mg/L) | 3.0 | 2.20 | 2.0 | 1.20 | 1.50 | 2.70 | 2.20 | 3.70 | 2.0 | 2.70 | 3.50 | 1.50 | 1.10 | 1.30 | 1.50 | 1.00 | 2.20 | 2.40 |
| Total Dissolved Solids (Mg L) | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 10.0 | 7.62 | 10.0 | 10.0 | 9.55 | 9.61 | 8.78 | 0.79 | 1.12 | 0.55 | 0.02 | 0.140.12 | 0.12 |
| Lead (mg L) | 0.06 | 0.04 | 0.05 | 0.06 | 0.05 | 0.07 | 0.03 | 0.02 | 0.05 | 0.29 | 0.31 | 0.03 | 0.01 | 0.10 | 0.02 | 0 | 0 | 0 |
| Copper (mg/L) | 2.90 | 3.27 | 3.10 | 2.92 | 3.36 | 3.29 | 5.60 | 4.70 | 4.20 | 4.60 | 4.44 | 3.70 | 4.50 | 5.50 | 4.60 | 3.60 | 4.21 | 3.60 |
| Mercury (mg/L) | ND | ND | ND | ND | ND | ND | nd | nd | nd | ND | ND | ND | nd | nd | nd | ND | ND | ND |
| Silica (mg/L) | 0.20 | 0.34 | 0.22 | 0.23 | 0.35 | 0.24 | 0.30 | 0.44 | 0.29 | 0.04 | 0.30 | 0.009 | 0.22 | 0.14 | 0.17 | 0.05 | 0.04 | 0.019 |
| Dissolved Oxygen (mg/L) | 5.40 | 5.00 | 5.50 | 5.10 | 5.20 | 5.20 | 5.50 | 5.70 | 5.00 | 5.00 | 5.20 | 5.40 | 5.20 | 5.00 | 5.10 | 5.00 | 5.10 | 5.00 |
| Biological Oxygen Demand (mg/L) | 9.0 | 10.0 | 9.0 | 8.0 | 9.0 | 6.0 | 11.0 | 9.0 | 8.0 | 10.0 | 7.0 | 6.0 | 9.0 | 8.0 | 9.0 | 10.0 | 9.0 | 11.0 |
| Chemical Oxygen Demand (mg/L) | 12.0 | 10.0 | 9.0 | 10.0 | 12.0 | 8.0 | 14.0 | 12.0 | 10.0 | 13.0 | 11.0 | 13.0 | 14.0 | 11.0 | 15.0 | 14.0 | 12.0 | 15.0 |

| Parameter | August 2010 | | | September 2010 | | | October 2010 | | | November 2010 | | | December 2010 | | | January 2011 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| Surface Water temperature (°C) | 26.7 | 26.6 | 26.6 | 27.1 | 27.1 | 27.2 | 27.5 | 27.6 | 27.9 | 28.0 | 27.6 | 27.5 | 28.6 | 28.3 | 28.2 | 27.3 | 26.9 | 26.7 |
| Transparency (cm) | 54.0 | 80.0 | 79.0 | 70.0 | 54.0 | 59.0 | 41.0 | 55.0 | 44.0 | 48.0 | 41.0 | 42.0 | 74.0 | 82.0 | 67.0 | 140.0 | 141.0 | 102.0 |
| pH | 8.4 | 8.4 | 8.6 | 6.8 | 7.2 | 7.2 | 7.2 | 7.2 | 7.1 | 6.8 | 7.2 | 7.2 | 6.5 | 6.5 | 6.5 | 6.7 | 6.6 | 6.8 |
| Conductivity (us cm) | 0.62 | 0.58 | 0.14 | 0.04 | 0.05 | 0.18 | 0.07 | 0.08 | 0.08 | 0.00 | 0.08 | 0.09 | 1.26 | 2.19 | 1.20 | 8.43 | 14.06 | 10.46 |
| Total Suspend Solids (mg/L) | 1.10 | 1.00 | 1.00 | 1.40 | 1.10 | 1.20 | 1.10 | 1.20 | 1.10 | 1.40 | 1.10 | 1.20 | 1.00 | 1.10 | 2.10 | 1.20 | 1.10 | 1.OO |
| Total Dissolved Solids (Mg L) | 0.31 | 0.30 | 0.21 | 0.02 | 0.02 | 0.09 | 0.04 | 0.04 | 0.04 | 0.00 | 0.04 | 0.04 | 0.63 | 1.16 | 0.59 | 4.16 | 7.05 | 5.25 |
| Lead (mg L | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.02 | 0.03 | 0.001 | ND | ND | ND |
| Copper (mg/L | 1.20 | 0.70 | 1.50 | 1.40 | 1.20 | 1.30 | 1.10 | 1.30 | 1.12 | 1.40 | 1.20 | 1.30 | 1.23 | 1.10 | 1.04 | 2.00 | 2.10 | 1.60 |
| Mercury (mg/L) | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND |
| Silica (mg/L) | 0.20 | 0.34 | 0.22 | 0.23 | 0.35 | 0.24 | 0.30 | 0.44 | 0.29 | 0.40 | 0.30 | 0.009 | 0.22 | 0.14 | 0.17 | 0.05 | 0.04 | 0.019 |
| Dissolved Oxygen (mg/L) | 0.02 | 0.04 | 0.03 | 0.02 | 0.04 | 0.02 | 0.01 | 0.11 | 0.03 | 0.02 | 0.04 | 0.01 | 0.21 | 0.14 | 0.02 | 0.01 | 0.01 | 0.02 |
| Biological Oxygen Demand (mg/L) | 7.0 | 8.0 | 9.0 | 9.0 | 8.0 | 9.0 | 11.0 | 13.0 | 11.0 | 9.0 | 8.0 | 9.0 | 10.0 | 11.0 | 10.0 | 12.0 | 10.0 | 11.0 |
| Chemical Oxygen Demand (mg/L) | 10.0 | 12.0 | 11.0 | 15.0 | 13.0 | 12.0 | 14.0 | 16.0 | 13.0 | 15.0 | 13.0 | 12.0 | 12.0 | 13.0 | 12.0 | 15.0 | 14.0 | 13.0 |

mercury-in-glass thermometer and recorded in degree Celsius (°C). *In situ* measurement of transparency and salinity were determined using 20 cm diameter Secchi disc and handheld refractometer respectively. Total suspended solids (TSS) and total dissolved solids were estimated using gravimetric method (APHA, 1998). The pH was determined using a Cole Parmer Testr3 while conductivity values were measured using Philip PW9505 conductivity meter. Dissolved oxygen, chemical oxygen demand and

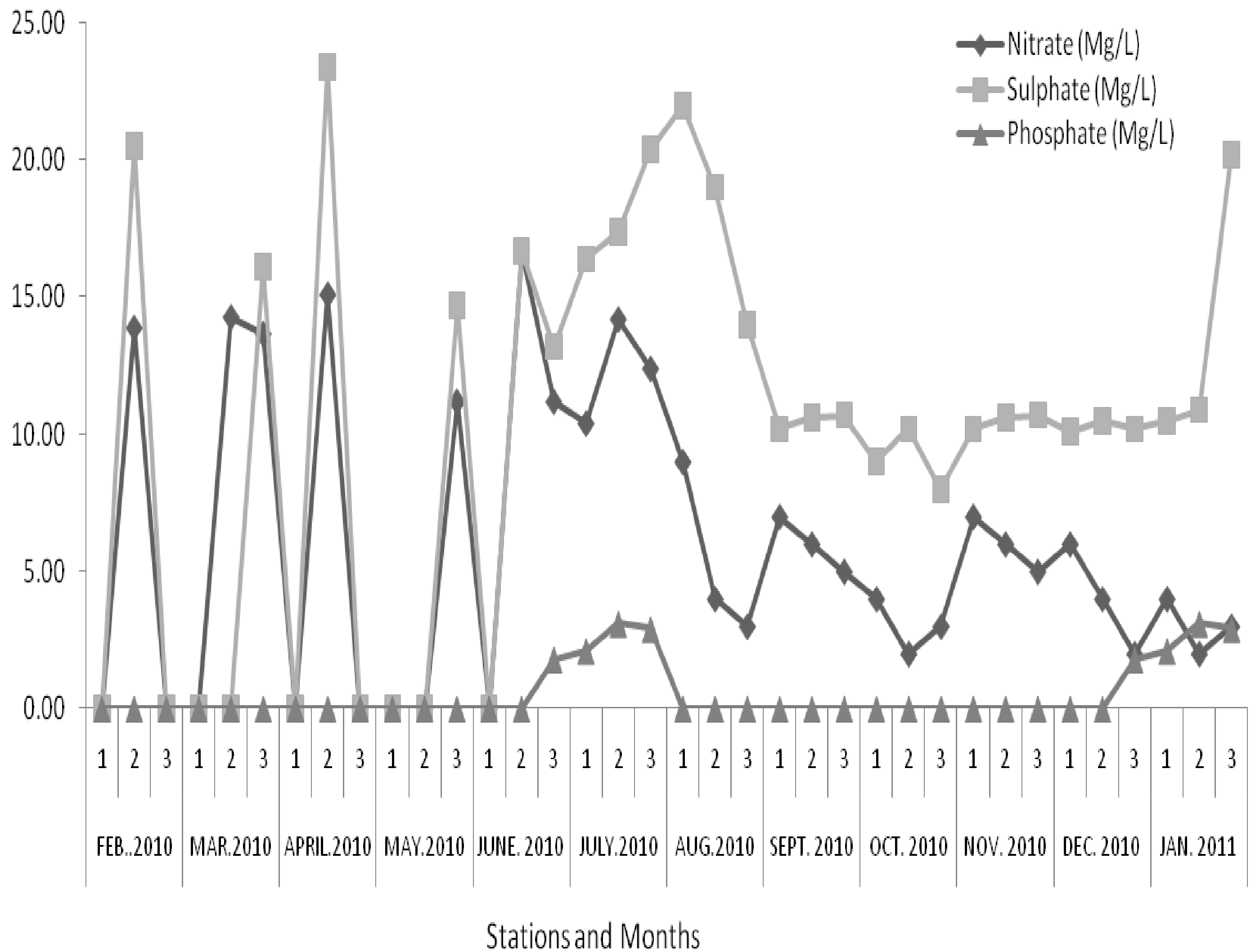


**Figure 2.** Temporal distribution of dissolved inorganic nutrients at Ipa-Itako.

River, Erondu and Chindah (1991) in the new Calabar River, Niger Delta, Adesalu and Nwankwo (2005, 2008) in Olero and Abule Eledu creek respectively, Adesalu et al. (2008) in Ogbe creek and Nwankwo (1986, 1991) in the Lagoons of South western Nigeria. The presence and abundance of *Oscillatoria* sp. among the blue-green supported Nwankwo (2004) who stated that the blue green algal forms found in the creek were mostly filamentous forms and could be opportunistic forms which by biomodification of physical processes usually proliferate to advantages of other species. Akpata et al. (1993), Chukwu and Nwankwo (2004) reported that the creeks and lagoons of South-western Nigeria, apart from their more ecological and economic significance, serve as sink for the disposal of an increasing array of waste types. Sewage, wood waste, refine oil, waste heat, municipal and industrial effluents among others find their way unabated into immediate coastal waters through conduits such as storm water channel, rivers, creeks and lagoons. The presence of *Coscinodiscus, Oscillatoria limosa* and *Euglena acus* were indications that probably Ipa Itako creek is organically polluted. This agrees with the finding of Palmer (1969) that some euglenoids can tolerate various levels of organically polluted waters therefore they can be used as biological indicators of pollution. Adesalu and Nwankwo (2008) also stated *Oscillatoria limosa* as biological indicator of organically polluted environment. Variations in the appearance of different species in relation to months and time of the year could be attributed to the observation of past characteristics, such that during the rainy season, an immerse volume of fresh water passes through the harbour and out into the sea whereas during the dry season, the flow of fresh water ceases and sea water enters the harbour giving rise to marine conditions near the harbour mouth and to brackish water extending to

