EQA - International Journal of Environmental Quality
ISSN 2281-4485 - Vol. 53 (2023): 21-34
Journal homepage: https://eqa.unibo.it/

published by

Dynamism in plankton species occurrence and diversity of an impacted aquatic ecosystem, Southeastern Nigeria

Chinedu Emeka Ihejirika[1]*, Uwakwe Angelbert Orji[1], Peter Ndu Okeke[1], Ejeagba Okorie Imo[2], Joseph Ikechukwu Nwachukwu[1]

1 Department of Environmental Management, Federal University of Technology, Owerri, Nigeria
2 Department of Microbiology, Federal University of Technology, Owerri, Nigeria

*Corresponding author E-mail: chinedu.ihejirika@futo.edu.ng

Article info
Received 18/1/2023; received in revised form 31/1/2023; accepted 16/2/2023
DOI: 10.6092/issn.2281-4485/16298

Abstract
Anthropogenic activities in rivers have been a major ecological problem affecting river morphology, water hydraulics, aquatic bio-systems and processes, and general water quality. This study established the diversity of planktons and physicochemical properties of dredging site of Otammiri River, Imo State. Water samples were collected from upstream, dredging site and downstream, with the aid of clean water sampling bottles and immediately transported to the laboratory for analysis. Plankton net of 55µm mesh was used to collect plankton samples and immediately transferred to plastic containers for microscopic examination, enumeration and classification. Occurrences of phytoplankton and zooplankton species were determined while Index of Diversity was computed using Margalef's model. Multivariate redundancy analysis and biplot were used to show association among the planktons and the proportion of their occurrences at the sampling points. Phytoplankton was classified into Bacillariophyceae (Diatoms) (51.19%), Cyanophyceae (26.62%), Chlorophyceae (14.68%), Euglenophyceae (2.05%), Chrysophyceae (3.07%), and Xanthophyceace (2.39%); while zooplanktons were classified into Protozoa (47.06%), Rotifera (35.29%) and Cladocera (17.65%). Index of Diversity for phytoplankton species were: upstream (4.82), dredging site (5.19) and downstream (5.82); while for zooplankton were (1.86), (0.91) and (1.37) respectively. Physicochemical parameters showed significant variation ($P<0.05$) at the different sampling points. Dredging and other anthropogenic activities might be responsible for alterations in physicochemical characteristics and diversity of planktons in Otammiri River with consequences of ecological imbalance in the aquatic ecosystem.

Keywords
Anthropogenic, Diversity, Occurrence, Otammiri River, Planktons, Species

Introduction

The disturbance of bottom sediments in rivers is generally considered injurious to the aquatic habitat and biota therein. In terms of the actual physicochemical disruption of the sub-stream, as overall stream bed stability decrease, there tends to be a corresponding decrease in species number (Coles et al., 2012). However, the response of the aquatic fauna varies with the intensity and the frequency by sand and gravel mining. In-stream sand mining results in the destruction of aquatic and riparian habitat through large changes in the channel morphology. There tends to be a corresponding decrease in species number (Koehnken *et al.,* 2020). Sequels to this, many groups of organisms have been used as indicators of water quality and environmental changes in freshwater bodies. Plankton, which are mixed group of tiny,

DOI: 10.6092/issn.2281-4485/16298

living plants and animals that float, drift freely or feebly swim in water column independent of the shore and bottom (Adelakun *et al.,* 2016) and occupy the base level of food chains (autotrophs) that lead up to commercially important fisheries have severally been used as bioindicators of water quality (Keller *et al.,* 2008). Plankton communities play a major role in the biogeochemical cycles of many important elements such as the carbon cycle, nitrification, denitrification, re-mineralization and methanogenesis. These cycles bring about such processes as primary production and recycling. Planktons are ideal for theoretical and experimental population ecology due to their small sizes, short generation time and a relatively homogenous habit. Several researchers have reported that variations in physicochemical factors exert propound effects on the number, abundance and distribution of the flora and fauna present in any aquatic system. Otamiri is a stream in Nigeria that cuts across three States: Imo, Abia and Rivers States. In Imo State, the river runs through Egbu, Nekede, Ihiagwa, Eziobodo, Olokwu Umuisi, Mgbirichi and Umuagwo to Ozuzu in Etche in Rivers State, from where it empties into the Atlantic Ocean. Due to increasing rate of urbanization in Nigeria, uncontrolled and continuous sand dredging in Otamiri River, the ecosystem may gradually loose its primary functions due to loss of plankton diversity. This study therefore established the dynamism of occurrence and diversity of plankton species at the sand mining sites of the freshwater body.

Materials and Methods

Study area

The map of the study area is as shown in Figure1. Within its location, rainfall is the greatest climatic variable with annual total mean of 2190mm (Imo State Govt. Ministry of Works and Transport, 1984). The mean monthly temperature for dry season is 34˚C and 30˚C for rainy season. The river has average flow of 10.7m^3/s in the rainy season (September - October) and a minimum average flow of about 3.4m^3/s in the dry season (November to February). The total annual discharge of the Otamiri is about $1.7 \times 10^8 m^3$, and 22 percent of this ($3.4 \times 10^7 m^3$) comes from direct runoff from rainwater and constitutes the safe yield of the river.

The southern part of the River is relatively undisturbed. The forest is dense and consists of 3 layers; high dominant trees, low dominant trees, shrubs and herds all interwoven by lianas and climbers. Tress here attains the heights of between 25-30 meters. The major occupation of the people is agriculture and small-scale industries. The river serves as sources of water for the citizens, sand for all types of construction works, and fish for villagers.