**Table 2.** Phytoplankton composition at Ipa-Itako creek.

| S/N | Classification | February 2010 | | | March 2010 | | | April 2010 | | | May 2010 | | | June 2010 | | | July 2010 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Division:Bacillariophyta** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
| | **Class: Bacillariophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order: Achnanthales** | | | | | | | | | | | | | | | | | | |
| | **Family:Catenulaceae** | | | | | | | | | | | | | | | | | | |
| 1 | *Achnanthes lanceolata* (Breb) Grun. | | | | | | | | | | | | | | | | | | |
| | **Family: Catenulaceae** | | | | | | | | | | | | | | | | | | |
| 2 | *Amphipleura pallucida* Kutzing | | | | | | | | | | | | | | | | | | |
| 3 | *Amphora custata* Hust. | | | | | | | | | | | | | | | | | | |
| 4 | *A. holsatica* Hustedt | | | | | | | | | | | | | | | | | | |
| 5 | *A. microcephala* Kutzing | | | | | | | | | | | | | | | | | | |
| 6 | *A. pediculus* var.minor Grun. | | | | | | | | | | | | | | | | | | |
| 7 | *Amphora* sp | | | | | | | | | | | | | | | | | | |
| | **Order: Fragilariaceae** | | | | | | | | | | | | | | | | | | |
| | **Family: Fragilaraceae** | | | | | | | | | | | | | | | | | | |
| 8 | *Asterionella ralfsii* W.Sm | | | | 1 | | | 2 | | | | | | | | 1 | | | |
| 9 | *Fragilaria construens* Her. | | | 1 | 2 | 4 | | | 1 | 1 | | | 3 | 1 | 1 | | | 1 | 3 |
| 10 | *F. virescenses* Ralf. | | | | | | | | | | | | | | | | | | |
| 11 | *Fragilaria* sp. | | | | | | | | | | | | | | | | | | |
| 12 | *Synedra delicatissima* W.Sm | | 2 | 2 | | | 2 | | | 1 | | 3 | | 1 | | 4 | 2 | | |
| 13 | *Synedra* sp. | | 1 | 3 | | | 1 | | | | | | | | | | | | |
| 14 | *Ulnaria ulna* (*Nitzsch*) Ehrenberg | | | | | | | | | | | | | | | | | | 1 |
| | **Order: Bacillariales** | | | | | | | | | | | | | | | | | | |
| 15 | *Bacillaria paradoxa* Gmelin | | | 2 | 4 | 9 | 5 | | | 3 | 1 | 4 | 5 | 2 | | 1 | | 4 | 3 |
| 16 | *Nitzschia ignorata* Krasske | | | | | | | | | | | | | | | | | | |
| 17 | *N. obtusa* W.Sm. | | | | | | | | | | | | | | | | | | |
| 18 | *Nitzschia palae* (Kutzing) Wm Smith | 2 | 2 | 6 | 12 | 6 | 4 | 2 | 1 | 3 | 2 | | 2 | 1 | | | | 1 | 4 |
| | **Family: Cocconeidaceae** | | | | | | | | | | | | | | | | | | |
| 19 | *Cocconeis placentula* var. lineatus | | | | | | | | | | | | | | | | | | |
| 20 | *Cocconeis* sp | | | | | | | | | | | | | | | | | | |
| | **Family: cymbellellaceae** | | | | | | | | | | | | | | | | | | |
| 21 | *Cymbella affinis* Ehr | | | | | | | | | | | | | | | | | | |
| 22 | *C. aspersa* (Ehr) Cleve | | | 1 | | 1 | 4 | | 2 | 1 | | | | 3 | 2 | 2 | 2 | | |
| 23 | *C. ehrenbergii* Kutz | | | | | | | | | | | | | | | | | | |
| 24 | *C. gracilis* (Rabh) Cleve | | | | | | | | | | | | | | | | | | |
| 25 | *C. lanceolata* (Ehr) van | | | | | | | | | | | | | | | | | | |
| 26 | *C. obtuse* (Kutz) Grun | | | 1 | 1 | | 2 | 4 | 6 | 3 | 3 | 1 | 2 | 4 | 7 | 6 | | | |

**Table 2.** Contd.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 27 | *C. reinhardii* Krammer | | | | | | | | | | | | | | | | | | |
| 28 | *C. silesiaca* Bleisch. | | | | | | | | | | | | | | | | | | |
| 29 | *Cymbella* sp | | | | | | | | | | | | | | | | | | |
| | **Family: Eunotiaceae** | | | | | | | | | | | | | | | | | | |
| 30 | *Eunotia elegans* Øestrup | | | | | | | | | | | | | | | | | | |
| 31 | *E. pectinalis* var minor (Kutz)Rabh. | | | | | | | | | | | | | | | | | | |
| | **Family: Gomphonemataceae** | | | | | | | | | | | | | | | | | | |
| 32 | *Gomphonema* sp. | | | | | | | | | | | | | | | | | | |
| | **Order: Naviculales** | | | | | | | | | | | | | | | | | | |
| | **Family: Naviculaceae** | | | | | | | | | | | | | | | | | | |
| 33 | *Frustulia rhomboids* (Ehr.) de Toni | | | | 1 | | 2 | | | | 2 | | 1 | | | | 1 | | |
| 34 | *Gyrosigma acuminatum* (Kutzing) Rabh | | | | | | | | | | | | | | | | | | |
| 35 | *Luticola mutica* (Kutzing) | 2 | 4 | 5 | 2 | 9 | 8 | 5 | 9 | 12 | 4 | 6 | 2 | 5 | 2 | 7 | 8 | 5 | 9 |
| 36 | *Navicula cryptocephala* Kutz. | | | | | | | | | | | | | | | | | | |
| 37 | *N. exigua* (Greg) O. Mulla | 2 | 4 | 10 | 1 | | 4 | 2 | | | 3 | | | | 2 | 2 | 3 | 1 | 1 |
| 38 | *N. gracilis* Hautzsh | | | | | | | | | | | | | | | | | | |
| 39 | *N. muralis* Gum | 2 | 5 | 7 | 3 | 7 | 10 | 5 | 6 | 6 | 8 | 11 | 9 | 9 | 3 | 5 | 8 | 6 | 8 |
| 40 | *Navicula* sp. | | | | | | | | | | | | | | | | | | |
| 41 | *Neidium* sp | | | | | | | | | | | | | | | | | | |
| 42 | *Perlibellus berkeleya* (Kutz)E.. J Cox | 2 | | 3 | 1 | 4 | 4 | | 5 | 2 | 2 | | | 1 | 3 | | | | 1 |
| 43 | *Pinnularia acrosphaeria* Breb. | | | | | | | | | | | | | | | | | | |
| 44 | *P. biceps* Gregory | | | | | | | | | | | | | | | | | | |
| 45 | *P. braunii* (Grun) Cleve | | | | | | | | | | | | | | | | | | |
| 46 | *P. substomatophora* Hust | 1 | 2 | | 2 | | 4 | | | 3 | 5 | 5 | 9 | 6 | 2 | 4 | 6 | 2 | 2 |
| 47 | *Pinnularia* sp. | | | | | | | | | | | | | | | | | | |
| 48 | *Plaurosigma strigosum* W. Sm. | | | | | | | | | | | | | | | | | | |
| 49 | *Pleurosigma* sp | | | | | | | | | | | | | | | | | | |
| | **Family: Surirellaceae** | | | | | | | | | | | | | | | | | | |
| 50 | *Surirella* sp. | | | | | | | | | | | | | | | | | | |
| | **Order: Tabellariales** | | | | | | | | | | | | | | | | | | |
| | **Family: Tabellariaceae** | | | | | | | | | | | | | | | | | | |
| 51 | *Tabellaria fenestrate* (Lyng) Kutzing | | | | | | | | | | | | | | | | | | |
| 52 | *T. flocculosa* (Roth) Kut | 2 | | 3 | | 5 | 3 | | 7 | 2 | 4 | | 3 | 2 | | 3 | 1 | | 2 |
| | **Family: Stephanodiscaceae** | | | | | | | | | | | | | | | | | | |
| 53 | *Coscinodiscus centralis* Ehrenberg | 2 | 12 | 8 | 2 | 4 | 2 | | | 6 | 9 | 3 | 2 | | | | | | |
| 54 | *Cyclotella meneghiana* Kutzing | 1 | 3 | 6 | 2 | 3 | 4 | 2 | | | | | | | | | | | |
| 55 | *Diatomell* sp | | | | | | | | | | | | | | | | | | |

**Table 2.** Contd.

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Family: Diplodaceae** | | | | | | | | | | | | | | | | | |
| 56 | *Diploneis puella* (Schum) Cleve | | | | | | | | | | | | | | | | | |
| | **Family: Melosiraceae** | | | | | | | | | | | | | | | | | |
| 57 | *Melosira moniliformis* (OFM) Agardh | 2 | 6 | 4 | 9 | 6 | 10 | 2 | 4 | 8 | 2 | 5 | 7 | | 2 | 5 | 3 | 4 |
| | **Class: Cyanophyceae** | | | | | | | | | | | | | | | | | |
| | **Order I: Oscillatoriales** | | | | | | | | | | | | | | | | | |
| 58 | *Oscillatoria formosa* Bory | | 3 | | | 2 | | | | | | 2 | | 3 | | | | |
| 59 | *O. borneti* | 2 | 3 | 9 | | | | | | | | | | 2 | | | | |
| 60 | *O. limosa* (Roth). Ag | | 1 | 2 | 2 | | | | | | | | | 1 | | | | |
| 61 | *Spirulina laxa* G.m Smith | 2 | 3 | 1 | 6 | 5 | | | | 6 | | 2 | | 6 | 2 | | 6 | |
| 62 | *Spirulina* sp. | | | | | | | | | | | | | | | | | |
| 63 | *Pseudophormidium* sp. | | | | | | | | | | | | | | | | | |
| | **Order II: Chroococcales** | | | | | | | | | | | | | | | | | |
| 64 | *Chroococcus turicensis* (Nag) Hansgirg | | 3 | 1 | 2 | | | | | | | | | 1 | | | | |
| 65 | *Gleocapsa granosa* (Berk.) Kutz.. | | | | 2 | 2 | | | | | | | | 3 | | | | |
| 66 | *Microcystis aeruginosa* Nag | | | | 2 | 1 | | | | 2 | | | | 2 | 1 | | | |
| | **Class: Chlorophyceae** | | | | | | | | | | | | | | | | | |
| | **Order I Chlorococcales** | | | | | | | | | | | | | | | | | |
| 67 | *Ankistrodesmus falcatus* G.S West | 1 | 2 | 4 | 2 | 1 | | | | | | | | 2 | 2 | | | 2 |
| 68 | *Chaetosphaeridium globosum* (Nordst) Kleb. | | | | | | | | | | | | | | | | | |
| 69 | *Chaetosphaeridium* sp | | | | | | | | | | | | | | | | | |
| 70 | *Chlorella vulgaris* Beyerinck | | | 2 | 4 | 2 | | | | 4 | | | | 3 | | | | 5 |
| 71 | *Coelastrum* sp | | | | | | | | | | | | | | | | | |
| 72 | *Hyalotheca* sp | | | | | | | | | | | | | | | | | |
| 73 | *Pleurotanium* ovatum | | | | | | | | | | | | | | | | | |
| 74 | *Pithophthora* sp. | | | | | | | | | | | | | | | | | |
| 75 | *Scenedesmus bijuga* (Turp) Lagerheim | | | 3 | | 1 | | | | | | | | 2 | | | | 2 |
| 76 | *S. obliquus* (Turp) Kutzing | | | 3 | 6 | 5 | | | | 5 | | 4 | | 4 | 6 | | | 7 |
| 77 | *Treubaria* sp | | | | | | | | | | | | | | | | | |
| | **Order II: Desmidiales** | | | | | | | | | | | | | | | | | |
| 78 | *Closterium gracile* Breb. | | | | | | | | | | | | | | | | | |
| 79 | *C. incurvum* Breb | | | | | 1 | | | | 3 | | | | 4 | | | | 2 |
| 80 | *C. moniliferum* Her. | | | | | | | | | | | | | | | | | |
| 81 | *C. setaceum* Ehrenb. | | | | 2 | 4 | | | | 1 | | 2 | | 4 | | | | 3 |
| 82 | *C. venus* Kutz | 2 | | | 2 | 3 | | | | 1 | | 1 | | | 3 | | | 5 |
| 83 | *Closterium* sp. | | | | | | | | | | | | | | | | | |
| 84 | *Cosmarium dentatum* Wolle | | 2 | 1 | 2 | 4 | | | | | | | | 4 | 2 | | | |
| 85 | *C. mobiliforme* (Turp) Ralfs | | 2 | 1 | 2 | 4 | | | | 4 | | | | | 2 | | | |

**Table 2.** Contd.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 86 | *C. pseudobroomei* Wolle | 1 | 1 | 3 | | 2 | | | | 4 | | 2 | | | 4 | | | | |
| 87 | *Gonatozygon aculeatum* Hastings | | | 2 | 2 | 1 | | | | | | | | | 1 | | | | |
| 88 | *Penium cylindrus* (Her.) Breb. | | | | | 2 | | | | | | | | 2 | | | | | |
| | **Order III: Ulothricales** | | | | | | | | | | | | | | | | | | |
| 89 | *Ulothrix zonata* (Weber & Mohr) Kutz. | | 2 | 4 | | 4 | | | | | | | | 4 | 2 | | | | |
| | **Class: Euglenophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order: Euglenales** | | | | | | | | | | | | | | | | | | |
| 90 | *Euglena proxima* Dang | 2 | 2 | | 3 | | | | | 3 | | | | 1 | | | | | |
| 91 | *E. acus* Ehrenberg | 2 | 1 | | 4 | 3 | | | | | | | | | 2 | | | 3 | |
| 92 | *Phacus triqueter* Playfair | | 1 | 4 | 3 | | | | | | | 2 | | 4 | 5 | | | 5 | |
| | **Class: Xanthophyceae** | | | | | | | | | | | | | | | | | | |
| 93 | *Vaucheria* sp. | | | | | | | | | | | | | | | | | | |
| | Total Number of Species (s) | 17 | 23 | 29 | 30 | 29 | 16 | 8 | 9 | 23 | 12 | 16 | 11 | 28 | 21 | 11 | 10 | 22 | 12 |
| | Total Number of I ndividuals (N) | 30 | 67 | 95 | 89 | 105 | 69 | 24 | 41 | 84 | 45 | 58 | 42 | 84 | 56 | 40 | 36 | 79 | 39 |
| | Margalef Species Diversity (d) | 4.70 | 5.23 | 6.15 | 6.46 | 6.02 | 3.54 | 2.20 | 2.15 | 4.97 | 2.89 | 3.69 | 2.68 | 6.09 | 4.97 | 2.71 | 2.51 | 4.81 | 3.00 |
| | Shannon- Weaver (H) | 2.80 | 2.90 | 3.15 | 3.16 | 3.18 | 2.60 | 1.99 | 2.01 | 2.92 | 2.30 | 2.52 | 2.21 | 3.71 | 1.55 | 2.25 | 2.06 | 2.95 | 2.21 |
| | Species Evenness (j) | 0.99 | 0.93 | 0.94 | 0.93 | 0.95 | 0.94 | 0.96 | 0.91 | 0.93 | 0.93 | 0.91 | 0.92 | 0.95 | 0.51 | 0.94 | 0.90 | 0.95 | 0.89 |

| **S/N** | **Classification** | **August2010** | | | **September 2010** | | | **October 2010** | | | **November 2010** | | | **December 2010** | | | **January 2011** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Division: Bacillariophyta** | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| | **Class: Bacillariophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order: Achnanthales** | | | | | | | | | | | | | | | | | | |
| | **Family: Catenulaceae** | | | | | | | | | | | | | | | | | | |
| 1 | *Achnanthes lanceolata* (Breb) Grun. | | | | | | | | | | 3 | | 22 | | | | | | |
| | **Family: Catenulaceae** | | | | | | | | | | | | | | | | | | |
| 2 | *Amphipleura pallucida* Kutzing | | 3 | | | | | 2 | | 5 | | 5 | 19 | | | | | | |
| 3 | *Amphora custata* Hust. | | | | | | | | | | | | | | 1 | | | | |
| 4 | *A. holsatica* Hustedt | | | | | | | | | | | 1 | | | | | | | |
| 5 | *A. microcephala* Kutzing | | | | | | | | | | | 1 | | | | | | | |
| 6 | *A. pediculus* var.minor Grun. | | | | | | | | | 1 | | | | | | | | | |
| 7 | *Amphora* sp | | | | | | | | | | | | | | | 3 | | | |
| | **Order: Fragilariaceae** | | | | | | | | | | | | | | | | | | |
| | **Family :Fragilaraceae** | | | | | | | | | | | | | | | | | | |
| 8 | *Asterionella ralfsii* W.Sm | | | | | | | | | | | | | | | | | | |
| 9 | *Fragilaria construens* Her. | | | | | | | | | | | | | | | | | | |
| 10 | *F. virescenses* Ralf. | | | | | | | 15 | | 1 | | | | | | | | | |
| 11 | *Fragilaria* sp. | | | | | | | | | | 218 | 1200 | 120 | 167 | 586 | 40 | | | |
| 12 | *Synedra delicatissima* W. Sm | | | | | | | | | | | | | | | | | | |

**Table 2.** Contd.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | *Synedra* sp. | | | | 1 | | 16 | | | 12 | 2 | 8 | 132 | 1 | | | 34 | 20 | |
| 14 | *Ulnaria ulna* (Nitzsch) Ehrenberg | | | | | | | | | | | | | | | | | | |
| | **Order: Bacillariales** | | | | | | | | | | | | | | | | | | |
| 15 | *Bacillaria paradoxa* Gmelin | | | | | | | | | | | | | | | | | | |
| 16 | *Nitzschia ignorata* Krasske | | | | | | | | | | | | | | 5 | | 2 | | |
| 17 | *N. obtusa* W.Sm. | | | | | | | | | 10 | | 1 | | 1 | | | | | |
| 18 | *Nitzschia palae* (Kutzing) Wm Smith | | | | | 2 | | | | | | | | | | | | | |
| | **Family: Cocconeidaceae** | | | | | | | | | | | | | | | | | | |
| 19 | *Cocconeis placentula* var. lineatus | | | 131 | | | | | | | | | | | | | | | |
| 20 | *Cocconeis* sp | | | | | | | | | | | 2 | 21 | | | | | | |
| | **Family: cymbellellaceae** | | | | | | | | | | | | | | | | | | |
| 21 | *Cymbella affinis* Ehr | | | | | | | | | | | 1 | | | | | | | |
| 22 | *C. aspersa* (Ehr) Cheve | | | | | | | | | | | | | | | | | | |
| 23 | *C. ehrenbergii* Kutz | | | | | | | | | | | | | 12 | | 4 | | | |
| 24 | *C. gracilis* (Rabh) Cleve | | | | | | | | | 1 | | | | | | | | | |
| 25 | *C. lanceolata* (Ehr) van | | | | | | | | | 5 | | | | | | | | | |
| 26 | *C. obtuse* (Kutz) Grun | | | | | | | | | | | | | | 5 | | | | |
| 27 | *C. reinhardii* Krammer | | | | | | | | | | | | 1 | | | | | | |
| 28 | *C. silesiaca* Bleisch. | 4 | | 12 | | | | | | | | | | | | | | | |
| 29 | *Cymbella* sp | | | | | | | | | 12 | | | | | 1 | | | | 1 |
| | **Family: Eunotiaceae** | | | | | | | | | | | | | | | | | | |
| 30 | *Eunotia elegans* 0estrup | | | | | 3 | | | | | | | | | 1 | | | | 1 |
| 31 | *E. pectinalis* var minor (Kutz)Rabh. | | | | | | | | | 2 | | | | | | | | | |
| | **Family: Gomphonemataceae** | | | | | | | | | | | | | | | | | | |
| 32 | *Gomphonema* sp. | | | | | | | 1 | | 2 | | | | | | 1 | | | |
| | **Order: Naviculales** | | | | | | | | | | | | | | | | | | |
| | **Family: Naviculaceae** | | | | | | | | | | | | | | | | | | |
| 33 | *Frustulia rhomboids* (Ehr.) de Toni | | | | | | | | 2 | 1 | | | | | | | 6 | 38 | 6 |
| 34 | *Gyrosigma acuminatum* (Kutzing) Rabh | | | | | | 1 | 5 | | | | | | | 1 | | | 10 | 10 |
| 35 | *Luticola mutica* (Kutzing) | | | | | | | | | 3 | | | | | | | | | |
| 36 | *Navicula cryptocephala* Kutz. | | | | 1 | | | 1 | | 1 | | 1 | | | | | | | |
| 37 | *N. exigua* (Greg) O. Mulla | | | | | | | | | | | | | | | | | | |
| 38 | *N. gracilis* Hautzsh | | | | | | | | | 2 | | | | | 2 | | | | |
| 39 | *N. muralis* Gum | | | | | | | | | 2 | | | | | 2 | | | | |
| 40 | *Navicula* sp. | | | | | | | | 2 | | | | | 2 | | | | | |
| 41 | *Neidium* sp | | | | 3 | 3 | | | | | | | | | | | | | |
| 42 | *Perlibellus berkeleya* (Kutz)E.. J Cox | | | | | | | | | | | | | | | | | | |