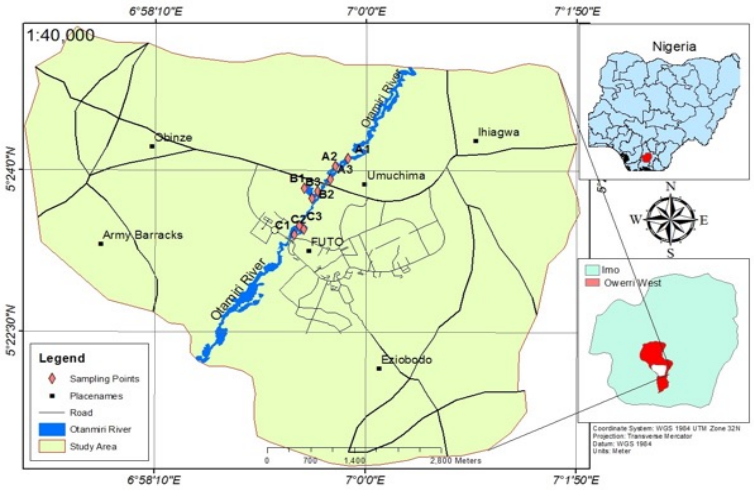


Figure 1. *Study area showing the sampling points.*

DOI: 10.6092/issn.2281-4485/16298

Sample collection

Site selection along the river for biological and physicochemical assessments was based on observation of possible impacts on the water resulting from sand mining. Therefore, sampling sites was based on known and existing activities, that is, the presence of river mining activities identified in previous visits to the rivers.

To evaluate meaningfully "biological conditions" in a targeted design, sampling locations were expected to show similarity in biodiversity without impact from mining.

Collection of planktons

The method described by Ogbuagu and Ayoade (2012) was adopted for the collection of plankton samples. Plankton net of 55µm mesh size was hauled horizontally along the river for 5 minutes at each sampling point. The resultant concentrated plankton samples were later transferred to plastic containers. Samples so collected were fixed and preserved in 4% formalin solution in the field. Samples were immediately transported to the laboratory for plankton counting/enumeration and identification. River water samples were collected with the aid of clean sampling bottles by grab sampling method and immediately transported to the laboratory for physicochemical analysis.

Identification and enumeration of planktons

In the laboratory, with the use of a wide-mouthed pipette, 1ml of the plankton subsample was withdrawn from each field sample that had been homogenized by inverting the containers few times, and placed on a Sedge-wick rafter-counting chamber and observed by direct microscopy. The methods provided by Jeje and Fernando (1986), Egborge (1994) and APHA (1998) were used for species identification. Counts were made in triplicates and their averages taken and expressed as number of organisms (for zooplankton) or cells/ml (for phytoplankton) of water.

Diversity Index

The computation of diversity index was carried out using Margalef's Index of Diversity (Morris *et al.,* 2014). Margalef's Index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). Thus:

$$D = \frac{S - 1}{\log_n N} \quad [1]$$

where 'S' is the total number organisms of species identified and, 'N' is the total number of individuals. The value of D ranges between 0 and 1.

Chemical analysis

Determination of pH (APHA 4500 H+). Measurements were carried out by means of a Win Lab pH meter (WinLab 192363, Germany) with a sensitivity of +0.01. Calibration was checked by measuring standard buffer solutions pH 4, and 7.

Determination of Electrical Conductivity (APHA-2540-C). Measurements were carried out by means of a Win Lab Conductivity meter (WinLab 200363, Germany) with a sensitivity of +0.01**.** Calibration was checked by measuring standard conductivity solutions.

Determination of Total Suspended Solids (TSS). This was determined using a spectrophotometer. A 25 ml cuvette or vial filled with deionised water served as the blank while another 25ml cuvette was filled with the test sample. The 25ml cuvette blank was used to adjust the wavelength dial of the spectrophotometer to 700nm. Then the test sample cuvette was inserted in the vial chamber and the light shield closed. The reading of the spectrophotometer was recorded in mg/L suspended solids.

Determination of Turbidity (APHA 2130B). Turbidity of collected samples were analysed the same day using Horiba U-53 (U-53, Tokyo) multi-parameter water quality meter. Calibration was checked by measuring standard turbidity solution and unit of readings were recorded in NTU.

Determination of Heavy Metals (APHA 3030 E). The concentrations in mg/L of heavy metals in the collected samples were determined (after nitric acid digestion) by means of an Atomic Absorption Spectrophotometer (Biotech Engineering, Phoenix 986- UK). 100mL of the water sample was measured and 5mL of nitric acid was added (Nitric acid digestion) into a beaker. The sample was placed on a hot plate and heated in fume hood until white fumes

DOI: 10.6092/issn.2281-4485/16298

evolved. The digested sample was allowed to cool and filtered into a 100mL volumetric flask and made up to mark with de-ionised water. The sample was then transferred to 100mL plastic can for heavy metal analysis.

Specific metal standards (AccuStandards, USA) in the linear range of the metal were used to calibrate the equipment. The concentrated and digested samples were then aspirated and the actual concentrations were obtained by referring to the calibration graph and necessary calculations.

Statistical analysis

By using CANOCO 5.0 software which is a multivariate ordination package (Ter Braak and Smilauer, 2012), the of Redundancy analysis (RDA) was performed. This was followed by a Monte Carlo Permutation test with 999 permutations which was implemented to evaluate the interactions between the phytoplanktons, zooplanktons and the sampling points. Ordination diagram was produced by applying the CanoDraw program which prompted the presentation and visualization of the RDA results.

Results and Discussion

Results

Physicochemical properties. This section presented the results (Table 1) of physicochemical analysis of Otammiri water samples. All parameters except Zn, showed significant variations ($P<0.05$) between upstream water sample (SP_1), point of sand excavation water sample (SP_2) and downstream water sample (SP_3).

Average pH values ranged from 7.44±0.07 to 5.90±0.03, with the maximum mean value at SP_2 and minimum mean value at SP_3. The values of pH varied significantly at P=0.00 at all sampling points. Multiple comparison of mean pH values at all sampling points showed significant variations from each other at P=0.00.

Average Dissolved Oxygen (DO) values ranged from 10.31±2.12 to 4.55±2.12 mg/L, with the maximum mean at SP_1 and minimum mean value at SP_3. The values of DO varied significantly at P=0.00 at all sampling points. Multiple comparisons of DO at all the sampling points showed that all samples varied significantly from each other at P = 0.00.