**Table 2.** Contd.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | *Pinnularia acrosphaeria* Breb. | | | | | | | | | | | | | 1 | 8 | 31 | | | |
| 44 | *P. biceps* Gregory | | | | | | | | | 1 | | | | | | 5 | | | |
| 45 | *P. braunii* (Grun) Cleve | | | | | | | | | 5 | 1 | | | | | | | 1 | 6 |
| 46 | *p. substomatophora* Hust | | | | | | | | | | | | | | | | | | |
| 47 | *Pinnularia* sp. | | | | 1 | | | | | 1 | | 1 | | | 15 | | | | 1 |
| 48 | *Plaurosigma strigosum* W. Sm. | 1 | | | 1 | | | | | | 2 | 5 | 7 | | | | | 25 | 25 |
| 49 | *Pleurosigma* sp | | | | | | | | | | | | | | 38 | 5 | | | |
| | **Family: Surirellaceae** | | | | | | | | | | | | | | | | | | |
| 50 | *Surirella* sp. | 1 | | | 1 | | | | | | | | | | 5 | | | | 2 |
| | **Order: Tabellariales** | | | | | | | | | | | | | | | | | | |
| | **Family: Tabellariaceae** | | | | | | | | | | | | | | | | | | |
| 51 | *Tabellaria fenestrate* (Lyng) Kutzing | 2 | | | 1 | | 9 | 17 | 4 | 15 | 4 | 1 | 3 | 1 | 10 | 10 | | 47 | |
| 52 | *T. flocculosa* (Roth) Kut | | | | | | | | | | | | 1 | | 1 | | | | |
| | **Family : Stephanodiscaceae** | | | | | | | | | | | | | | | | | | |
| 53 | *Coscinodiscus centralis* Ehrenberg | | | | | | | | | | | 5 | 43 | | | | | | |
| 54 | *Cyclotella meneghiana* Kutzing | | | | | | 1 | | | | | | | | | | | | |
| 55 | *Diatomell* sp | | 3 | | | | | | | | | | | | | | | | |
| | **Family: Diplodaceae** | | | | | | | | | | | | | | | | | | |
| 56 | *Diploneis puella* (Schum) Cleve | | | | | | | | | 3 | | | | | | | | | |
| | **Family: Melosiraceae** | | | | | | | | | | | | | | | | | | |
| 57 | *Melosira moniliformis* (OFM) Agardh | | | | | | | 3 | | | 2 | 13 | 60 | 1 | | 10 | | | 1 |
| | **Class: Cyanophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order I: O scillatoriales** | | | | | | | | | | | | | | | | | | |
| 58 | *Oscillatoria formosa* Bory | | | | | | | | | | | | | | | | | | |
| 59 | *O. borneti* | | | | | | | | | | | | | | | | | | |
| 60 | *O . limosa* (Roth). Ag | | | | | | | | | | | | | | | | | | |
| 61 | *Spirulina laxa* G.m Smith | | | | | | | | | | | 6 | | 8 | 60 | 15 | | | |
| 62 | *Spirulina* sp. | | | | | | 150 | | | | | | | | | | | | |
| 63 | *Pseudophormidium* sp. | | | | | | | | | | | | | | | | | | |
| | **Order II: Chroococcales** | | | | | | | | | | | | | | | | | | |
| 64 | *Chroococcus turicensis* (Nag) Hansgirg | | | | | | | | | | | | | | | | | | |
| 65 | *Gleocapsa granosa* (Berk.) Kutz.. | | | | | | | | | | | | | | | | | | |
| 66 | *Microcystis aeruginosa* Nag | | | | | | | | | | | | | | | | | | |
| | **Class: Chlorophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order I Chlorococcales** | | | | | | | | | | | | | | | | | | |

**Table 2.** Contd.

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | *Ankistrodesmus falcatus* G.S West | | | | | | | | | | | | | | | | | | |
| 68 | *Chaetosphaeridium globosum* (Nordst) Kleb. | 1 | | | 300 | | | | | | | | | | | | | | |
| 69 | *Chaetosphaeridium* sp | 39 | 5 | | | | | | | | | | | | | | | | |
| 70 | *Chlorella vulgaris* Beyerinck | | | | | | | | | | | | | | | | | | |
| 71 | *Coelastrum* sp | 40 | | | | | | | | | | | | | | | | | |
| 72 | *Hyalotheca* sp | 1 | | | | | | | | | | | | | | | | | |
| 73 | *Pleurotanium ovatum* | | 7 | | 2 | | | 73 | 1 | 15 | | | | | | | | | |
| 74 | *Pithophthora* sp. | 83 | | | | | | | | | | | | | | | | | |
| 75 | *Scenedesmus bijuga* (Turp) Lagerheim | | | | | | | | | | | | | | | | | | |
| 76 | *S. obliquus* (Turp) Kutzing | | | | | | | | | | | | | | | | | | |
| 77 | *Treubaria* sp | | | | | | | 2 | | 2 | | | | | | | | | |
| | **Order II: Desmidiales** | | | | | | | | | | | | | | | | | | |
| 78 | *Closterium gracile* Breb. | | | | | | | | | | | | | | 1 | 5 | | | |
| 79 | *C. incurvum* Breb | | | | | | | | | | | | | | | | | | |
| 80 | *C . moniliferum* Her. | | | | 20 | | | 2 | 1 | | | | | | | | | | |
| 81 | *C. setaceum* Ehrenb. | | | 3 | 3 | | | | | | | | | | | | | | |
| 82 | *C. venus* Kutz | | | | | | | | | | | | | | | | | | |
| 83 | *Closterium* sp. | | | | | | | 29 | | | | | | | | | | | |
| 84 | *Cosmarium dentatum* Wolle | | | | | | | | | | | | | | | | | | |
| 85 | *C. mobiliforme* ( Turp) Ralfs | | | | | | | | | | | | | | | | | | |
| 86 | *C. pseudobroomei* Wolle | | | | | | | | | | | | | | | | | | |
| 87 | *Gonatozygon aculeatum* Hastings | | | | | | | | | | | | | | | | | | |
| 88 | *Penium cylindrus* (Her.) Breb. | | | | | | | | | | | | | | | | | | |
| | **Order III: Ulothricales** | | | | | | | | | | | | | | | | | | |
| 89 | *Ulothrix zonata* (Weber & Mohr) Kutz. | | | | | | | | | | | | | | | | | | |
| | **Class: Euglenophyceae** | | | | | | | | | | | | | | | | | | |
| | **Order: Euglenales** | | | | | | | | | | | | | | | | | | |
| 90 | *Euglena proxima* Dang | | | | | | | | | | | | | | | | | | |
| 91 | *E. acus* Ehrenberg | | | | | | | | | | | | | | | | | | |
| 92 | *Phacus triqueter* Playfair | | | | | | | | | | | | | | | | | | |
| | **Class: Xanthophyceae** | | | | | | | | | | | | | | | | | | |
| 93 | *Vaucheria* sp. | 3 | 1 | | | | | | | | | | | | | | | | |
| | Total Number of Species (s) | 10 | 5 | 3 | 13 | 2 | 5 | 10 | 5 | 22 | 7 | 16 | 10 | 9 | 17 | 11 | 3 | 6 | 9 |
| | Total Number of I ndividuals (N) | 175 | 19 | 146 | 338 | 8 | 178 | 145 | 10 | 100 | 232 | 1252 | 428 | 194 | 742 | 129 | 42 | 141 | 53 |
| | Margalef Species Diversity (d) | 1.74 | 1.36 | 0.40 | 2.06 | 0.48 | 0.77 | 1.81 | 1.74 | 4.56 | 1.10 | 2.10 | 1.49 | 1.52 | 2.42 | 2.06 | 0.54 | 1.01 | 2.01 |
| | Shannon- Weaver (H) | 1.35 | 1.46 | 0.38 | 0.55 | 0.66 | 0.59 | 1.48 | 1.47 | 2.64 | 0.33 | 0.27 | 1.78 | 0.62 | 0.91 | 1.96 | 0.59 | 1.53 | 1.59 |
| | Species Evenness (j) | 0.59 | 0.91 | 0.35 | 0.21 | 0.95 | 0.37 | 0.64 | 0.91 | 0.85 | 0.17 | 0.10 | 0.77 | 0.28 | 0.23 | 0.82 | 0.54 | 0.85 | 0.72 |

**Table 3.** Percentage composition of different classes of algae observed at the Ita-ipako stations.

| Class: | Feb. 2010 | Mar.2010 | April 2010 | May 2010 | June 2010 | July 2010 | Aug. 2010 | Sept. 2010 | Oct. 2010 | Nov. 2010 | Dec. 2010 | Jan. 2011 | Total Phytoplankton/Class (Cells/ml) | Percentage composition |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bacillariophyceae | 121 | 170 | 116 | 129 | 100 | 98 | 151 | 42 | 140 | 1910 | 946 | 236 | 4159 | 72.85 |
| Cyanophyceae | 23 | 35 | 38 | 37 | 21 | 44 | 0 | 0 | 150 | 6 | 83 | 0 | 437 | 7.65 |
| Chlorophyceae | 36 | 74 | 65 | 61 | 68 | 80 | 179 | 335 | 125 | 0 | 6 | 0 | 1029 | 18.02 |
| Euglenophyceae | 12 | 19 | 6 | 11 | 14 | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 80 | 1.40 |
| Xanthophyceae | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 | 0.07 |
| Total Phytoplankton/month (cells/ml) | 192 | 298 | 225 | 238 | 203 | 240 | 334 | 377 | 415 | 1916 | 1035 | 236 | | |
| Percentage Composition/month | 3.36 | 5.22 | 3.94 | 4.17 | 3.56 | 4.20 | 5.85 | 6.60 | 7.27 | 33.56 | 18.13 | 4.13 | | |