Average Electrical Conductivity (EC) values ranged from 38.08±0.40 to 31.09±0.19 µS/cm, with the maximum mean at SP_1 and minimum mean value at SP_2. The values of EC varied significantly at P = 0.00 at all sampling points. Multiple comparison of mean EC values at all sampling points showed that SP_1 varied significantly (P = 0.00) from SP_2 and SP_3, while SP_2 did not vary significantly from SP_3 (P = 0.67).

Average Total Suspended Solids (TSS) values ranged from 99.77±3.83 to 24.74±5.31 (mg/L), with the maximum mean at SP_2 and minimum mean value at SP_1. The values of TSS varied significantly at P=0.00 at all sampling points. Multiple comparisons of TSS at all the sampling points showed that all samples varied significantly from each other at P = 0.00.

Average Turbidity values ranged from 221.15±4.22 to 24.11±1.07 (NTU), with the maximum mean at SP_2 and minimum mean value at SP_1. The values of Turbidity varied significantly at P = 0.00 at all sampling points. Multiple comparisons of Turbidity at all the sampling points showed that all samples varied significantly from each other at P = 0.00.

Mean values of nitrate (mg/L) ranged from 0.11±0.02 to 0.06±0.01, with the maximum mean at SP_1 and minimum mean value at SP_2. The values of nitrate varied significantly at P = 0.01 at all sampling points. Multiple comparisons of nitrate at all the sampling points showed that SP_1 varied significantly from SP_2 (P = 0.00); SP_2 varied significantly from SP_3 (P = 0.02); while SP_1 did not vary significantly from SP_3 (P = 0.14).

Mean values of phosphate (mg/L) ranged from 0.10±0.01 to 0.05±0.01, with the maximum mean at SP_1 and minimum mean value at SP_2. The values of phosphate varied significantly at P = 0.01 at all sampling points. Multiple comparisons of phosphate at all the sampling points showed that SP_1 varied significantly from SP_2 (P = 0.00), but did not vary significantly from SP_3 (P = 0.05). Sample SP_2 varied significantly from SP_3 (P = 0.67).

Mean values of sodium (Na) (mg/L) ranged from 2.02±0.02 to 1.25±0.06, with the maximum mean at SP_1 and minimum mean value at SP_2. The values of Na varied significantly at P = 0.00 at all sampling points. Multiple comparisons of Na at all the sampling points showed that all samples varied significantly from each other at P = 0.00.

Mean values of potassium (K) (mg/L) ranged from 1.98±0.02 to 1.38±0.03, with the maximum mean at SP_1 and minimum mean value at SP_3. The values of K varied significantly at P=0.00 at all sampling points.

DOI: 10.6092/issn.2281-4485/16298

Multiple comparisons of K at all the sampling points showed that all samples varied significantly from each other at P=0.00.

Mean values of lead (Pb) (mg/L) ranged from 0.01±0.01 to 0.00, with the maximum mean at SP_2 and SP_3, and minimum mean value at SP_1. The values of Pb varied significantly at P = 0.04 at all sampling points. Multiple comparisons of Pb at all the sampling points showed that SP_1 varied significantly from sample SP_2 (P = 0.01) and did not vary significantly from SP_3 (P = 0.13). Sample SP_2 did not vary significantly from SP_3 (P = 0.13).

Mean values of zinc (Zn) (mg/L) ranged from 0.09±0.02 to 0.07±0.01, with the maximum mean at SP_1 and minimum mean value at SP_3. The values of Zn did not vary significantly at P = 0.14 at all sampling points. Multiple comparisons of Zn at all the sampling points showed that all samples did not vary significantly from each other at P>0.05.

Mean values of cadmium (Cd) (mg/L) ranged from 2.87±0.02 to 1.46±0.02, with the maximum mean at SP_2 and minimum mean value at SP_3. The values of Cd varied significantly at P = 0.00 at all sampling points. Multiple comparisons of Cd at all the sampling points showed that SP_2 was significantly different from other samples, while SP_1 varied significantly from SP_3 (P = 0.67).

Mean values of iron (Fe) (mg/L) ranged from 0.13±0.01 to 0.01±0.01, with the maximum mean at SP_3 and minimum mean value at SP_2. The values of Fe varied significantly at P = 0.00 at all sampling points. Multiple comparisons of Fe at all the sampling points showed that sample SP_3 varied significantly from other samples (P<0.05), while samples SP_1 and SP_2 did not vary from each other (P = 0.39).

Mean values of iron (Cu) (mg/L) ranged from 2.87±0.02 to 2.42±0.02, with the maximum mean at SP_1 and minimum mean value at SP_3. The values of Cu varied significantly at P = 0.00 at all sampling points. Multiple comparisons of Cu at all the sampling points showed that all samples varied significantly from each other at P<0.05.

Table 1. *Physicochemical parameters at different sampling points of Otammiri River*

S/no	Parameters	Sampling points			P-value
		SP_1	SP_2	SP_3	
1.	pH	6.05±0.03	7.44±0.07	5.90±0.03	0.00
2.	DO (mg/L)	10.31±2.12	4.55±2.12	7.62±3.44	0.00
3.	EC (μS/cm)	38.08±0.40	31.09±0.19	31.42±0.60	0.00
4.	TSS (mg/L)	24.74±5.31	99.77±3.83	31.62±2.44	0.00
5.	Turbidity (NTU)	24.11±1.07	221.15±4.22	47.34±7.13	0.00
6.	Nitrate (mg/L)	0.11±0.02	0.06±0.01	0.09±0.01	0.01
7.	Phosphate (mg/L)	0.10±0.01	0.05±0.01	0.08±0.01	0.00
8.	Na (mg/L)	2.02±0.02	1.68±0.03	1.25±0.06	0.00
9.	K (mg/L)	1.98±0.02	1.56±0.04	1.38±0.03	0.00
10.	Pb (mg/L)	0.00	0.01±0.01	0.01±0.01	0.04
11.	Zn (mg/L)	0.09±0.02	0.08±0.01	0.07±0.01	0.14
12.	Cd (mg/L)	1.47±0.02	2.87±0.02	1.46±0.02	0.00
13.	Fe (mg/L)	0.02±0.01	0.01±0.01	0.13±0.01	0.00
14.	Cu (mg/L)	2.87±0.02	0.00	2.42±0.02	0.00