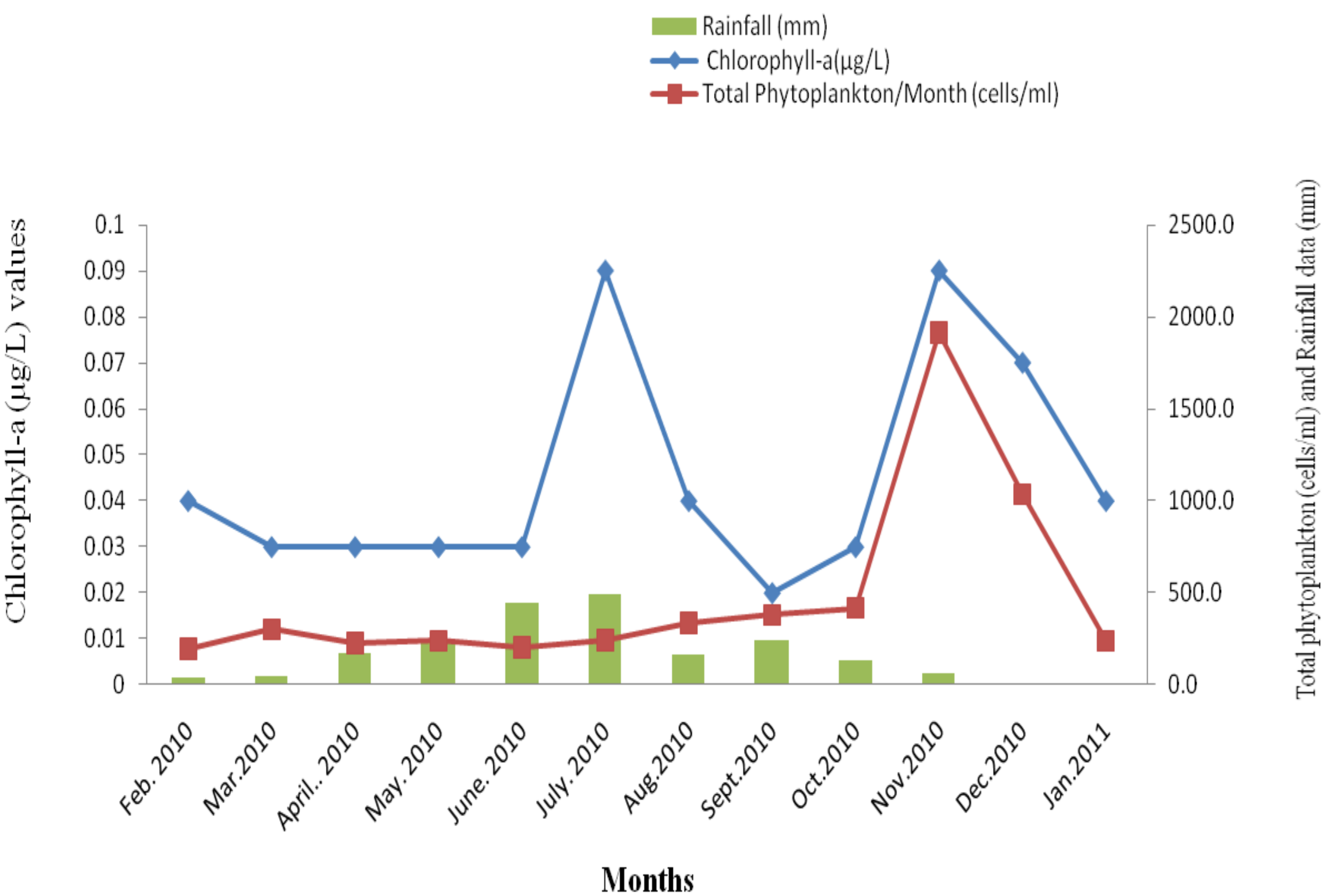


**Figure 3.** Variations between rainfall chlorophyll ‘a’ and total phytoplankton at Ipa-Itako.

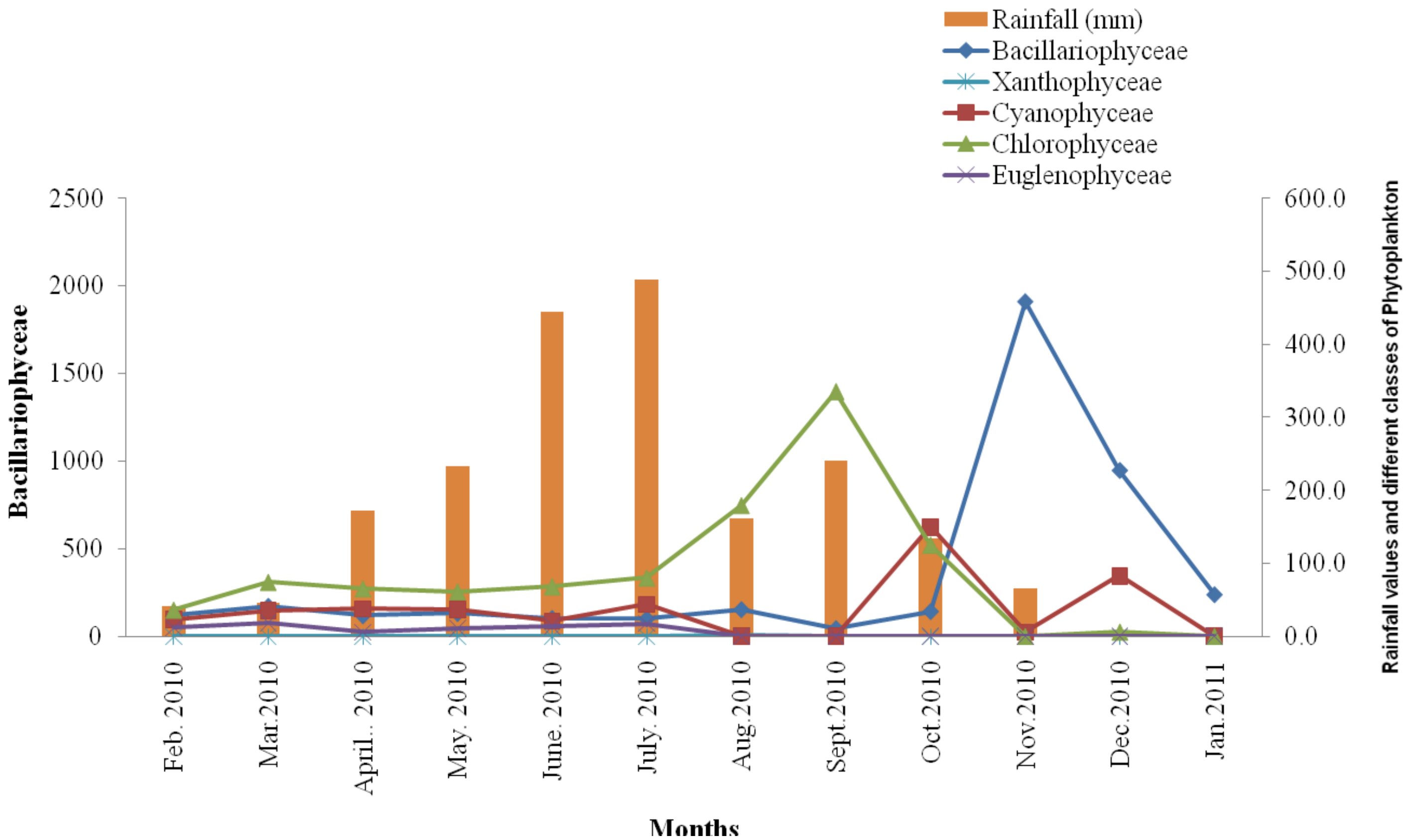


**Figure 4.** Temporal variations in rainfall data and different classes of phytoplankton at Ipa-Itako.

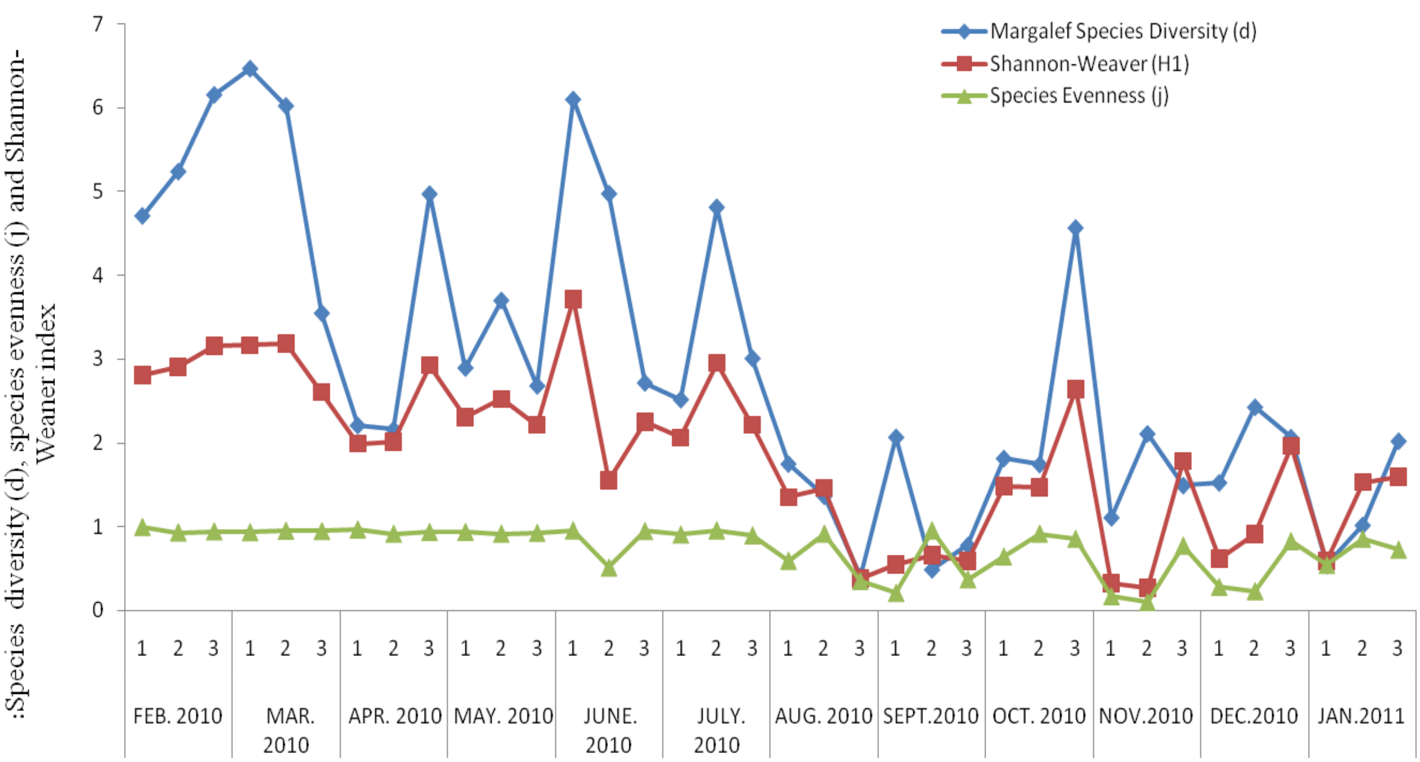


**Figure 5.** Relationship between community structure analysis at Ita-Ipako.

about 32 km up the lagoons and creeks. Thus, the organisms in this area are subjected to seasonal fluctuations from fresh water to brackish conditions. It is of note worthy that part of Ipa-Itako is undergoing construction now for expansion of Ikorodu road, hence this study served as baseline study and pre-construction data.