Abundance and diversity of plankton. Table 2 shows abundance and diversity of Plankton taxa identified in Otammiri River. Phytoplankton taxa identified included Bacillariophyceae (Diatoms) with 11 species accounting for total abundance of 36, 42, and 72cell/ml at SP_1, SP_2 and SP_3 respectively. The diatoms accounted for total abundance of 150 cell/ml (51.19%) with dominant species as *Diatoma* sp., *Melosira granulata*, *Cyclotella operculata*, *Pinnularia major*, *Asterionella formosa*, *Tabellonia flocculosa*, *Fragillaria virescens* and *Navicula angelica*; Cyanophyceae with species accounting

DOI: 10.6092/issn.2281-4485/16298

for total abundance of 78 cell/ml (26.62%) in SP_1 (16), SP_2 (20) and SP_3 (42) with dominant species as *Dactylococcopsis irregularis, Microcystis aeruginosa, Anabaena spiroides, A. flos-aquae, Gomphosphaeria lacustris, Aphanizomenon flos-aquae, Oscillatoria lacustris, Phormidium mucicola* and *Raphidiopsis mediterranea*; Chlorophyceae with species accounting for total abundance of 43cell/ml (14.68%) in SP_1 (6), SP_2 (16) and SP_3 (21), with dominant species as *Chlamydomonas* sp., *Volvox globator, Golenkinia radiate, Chlorella vulgaris, Ankistrodesmus falcatus, Crucigenia fenestrate* and *Closterium parvulum*; Euglenophyceae with species accounting for total abundance of 6 (2.05%) in SP_1 (1), SP_2 (2) and SP_3 (3), with dominant species as *Euglena* sp. and *Trachelomonas* sp.; Chrysophyceae with species accounting for total abundance of 9 (3.07%) in SP_1 (2), SP_2 (3) and SP_3 (4), with dominant species as *Chlamydomonas* sp., *Volvox globator* and *Golenkinia radiate*; and Xanthophyceace with species accounting for abundance of 7 (2.39%) in SP_1 (2), SP_2 (1) and SP_3 (4), with dominant species as *Chlamydomonas* sp. and *Volvox globator.* The composition and percentage occurrence of phytoplankton are as shown in figure 2.

The Zooplankton was classified i nto P rotozoa with species accounting for abundance of 8 (47.06%) in SP_1 (3), SP_2 (1) and SP_3 (4), with dominant species as *Arcella* sp. and *Peridinium umbonatum*; Rotifera with species accounting for abundance of 6 (35.29%) in SP_1 (1), SP_2 (2) and SP_3 (3), with dominant species as *Colurella ancinata* and *Cephalodella* sp.; and Cladocera with species accounting for abundance of 3 (17.65%) in SP_1 (1), SP_2 (0) and SP_3 (2), with dominant species as *Ceriodaphnia setosa*. The composition and percentage occurrence of zooplanktons are as shown in figure 3.

The results from the redundancy multivariate ordination analysis which revealed that sampling point 1 had fewer phytoplanktons when compared with the sampling point 2 and sampling point 3. The eigenvalues for axis 1 and axis 2 were 0.6856 and 0.3144 respectively (Fig. 2), indicating that the first axis had higher concentrations of the species when compared with the second axis. On the other hand, the explained cumulative variation for the first axis was 68.6%, while that for the second axis was 100%.

In terms of zooplanktons concentrations, sampling point 2 and sampling point 3 had more species relative to sampling point 1. The only species dominant in the sampling point 1 was *Arcella* sp. The eigenvalues for axis 1 and axis 2 were 0.8733 and 0.1217 respectively (Fig. 2). In sum, sampling point 3 had more species followed by sampling point 2 while point 1 had the lowest species of both the phytoplanktons and zooplankton. Regarding the diversity of Phytoplanktons and Zooplanktons, a comparative assessment revealed that sampling point 3 had the highest diversity for Phytoplanktons while sampling point 2 had the highest for Zooplanktons.

The results from the redundancy multivariate ordination analysis as shown in the biplot indicated that sampling point 1 had fewer phytoplanktons when compared with the sampling point 2 and sampling point 3 (Fig. 2). *Euglena* sp and *A. flos-aquae* were dominant in the sampling point 3, and *Raphidiopsis mediterranea* had high association with sampling point 2, while *Chlamydomonas* species were dominant in sampling point 1 (Fig. 2b). Statistically, the eigenvalues for axis 1 and axis 2 were 0.6856 and 0.3144 respectively (Fig. 2). On the other hand, the explained cumulative variation for the first axis was 68.6%, while that for the second axis was 100%.

In terms of zooplanktons, sampling point 2 and sampling point 3 had more species relative to sampling point 1 (Fig. 3). The only species dominant in the sampling point 1 was *Arcella* sp.

Index of Diversity. The indices of Diversity and equitability of Phytoplankton taxa in the Otammiri River are as shown in Tables 2a and b. Phytoplankton was 4.827 at SP1, 5.191 at SP2 and 5.819 at SP3 (SP3>SP2>SP1). Equitability index were 1.864, 0.910 and 1.365 for phytoplankton taxa at SP1, SP2 and SP3 respectively.

The indices of Diversity and equitability of zooplankton taxa in the Otammiri River are shown in Table 2c were 1.864, 0.910 and 1.365 at SP1, SP2 and SP3 respectively ((SP1>SP3>SP2). However, it was 0.961, 0.918 and 0.987 for the zooplankton taxa at SP1, SP2, and SP3 respectively.