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# Biofuel potential and land availability: The case of Rufiji District, Tanzania

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**Africa's attractiveness to potential biofuel investors is based on the assumption that there is plenty of unused land available for investment in different countries of the continent. However, their postulations are not based on any concrete studies on land available at country, regional or local level. This study investigates land availability for potential biofuel investment at the local level, using Rufiji district in Tanzania as a case study. We have analyzed different land cover/land use types and separated them into areas of potential biofuel investment and areas where biofuel investment is not possible by a process of elimination. The results suggest that land available is inadequate to meet the needs of biofuel investors. The land assumed to be unused or underutilized by biofuel investors is either part of the fallow system or used to harvest natural resources and for other traditional uses. Expropriating the assumed idle land will have impact on the livelihoods of the local communities.**

**Key words:** Biofuel investment, land available, Rufiji District.

## INTRODUCTION

The alleged existence of abundant underutilized land in Africa has attracted biofuel investors from wealthy countries to the continent (Cotula et al., 2009; Madoffe et al., 2009). The assertion is part of a long held dogma, where African lands are perceived to be unoccupied and therefore in need of investments (Neville and Dauvergne, 2012). However, there is a huge difference between those assertions and the appraisal of land available for biofuel production according to the International Energy Agency (Haugen, 2010). The discrepancy between the assertions of the potential biofuel investors and the assessment by the International Energy Agency can be attributed to little research on land availability in Africa, and emphasizes the need for more research and more high quality data (Cotula et al., 2009; Ahlberg, 2011). Nevertheless, there are recent studies estimating land availability for biofuel production at the global level using both coarse resolution remote sensing data (Cai et al., 2011) and high resolution remote sensingdata (Fritz et al., 2013). Using high resolution remote sensing data, Fritz et al. (2013) substantially lowered the amount of estimated land available for biofuel production. Yet, the remote sensing studies have neither considered land availability at country, regional or local level, nor have

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they considered other activities that might be competing for land apart from biofuel production.

Sulle and Nelson (2009:7) define biofuels as “liquid, solid or gaseous fuels that are predominantly or exclusively produced from biomass”. In general, biofuels, such asbiodiesel, ethanol and biogas are derived from crops, plant residues or garbage. The acquisition of land for biofuel and biodiesel production has increased worldwide, in particular in Sub-Saharan Africa (Havnevik, 2009), where the acquisition has been received with mixed feelings. Some construe the biofuel sector as important in revolutionizing agriculture and alleviating poverty. Others are afraid that the biofuel sector will inevitably lead to harmful land use changes once the land is converted to estate agriculture (Martin et al., 2009; Schoneveld et al., 2011).

Biofuel production is also evolving as a critical policy matter in agricultural development and natural resources management (Sosovele, 2010). In most African countries, policy institutions are passive in decision making (Romijn and Caniëls, 2011), and at the advent of biofuel investment in Africa, most countries did not have policies in place to monitor and control biofuel investments. As a consequence, national and local government agencies were trapped in a confusing role between defending interests of the local people and those of the biofuel investors (Cotula et al., 2009). Moreover, in dealing with biofuel investors, local communities are at a disadvantage in protecting their interests, because they do not comprehend the full effects of biofuel investments (Beyene et al., 2013).

There is a belief that Tanzania will reap the benefits of biofuel investments in terms of capital, expertise and knowledge transfer (Kweka, 2012). In addition, it is hoped that biofuels will lessen the economic burden of importing petroleum, thus improving environmental conservation and livelihoods (Martin et al., 2009). The optimism in the benefits of biofuel investments has resulted in Tanzania becoming a major destination for potential biofuel investtors for the supposed existence of enormous unexploited lands (Habib-Mintz, 2010). However, Sulle and Nelson (2009) contend that land pursued for biofuel investment might be physically unoccupied but not unused. The land might be in fallow, or it may be common land used for example, charcoal production, and fuel wood and timber collection. If such land is lost to biofuel investment, not only will the livelihoods of the locals be affected, but this will also lead to shortened fallows that in turn will adversely affect soil fertility (Daley and Scott, 2011).

Despite all the optimism and potential of the biofuel sector, Tanzania lacks a coherent biofuel policy base (Sosovele, 2010). The existing policy does not address a wide range of energy options and has shaky institutional and legal frameworks. Under such circumstances, developing the biofuel industry will be a difficult task, some stakeholders in the biofuel sector have advised the government to halt the biofuel investments until appropriate policies are in place (Sosovele, 2010).

## Biofuel potential in Rufiji district

Rufiji district covers a total area of 13,339 km$^2$ according to official figures (URT, 2013). The population density is among the lowest of any district in Tanzania according to the 2012 census, with 16 inhabitants per km$^2$, against the national average of 51 inhabitants per km$^2$. These figures might present a picture of huge tracts being available for biofuel investment in Rufiji District.

The choice of Tanzania by a Swedish company, SEKAB (now taken over by Eco Energy, to be referred to as SEKAB/Eco Energy), was based on the presumed availability of apt land for large scale biofuel investment (Havnevik, 2009). Authors have quoted various figures regarding what SEKAB/Eco Energy intended to acquire in Rufiji district, ranging from 250,000 (Neville and Dauvergne, 2012) to 500,000 ha (Cotula et al., 2009). Another company, Africa Green Oil (AGO), was negotiating with six villages in Rufiji District for 30,000 ha of land. In the course of their negotiations, they settled on 5000 ha, of which in the end only 2800 ha were actually available (Neville and Dauvergne, 2012). In Nyamatanga, one of the villages where AGO acquired land, the local population have not only lost agricultural land, but also income generated from the selling of products they were collecting from the acquired land (Daley and Scott, 2011). The direct engagement of biofuel companies with the villages without any government oversight has left the local people in a precarious position as far as their interests are concerned (Beyene et al., 2013).

The AGO narrative (seeking 30,000 ha of land but finding that only 2800 ha were actually available) demonstrates that there is a huge gap between the biofuel investor’s wishes and the actual land available for biofuel investments. According to Mwakaje (2012), Rufiji district offers one of the best case studies for biofuel investments because it has attracted a considerable number of potential biofuel investors. This paper aims to investigate the hypothesis that there is abundant, idle or unused land that can be used for large scale biofuel production at the local level in developing countries like Tanzania. The study will therefore contribute to developing methods of assessing land availability for biofuel investments at the country, regional or local level supplementing those done at the global level.

## METHODOLOGY

### Study area

Rufiji District is located in the Coast (Pwani) Region (7°30’S to 8°40’S and 37°50’ to 39°40’E) in Eastern Tanzania and is dominated by the Rufiji River that runs almost in the middle of the district embracing the flood plain on both sides and an extensive mangrove delta at the river mouth (Figure 1)

Rufiji district is one of the six districts in the Coast Region of

Tanzania. About 75% of the region's economy comes from the agricultural sector, mostly managed by smallholder farmers who do not practice improved farming. As a result, yield per acre is relatively low. Rufiji district has 482,466 ha of arable land (20.7%) out of which only 90,000 is under active crop production (URT, 2007). FAO (2010, p. 17) defines arable land as "land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category". This is an important distinction, as potentially arable land, such as land under fallow for prolonged periods, is not included in the definition.

Livelihood schemes in Rufiji demonstrate a strong interconnecttion of activities between the floodplain, the forested areas in the north and south and the lakes located close to the flood plain (Hamerlynck et al., 2010). In principle, there are three agricultural systems: the flood plain agriculture, practiced by the majority; the delta agriculture and the hill agriculture. The latter is characterized by low fertility and low yields (Havnevik, 1983). In all three systems, shifting cultivation is practiced. In the delta, where mangroves are cleared for agriculture, sedges replace crops during fallow phases (Semesi, 1989). In forests, north and south of the floodplain, cultivated fields are left fallow for a period of two to three years (Durand, 2003), and also in the flood plains, where cultivation is presently expanding, shifting cultivation is practiced (Hamerlynck et al., 2010).

#### Data sources

The study is based mainly on a literature review and on secondary data, mostly obtained from authorities and NGOs and from government offices in the Rufiji district council. Semi structured interviews were also conducted with relevant government officials.

#### Land use/land cover

Land use/land cover digital maps and boundaries of protected areas (game and forest reserves) were obtained from the database at the Tanzania Natural Resources Information Centre (TANRIC) at the Institute of Resource Assessment, University of Dar es Salaam. Land use/land cover types are based on Landsat TM images of 1994/95 (Hunting Technical Services, 1997). Of 64 land use/land cover digital sheets at the scale of 1:250,000 covering Tanzania, Rufiji District is covered by four sheets. We have modified the original classification of land use/land cover types based on extensive field experience from working in Rufiji District. For example, classes such as dense bushland, open bushland, bushland with emergent trees, have been merged into a single class called bushland. Likewise, closed woodland and open woodland have been merged into a single class called woodland.

#### *Boundaries of protected areas*

The best available map delineations of protected area boundaries have been used. The protected areas in Rufiji District consist of one game reserve and nineteen central government forest reserves including the Rufiji Delta (Appendix 1). A list of these forest reserves (Appendix 2), provided by the Rufiji District authorities contain discrepancies in size as compared to the size generated in GIS (Appendix 1), despite the fact that on the maps, they appear similarly in shape. In some cases, the area of certain forest reserves is not indicated at all in the official list. In addition to central government forest reserves, the list from Rufiji District officials contains local government forest reserves (owned by the district council) and community based village forest reserves (owned by village governments). It also includes a number of proposed community village forest reserves whose sizes are not indicated. The total area from the district list for all types of forest reserves (community, local government and central government) is 2278.2 $km^2$, while the area under protection, as calculated in GIS, reaches 5227.1 $km^2$. Though the mangroves are a forest reserve, they have been considered separately. Unlike the rest of the forest reserves, mangrove forest reserves have no definite boundary, but are defined by the intertidal range. Thus, the boundary delineation is based on extent of mangroves as mapped from the images. The Selous Game Reserve, one of the largest faunal reserves in the world with an area estimated to be 54,600 $km^2$, cuts across several regions and districts, with 6.5% of its area in Rufiji District alone.

The digital district boundary used is the same as the one that appears on various documents. The area of Rufiji District from this digital source is 12,998.5 $km^2$, which is 97.4% of the figure quoted in official documents. This discrepancy in area is common in many administrative units (region, district) between the official figures and digital sources even from those obtained from the Survey and Mapping Division – the ultimate mapping authority in Tanzania.

#### GIS manipulation

We have applied a Geographical Information System (GIS) to produce maps and to generate data. The process of obtaining the area that might be considered for biofuel investment was done by elimination or subtraction (Figure 1). First, relevant digital land use/land cover sheets coverage was merged. Then, the land use/land cover map of Rufiji district was clipped (extracted). This was followed by superimposing boundaries of the protected areas (the game reserve, forest reserves, and the extent of mangroves) on the district land use/cover map. The areas covered by protected areas were then subtracted, leaving possible areas to be considered for biofuel investment.

The figure obtained from the GIS manipulation was used to deduct arable land (URT, 2007) from various land use/land cover-types to obtain the possible biofuel investment areas. The main limitation of this study was the inability to map or segregate arable land from different land use/land cover types (non GIS in Figure 2).

## RESULTS AND DISCUSSION

### Various land use/cover type

Land use/land cover in Rufiji District is dominated by woodland, wooded grassland and the floodplain (Table 1). Cultivation is represented by two land use/land cover types, mixed cropping and scattered cultivation. The sum of the two cultivation land use/land cover types is relatively low. Given that the size of the farms on an average is approximately 1.2 ha per household (Turpie, 2000), it is likely that cultivated land is underrated, as such small areas cannot easily be detected with the 30 x 30 m resolution of the Landsat images. However, also without taking cultivated land into consideration, the results suggest that a huge portion (40.2%) of the district is covered by protected areas (game and forest reserves), a portion of Rufiji district that cannot be considered for biofuel investment.