DOI: 10.6092/issn.2281-4485/16298

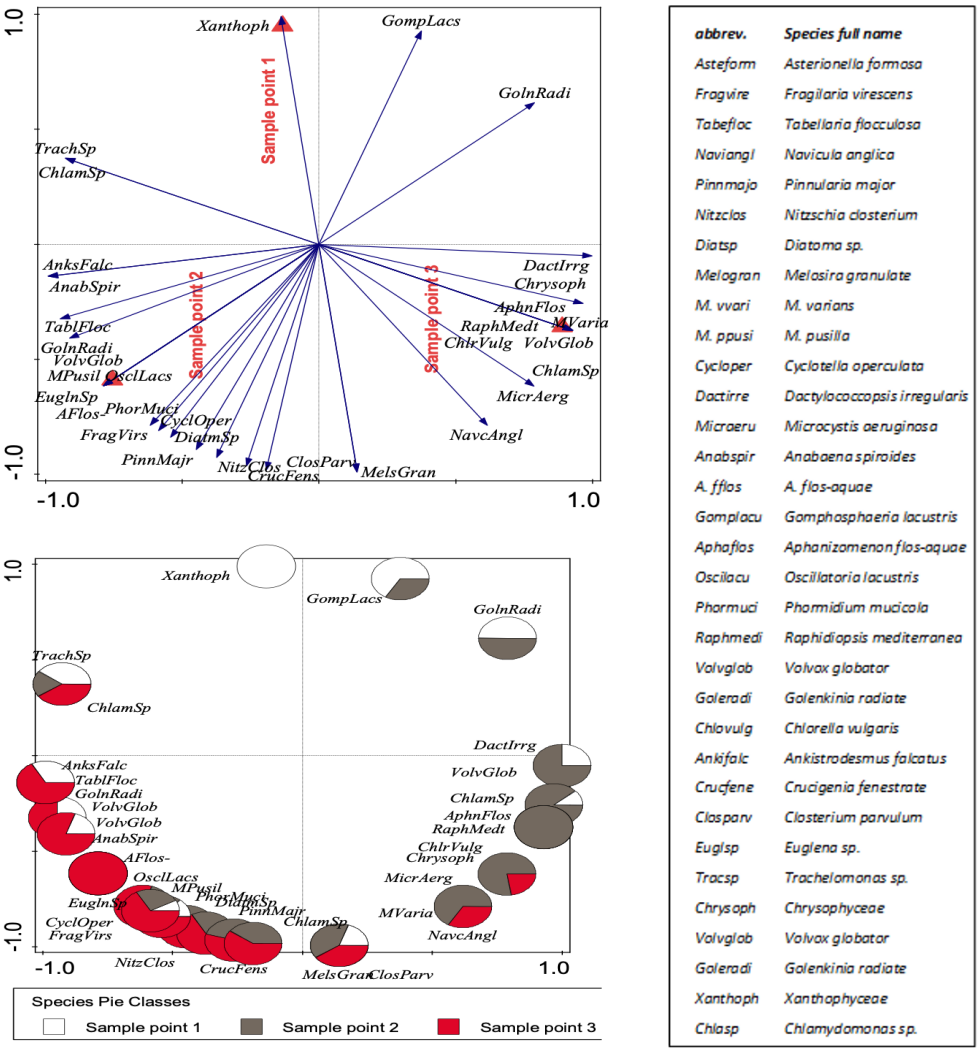
Plankton species	Sampling points			Total Abundance	% composition occurrence/mL
	SP_1	SP_2	SP_3		
Phytoplankton					
1. Bacillariophyceae (Diatoms)					
Asterionella formosa	1	3	3		
Fragilaria virescens	-	1	4		
Tabellaria flocculosa	2	-	6		
Navicula anglica	-	2	1		
Pinnularia major	1	4	8		
Nitzschia closterium	-	1	2		
Diatoma sp.	28	22	34		
Melosira granulate	2	5	5		
M. varians	1	-	1		
M. pusilla	-	1	-		
Cyclotella operculata	1	3	8		
Total	**36**	**42**	**72**	**150**	**51.19**
2. Cyanophyceae					
Dactylococcopsis irregularis	**1**	**2**	**6**		
Microcystis aeruginosa	**-**	**7**	**2**		
Anabaena spiroides	**2**	**-**	**4**		
A. flos-aquae	**-**	**3**	**8**		
Gomphosphaeria lacustris	**-**	**4**	**2**		
Aphanizomenon flos-aquae	**8**	**2**	**15**		
Oscillatoria lacustris	**2**	**2**	**4**		
Phormidium mucicola	**-**	**-**	**1**		
Raphidiopsis mediterranea	**3**	**-**	**-**		
Total	**16**	**20**	**43**	**78**	**26.62**
3. Chlorophyceae					
Chlamydomonas sp.	2	4	2		
Volvox globator	-	2	5		
Golenkinia radiat	1	-	4		
Chlorella vulgaris	-	4	-		
Ankistrodesmus falcatus	1	-	2		
Crucigenia fenestrate	1	4	6		
Closterium parvulum	1	2	2		
Total	**6**	**16**	**21**	**43**	**14.68**
4. Euglenophyceae					
Euglena sp.	-	2	2		
Trachelomonas sp.	1	-	1		
Total	**1**	**2**	**3**	**6**	**2.05**
5. Chrysophyceae					
Chlamydomonas sp.	-	2	3		
Volvox globator	1	-	1		
Golenkinia radiate	1	1	-		
Total	**2**	**3**	**4**	**9**	**3.07**
6. Xanthophyceae					
Chlamydomonas sp.	2	1	1		
Volvox globator	-	-	2	**7**	**2.39**
Total	**2**	**2**	**4**		
Grand total				**293**	

Table 2. *Abundance and diversity of phytoplankton in Otammiri River across the sampling points.*

DOI: 10.6092/issn.2281-4485/16298

Table 3. *Abundance and Diversity of Zooplankton in Otammiri River across the sampling points*

Plankton species	sampling points			Total abundance	% composition occurrence/mL
	SP_1	SP_2	SP_3		
Zooplankton					
1. Protozoa					
Arcella sp.	2	1	2		
Peridinium umbonatum	1	0	2		
Total	**3**	**1**	**4**	**8**	**47.06**
2. Rotifera					
Colurella ancinata	1	0	3		
Cephalodella sp.	0	2	0		
Total	**1**	**2**	**3**	**6**	**35.29**
3. Cladocera					
Ceriodaphnia setosa	1	0	2		
Total	**1**	**0**	**2**	**3**	**17.65**
Grand total	**5**	**3**	**9**	**17**	



abbrev.	Species full name
Asteform	Asterionella formosa
Fragvire	Fragilaria virescens
Tabefloc	Tabellaria flocculosa
Naviangl	Navicula anglica
Pinnmajo	Pinnularia major
Nitzclos	Nitzschia closterium
Diatsp	Diatoma sp.
Melogran	Melosira granulate
M. vvari	M. varians
M. ppusi	M. pusilla
Cycloper	Cyclotella operculata
Dactirre	Dactylococcopsis irregularis
Microeru	Microcystis aeruginosa
Anabspir	Anabaena spiroides
A. fflos	A. flos-aquae
Gomplacu	Gomphosphaeria lacustris
Aphaflos	Aphanizomenon flos-aquae
Oscilacu	Oscillatoria lacustris
Phormuci	Phormidium mucicola
Raphmedi	Raphidiopsis mediterranea
Volvglob	Volvox globator
Goleradi	Golenkinia radiate
Chlovulg	Chlorella vulgaris
Ankifalc	Ankistrodesmus falcatus
Crucfene	Crucigenia fenestrate
Closparv	Closterium parvulum
Euglsp	Euglena sp.
Tracsp	Trachelomonas sp.
Chrysoph	Chrysophyceae
Volvglob	Volvox globator
Goleradi	Golenkinia radiate
Xanthoph	Xanthophyceae
Chlasp	Chlamydomonas sp.

Figure 2. *Multivariate redundancy analysis (RDA) and biplot showing (a) the association among the phytoplanktons and the sampling points, (b) the proportion of each phytoplankton occurrences at the sampling points.*

DOI: 10.6092/issn.2281-4485/16298

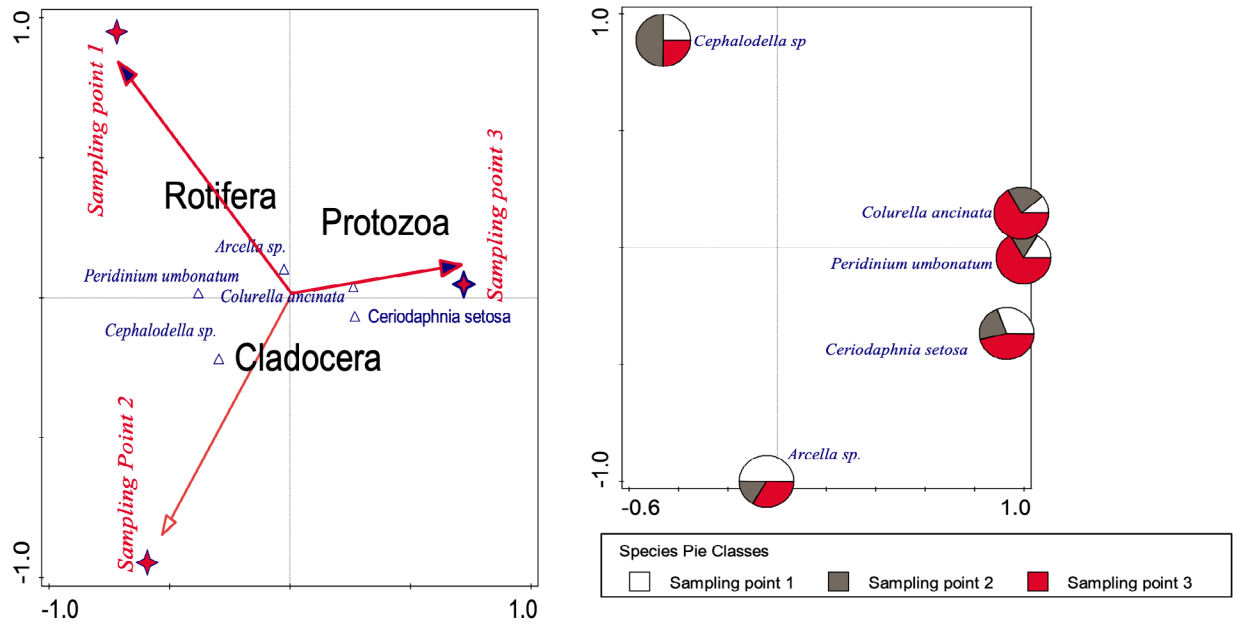


Figure 3. *Multivariate redundancy analysis (RDA) and biplot showing (a) the association among the zooplanktons and the sampling points, (b) the proportion of each zooplankton occurrences at the sampling points.*

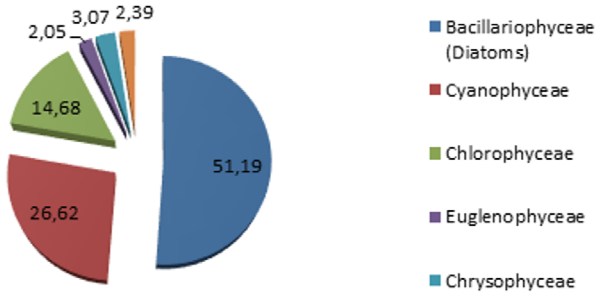


Figura 4. *Percentage composition and occurrence/mL of phytoplankton in the study area.*

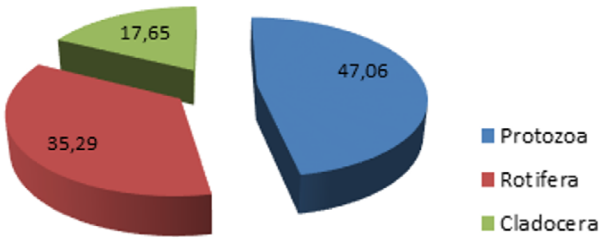


Figure 5. *Percentage composition and occurrence /mL of zooplanktons in water samples.*