The results can be analyzed under two scenarios (Table 2). The first scenario assumes that protected

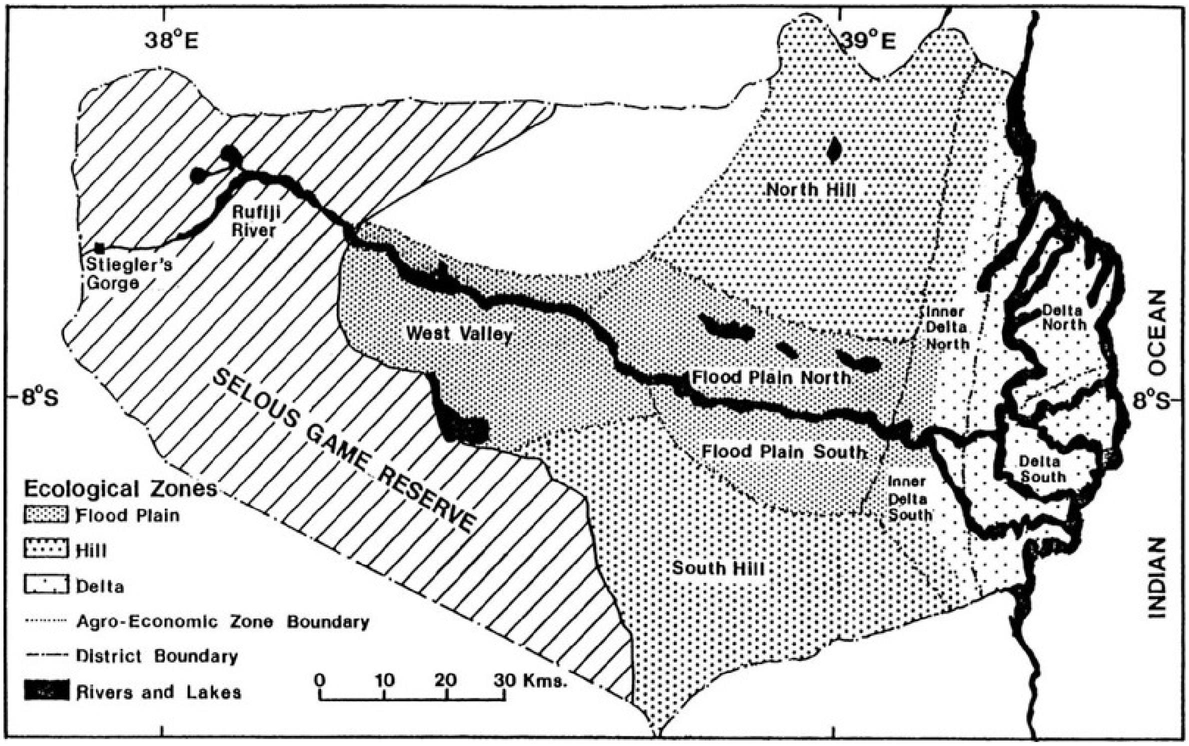


**Figure 1.** Rufiji District Agro-Ecological Ecological Zones (AEZ). Source: Havnevik (1981).

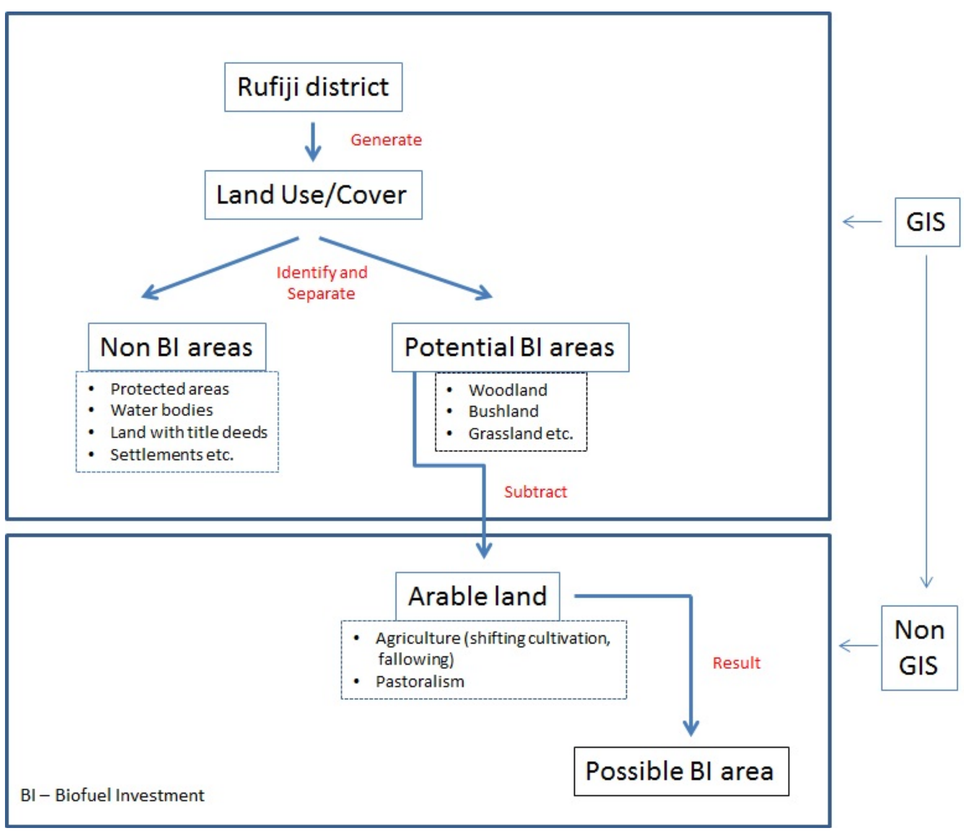


**Figure 2.** Flowchart of GIS manipulation.

**Table 1.** Distribution of land use/cover types in Rufiji District.

| Land use/cover | Total area | | Protected areas | | Non-protected areas | |
|---|---|---|---|---|---|---|
| | Area (x 100 km$^2$) | % | Area (x 100 km$^2$) | % | Area (x 100 km$^2$) | % |
| Mangroves | 4.8 | 3.7 | 4.8 | 3.7 | | |
| Natural/Riverine Forest | 2.4 | 1.9 | 0.9 | 0.7 | 1.6 | 1.2 |
| Forest Plantation | 0.0 | 0.. | | | 0.0 | 0 |
| Woodland | 54.5 | 41.9 | 23.7 | 18.3 | 30.7 | 23.7 |
| Bush land | 7.4 | 5.7 | 1.2 | 0.9 | 6.2 | 4.8 |
| Scattered Cultivation | 8.7 | 6.7 | 3.0 | 2.3 | 5.7 | 4.4 |
| Wooded Grassland | 21.6 | 16.6 | 15.1 | 11.6 | 6.4 | 4.9 |
| Flood Plain | 19.5 | 15 | 1.1 | 0.8 | 18.4 | 14.2 |
| Mixed Cropping | 6.2 | 4.8 | 0.3 | 0.2 | 5.9 | 4.6 |
| Bare Soil/Sand Dunes | 0.8 | 0.6 | 0.2 | 0.1 | 0.6 | 0.5 |
| Permanent Swamp | 2.3 | 1.7 | 1.4 | 1.1 | 0.8 | 0.6 |
| Lakes/Major River | 1.8 | 1.4 | 0.5 | 0.4 | 1.3 | 1 |
| Settlements/Urban Areas | 0.1 | 0 | | | 0.1 | 0 |
| | 130.0 | 100 | 52.2 | 40.1 | 77.7 | 59.9 |

Source: University of Dar es Salaam - Land Use / Cover based on Landsat TM of 1994/95.

**Table 2.** Comparison of biofuel investment scenarios.

| Scenario 1 | | Scenario 2 | |
|---|---|---|---|
| District total area (x 1,000 km$^2$ ) | 13.0 | District Total Area (x 1.000 km$^2$ ) | 13.0 |
| Protected areas | 5.2 | Protected areas | 5.2 |
| Arable land | 4.8 | Arable land under crop production | 0.9 |
| SEKAB/Eco energy investment request | 2.5 | SEKAB/Eco Energy Investment request | 2.5 |
| | 12.6 | | 8.6 |
| Balance after SEKAB/Eco Energy investment | 0.4 | Balance after Eco-Energy investment | 4.4 |

areas and presently cultivated land will not be considered for biofuel investment, while the second scenario assumes that only arable land under crop production will be considered for biofuel investment. The most conservative figure among the many figures is quoted by different authors for biofuel investment in Rufiji District, as suggested by SEKAB/Eco Energy, 2500 km$^2$. In the first scenario, only some 450 km$^2$ will remain for other land needs. In the second scenario, if the wishes of SEKAB/Eco Energy were to be granted, some 4400 km$^2$ would be available. However, there are other important issues to consider. First, the area under forest reserves is a very conservative estimate by any means. Only central government forest reserves have been considered, while some of the reserves, owned by district and village councils, whose figures are in some cases not available (Table 2), were neglected. Second, although only 900 km$^2$ of 4824 km$^2$ is estimated to be under crop production according to the Coast Region Social-economic profile (URT,2007), the area used for agriculture may be considerably higher, as the estimation of areas of arable land under crop production is very difficult in places where shifting cultivation and land fallowing is the norm. Third, only one potential investor (SEKAB/Eco Energy) has been considered, leaving out others like AGO. And finally, land availability has been gauged against the most conservative figure among those quoted for SEKAB/Eco Energy.

## Africa Green Oil's proposed investment

The proposed investment proposal of Africa Green Oil (AGO) sheds some light on the flawed perception of biofuel investors about vast lands being available for biofuel investment. The initial request was 30,000 ha in six villages - Mangwi, Nyamatanga, Nyanjati, Ruaruke A, Ruaruke B and Rungungu (Figure 3). The total area of the six villages obtained from a scanned map of village survey in the north eastern part of Rufiji district by the Regional Secretariat Surveyor is 35,003 ha. This means that AGO was requesting 85.7% of land in those six villages. This suggests that AGO had only vague ideas about the total area of the six villages before making the claim for30,000 ha. Some preliminary investigation of land use

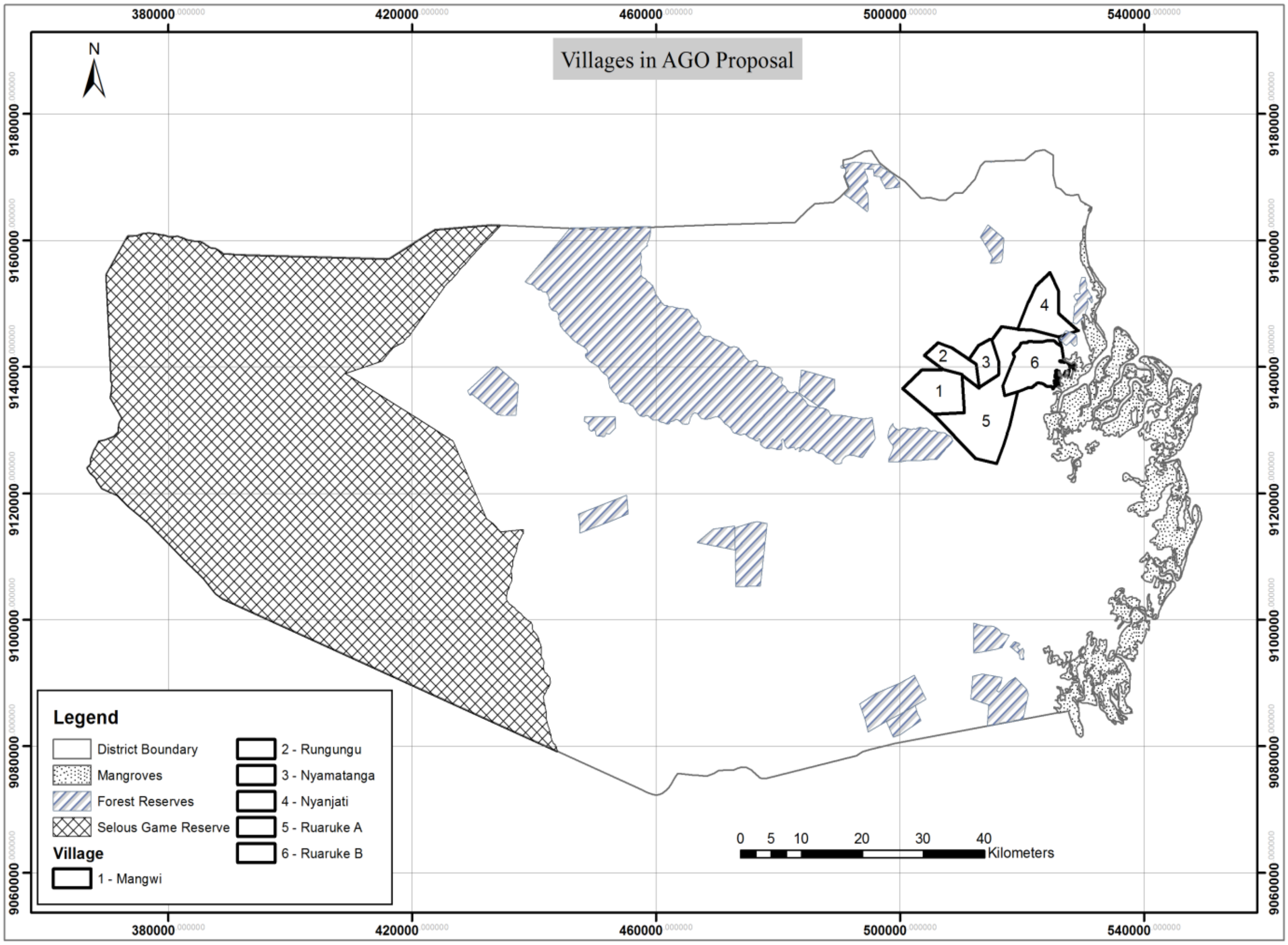


**Figure 3.** Rufiji district- Location of villages proposed for investment by AGO. Source: Regional Secretariat Surveyor – Coast Region. Registered Plan No. 45274 (30/01/2007).

and availability in the six villages, could have prompted AGO to further investigate the possibility of biofuel investment before committing resources and then realizing the futility of their expectations. The procedure outlined in Figure 2, with the necessary modification could constitute a starting point for accessing land availability for biofuel investment at the local level.

## Possible consequences of biofuel investment in Rufiji District

Expansion of agricultural areas for biofuel production should not deprive the local communities of their land (Haugen, 2010). In Rufiji district, livelihoods are often complemented with the use of natural resources obtained from rivers, lakes and forests (UNDP, 2012). Land acquisition by biofuel investors like AGO has resulted in the local population losing income generated from the selling of products they were collecting from land (Daley and Scott, 2011). After losing their land, the displaced communities will be compelled to seek alternative areas for settlements, farming and grazing (Madoffe et al., 2009). Seeking alternative areas after being displaced can be best illustrated by the Ujamaa villagization program that was implemented in Tanzania in the 1970s. It was aimed at settling people in designated villages, but some of the people refused to be settled in assigned villages and eventually settled in the inner delta (Figure 1), a transi-tion zone between the mangroves and the floodplain, where they cleared mangroves to establish new farms to support their livelihoods (Ochieng, 2000). After all, seeking refuge in the forests, including the mangroves of Rufiji Delta, in times of crisis is not a new phenomenon in Rufiji district. During the Maji Maji rebellion against the colonial German government, the Rufiji villagers made use of the forests as safe havens for the duration of the war. After the war, they continued to live in the forests and river islands of the delta to avoid forced labor, colonial government levy and controls imposed on their use of natural resources (Sunseri, 2003). Displacing people by biofuel investments could possibly result in the same situation exacerbating mangrove degradation.

## Conclusion

This study has demonstrated the possibility of assessing land availability for potential biofuel investment at the local level. However, the assessment must take into consideration the relevant biofuel investment policies. The case of Rufiji district has revealed that the existence of huge amounts of unused land or under-utilized is an incorrect perception. This suggests that biofuel investment in Rufiji district is only possible if the land currently used (or fallowed) by the people for their livelihoods is assumed to be unused. The unused land may be physically unoccupied but used for shifting cultivation or extraction of natural resources like harvesting of forest and non-forest products. Taking such land by whatever means will amount to land grabbing with the implied consequences for the livelihoods of people who have been using, are still using and will be using the land for their livelihoods. The procedure applied to assess land availability for biofuel investments in Rufiji district could be used with the necessary adjustment or modifications in other areas at the local level.

## Conflict of Interests

The author(s) have not declared any conflict of interests.

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**Appendix 1.** Protected areas in Rufiji District as generated from GIS.

| Protected area | Name | Area (x 100 km$^2$) | Total (x 100 km$^2$) |
|---|---|---|---|
| Game Reserve | Selous | 35.5 | 35.5 |
| Forest Reserves | Marenda | 0.0 | |
| | Mtita | 0.3 | |
| | Kingoma | 0.1 | |
| | Ruhoi | 7.9 | |
| | Mchungu | 0.1 | |
| | Kikale | 0.0 | |
| | Mtanza | 0.4 | |
| | Ngulakula | 0.2 | |
| | Kipo | 0.1 | |
| | Nyumburuni | 0.5 | |
| | Iyondo | 0.2 | |
| | Katundu | 0.5 | |
| | Utete | 0.1 | |
| | Mohoro | 0.2 | |
| | Mohoro River | 0.0 | |
| | Tambulu | 0.5 | |
| | Namakutwa | 0.5 | |
| | Nyamyete | 0.1 | 12.0 |
| Mangroves | Rufiji Delta | 4.8 | 4.8 |
| | | | 52.3 |

**Appendix 2.** Forest Reserves from Rufiji District Council.

| Forest reserve | Authority | Reference | Year established | Size ( x 100 km$^2$) |
|---|---|---|---|---|
| Nyamakutwa-Namuete FR | Central Government | Jb.2320 | 1930 | 0.4 |
| Muhoro FR | Central Government | Jb.615 | 1930 | 0.2 |
| Muhoro River | Central Government | Jb.602 | 1930 | 0.0 |
| Ngumburuni FR | Central Government | | 1930 | 0.3 |
| Kingoma FR | Central Government | | 1930 | |
| Mtita FR | Central Government | Jb.1026/RE/R/7/1 | 1930 | 0.3 |
| Mangroves | Central Government | Jb. 634 | 1930 | 6.8 |
| Utete FR | Central Government | Jb.625 | 1930 | 0.1 |
| Utete warm spring FR | Central Government | | 1930 | 0.1 |
| Tamburu FR | Central Government | Jb. 1620 | 1930 | 0.6 |
| Kipo FR | Central Government | Jb. 1084 | 1930 | 0.2 |
| Kikale FR | Central Government | Jb 1983 | 1930 | 0.1 |
| Mpanga FR | Central Government | Jb.1959b | 1930 | 0.5 |
| Mtanza FR | Central Government | Jb. | 1930 | 0.5 |
| Rupiage FER | Central Government | | 1930 | 0.4 |
| Katundu FR | Central Government | Jb 1086 | 1930 | 0.6 |
| Mbumi FR | Central Government | | 1930 | 0.1 |
| Mchungu FR | Central Government | Jb.1082 | 1930 | 0.1 |
| Ngulakula FR | Central Government | | 1930 | 0.2 |
| Nandundu FR | Central Government | Jb.RE/R/2/1 | 1930 | 0.0 |
| Marenda FR | Central Government | | 1930 | 0.0 |
| Kiwengoma FR | Central Government | Jb. 2310 | 1930 | 0.4 |
| Kirengoma FR | Central Government | Jb. RE/R/6/1 | 1930 | 0.0 |
| Kumbi FR | Central Government | Jb. E/R/2/1 | 1930 | 0.0 |

**Appendix 2.** Contd

| | | | | |
|---|---|---|---|---|
| Nerumba FR | Central Government | Jb.E/R/2/1 | 1930 | 0.0 |
| Ruhoi LAFR | Rufiji district Council | Jb.508 | 1965 | 6.9 |
| Kichi LAFR | Rufiji district Council | | 2000 | 1.5 |
| Mtanzamsona VLFR | Village Council | | 2009 | 0.9 |
| Tawi VLFR | Village Council | Jb.2351 | 2007 | 0.3 |
| Nyamwage VLFR | Village Council | Jb.1200 | 2007 | 0.1 |
| Nambunju VLFR | Village Council | Jb.2353 | 1998 | 0.2 |
| Mbwara VLFR | Village Council | Jb.2354 | 2007 | 0.2 |
| Mkoko VLFR | Village Council | | 2011 | 0.1 |
| Utunge VLFR | Village Council | | 2010 | 0.4 |
| Yelya VLFR | Village Council | Jb.1300 | 2007 | 0.1 |
| Nzenge VLFR (prop) | Village Council | | 2011 | 0.1 |
| Nyamitandai VLFR (prop) | Village Council | | 2011 | 0.2 |
| Mbingo VLFR (prop) | Village Council | | 2009 | |
| Urembo VLFR (prop) | Village Council | | 2009 | |
| Jogoobahari VLFR (prop) | Village Council | | 2009 | |
| Mkupuka VLFR (prop) | Village Council | | 2011 | |
| Muyuyu VLFR (prop) | Village Council | | 2011 | |
| Mangwi VLFR (prop) | Village Council | | 2011 | |
| Ruaruke VLFR (prop) | Village Council | | 2009 | |
| Minganje VLFR (prop) | Village Council | | 2009 | |
| Nyambawala VLFR (prop) | Village Council | | 2009 | |
| Mtunda VLFR (prop) | Village Council | | 2009 | |
| Nyambawala B VLFR (prop) | Village Council | | 2009 | |
| | | | | 22.8 |

*Source: Tarimo, Gaudence (District Forest Officer) and Mongo, Kennedy (District Fisheries Officer). Rufiji District Council (2011).


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