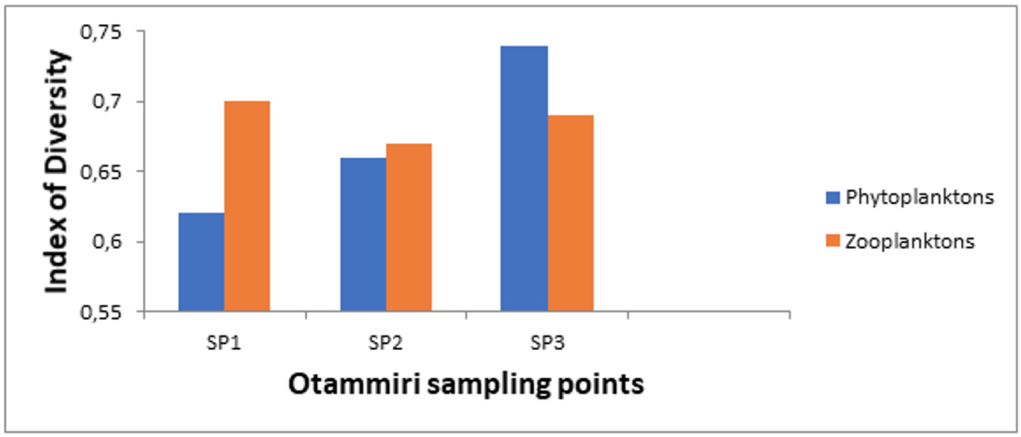


Figure 6. *Comparison of the impact of sand mining on the diversity of Phytoplanktons and Zooplanktons in Otammiri River samples.*

DOI: 10.6092/issn.2281-4485/16298

Discussion

Variation in pH recorded in this study can affect algal growth in a number of ways. It can change the distribution of carbon dioxide species and carbon availability, alter the availability of trace metals and essential nutrients, and at extreme pH levels potentially cause direct physiological effects. Most studies of pH effects on algae have been conducted in freshwater systems where the carbonate buffering system is weaker than in seawater and pH may fluctuate dramatically.

Variations in dissolved oxygen recorded in this study, is an important factor for fish respiration and zooplankton dynamics, its deficiency may present a hypoxic condition and fluctuating species diversity (Breitburg *et al*., 2009). DO content typically correlates with phytoplankton density in fish ponds (Kunlasak *et al*., 2013). Maintenance of phytoplankton populations at desired levels is an important but difficult aspect of fish pond management.

The Total Suspended Solids that were higher at the dredge site, than the other sampling points was in accordance with the works of Reisinger *et al.* (2017). Thus, according to Reisinger *et al.* (2017), dredging induced suspensions can perturb water quality and affect local biota. A concentration of re-suspended sediments and their subsequent distribution and deposition may be the primary agents causing the biological stresses mentioned above (Borges *et al*., 2002). Another possible consequence of concern might be the physical reduction in habitat area, which is a function of the rate of repopulation of the dredged area. According to Nesheim *et al*. (2015), if the sediments were organic-laden, the subsequent decomposition can lead to anaerobic conditions and the deterioration of the quality of the ambient water.

According to Peck Yen and Rohasliney (2013), TSS content between 80–400 mg/l had previously indicated the poor condition of aquatic ecosystems. This implied that the sand excavation site of Otammiri River was in a poor ecological condition. An increase in suspended contents may affect the zooplankton by reducing the food particles that are captured and by clogging the feeding system. Previous preliminary studies showed that the diversity and abundance of zooplankton in the Kelantan River were far lower than in the tributary (Peck Yen and Rohasliney, 2013). This may be one of the effects of turbidity and TSS on zooplankton.

The total suspended solid (TSS) (which includes silt and clay) shows an identical pattern with turbidity. The physical disturbance of the sediment while dredging the sand may have affected the suspended solids and increased the turbidity of the water. According to Supriharyono (2004), turbidity occurs when there are particles in the water that absorb light and cause backscattering. Gubbay (2003) noted that very fine sand that is dispersed by dredging may be carried up to 11 km from the dredging site, fine sand may be carried up to 5 km, medium sand may be carried up to 1 km and coarse sand may be carried less than 50 m. The turbidity-degraded water quality and the reduced light penetration within the river may affect the photosynthesis rates and the primary production rates of the river. This may definitely reduce the photosynthetic activity, productivity and growth of planktonic and benthonic animals (Kizhakke *et al*., 2023). The changes in production will then affect the food chain and the composition of phytoplankton (Supriharyono, 2004).

According to Prasanna and Ranjan (2010), the higher concentrations of nitrates and phosphate in sampling point 1 may be due to anthropogenic sources, such as domestic sewage, agricultural run-off and other waste effluents which contain nitrogenous compounds. According to Suthers and Rissik (2009), the major limiting nutrients for phytoplankton are nitrogen in form of ammonium (NH_4^+), nitrite (NO_2^-) and phosphate (PO_4^-). Nitrogen tends to be the limiting nutrients in marine systems, while phosphate in the limiting nutrient in the freshwater systems (Suthers and Rissik, 2009). These two nutrients are needed for cell membranes and for proteins such as enzymes (Kumar *et al.,* 2021).

According to Atici et al. (2010), the bioaccumulation of heavy metals in plankton depends on many factors, such as absorptive ability of individual species and season. The effects of heavy metals on planktons are numerous. According to Atici *et al*. (2008), Cd affects the photosynthesis and reduces the primary productivity of phytoplankton even at 0.2 and 5 mg/l, respectively; it affects the community structure of zooplankton.

Generally, primary producers are rare in river waters and the primary energy input will be in the form of organic detritus (Renaud *et al*., 2015). Sand mining depletes this crucial form of primary energy input, as a substantial part of detritus would be removed along with quarried sand. Non-availability of detritus

DOI: 10.6092/issn.2281-4485/16298

adversely affects the population of detritus feeders. Detritus is the food item to many fishes and other macro invertebrates. Sand mining destroys these benthic forms severely and prevent its recolonization (Sheeba, 2009).

Percentage occurrence of phytoplankton species in Otammiri River showed Bacillariophyceae (Diatoms) > Cyanophyceae > Chlorophyceae > Euglenophyceae > Chrysophyceace > Xanthophyceace. Percentage occurrence of zooplankton species in Otammiri River showed Protozoa > Rotifera > Cladocera. This result was not in agreement with the works of Suresh et al. (2009) which showed more seasonal dominance of Rotifera than Protozoa. This disparity might be due to the difference in condition of the study areas.

The redundancy multivariate ordination analysis could be attributed to the fact that dissolved inorganic macronutrients entering sampling point 2 and point 3 were higher relative to that of sampling point 1 (Isada *et al*., 2017). The eigenvalues for axis 1 and axis 2 indicated that the first axis had higher concentrations of the species when compared with the second axis (Jolliffe and Cadima, 2016). The application of RDA and PCA in the data analysis gave more productive result. RDA and PCA are multivariate statistical techniques. PCA is used to reduce the number of parameters in a dataset by converting them into a smaller number of components, where each component is a linear weighted combination of the initial variables (Salem and Hussein, 2019). Redundancy analysis (RDA) on the other hand permits the assessment of the relationships between these groups of variables and their directions, in this scenario, the association between the phytoplanktons, the zooplankton and the sampling points (Ter Braak and Smilauer, 2012).

The variations in zooplanktons populations at the different sampling points may be due to the presence of some environmental factors such as sunlight and temperature which tend to be more visible at sampling points 2 and 3 relative to sampling point 1 (Cuicui *et al*., 2019). The only species dominant in the sampling point 1 was *Arcella* sp. This was corroborated by the works of Mieczan and Pawlik-Skowrońska (2018) which established *Arcella* sp. dominance among other species in a treated experiment. The variation in eigenvalues for axis 1 and axis 2 may indicate that the data set is spread out on the line which is an eigenvector (Mishra *et al*., 2017). In summary, more species in sampling point 3, followed by sampling point 2 and point 1 for both the phytoplanktons and zooplankton could be due to the variations in river inflow, direct discharge of wastewater, dredging, deforestation, agricultural and other anthropogenic activities (Huisman *et al.*, 2005; Mbonde *et al.*, 2015). Regarding the diversity of Phytoplanktons and Zooplanktons, among the sampling points, it could be explained by the differences in the environmental and anthropogenic factors such as sunlight and sources of nutrients depositions which are lesser at the sampling point 1 relative to the other sampling points (Sedmak and Elersek, 2005; Isada *et al*., 2017).

According to Mason (1998), Index of Diversity is a good indicator of pollution in aquatic ecosystem. The pattern shown by the Index of Diversity variation for phytoplankton species in different Otammiri River water samples (SP_3>SP_2>SP_1) might imply that other major factors like washing of cloths by neighbouring communities, discharge of chemicals like detergents, and runoffs from drainage systems might have influenced the reduced diversity of phytoplankton species at SP_1. These activities might lead to the death and survival of phytoplankton species. Apart from these water shed activities; the upstream was characterized by tree sheds, which might reduce light penetration on the River, reducing photosynthetic processes which consequently will reduce phytoplankton diversity within the upstream area. Sand dredging site (SP_2) showed reduced diversity of phytoplankton species than at the downstream (SP_3) sampling site might imply possible gradual recovery from the effects of anthropogenic activities upstream and more effects from the dredging activities at SP_2. The highest diversity recorded at the downstream (SP_3) might be indicative of possible recovery of the River from activities of SP_1 and sand dredging at SP_2. The occurrence of phytoplankton species at SP_3 might be representative of the natural diversity of phytoplankton species in an unperturbed and unpolluted Otammiri River quality.

The pattern shown by the Index of Diversity of zooplankton species in different Otammiri River water samples (SP_1 > SP_3 > SP_2), greatly showed that activities of sand dredging might have negatively impacted on the diversity and occurrence of zooplankton species in Otammiri River. The pattern might imply that anthropogenic activities like flooding events might have enriched the occurrence and diversity of zooplankton species in SP_1. The possible chemical discharges at the upstream part of the study area might have significantly caused the

DOI: 10.6092/issn.2281-4485/16298

death and subsequent reduction of the diversity of zooplankton species at the sampling point.

The downstream water sample (SP_3) showed a close value to the diversity of zooplankton species at upstream water sample (SP_1) in Otammiri River. Downstream water sample was collected from an unpolluted Otammiri River site (SP_3) which might show the true diversity of zooplankton species in the River.

The comparable lowered diversity of zooplankton species at the dredging site (SP_2) might be indicative of possible destruction of zooplankton species due to sand excavation at the site. This was in similar to the works of Suresh *et al*. (2009), which stated that zooplankton population dynamics might be influenced by sand mining and other human activities in some selected stations of Tungabhadra River. Because zooplankton constitutes the food source of organisms like fishes at higher trophic levels, fish abundance depends on the higher abundance of zooplankton. This was in accordance with the works of Suresh *et al.* (2009).

Also according to Suresh *et al*. (2009), zooplankton is a good indicator of changes in water quality because it is strongly affected by environmental quality. Among the zooplankton, Rotiferas are apparently the most sensitive indicators of water quality (Sheeba *et al.,* 2009).

In an unpolluted and unaltered aquatic ecosystem, phytoplankton species should be more in abundance more in abundance than zooplankton species. This might be because phytoplankton species provide food for zooplankton species and therefore, should be more in abundance. Zooplankton species with lesser abundance than phytoplankton species occupy a central position between the autotrophs (phytoplankton) and other heterotrophs like fishes and should therefore be more in abundance than others. Reduction in the abundance of phytoplankton at SP_1 and SP_2 when compared with the unpolluted site at SP_3 might be due to effects of human activities at SP_1 and sand dredging at SP_2.

The variations in the diversity of Phytoplankton and Zooplanktons in Otammiri River samples were as shown in figure 6. In the upstream sample (SP_1), the Index of Diversity of Zooplankton (1.864) was lower than that of Phytoplankton (4.827); in sand mining site (SP_2), the Index of Diversity of Zooplankton (0.91) was lower than that of Phytoplankton (5.19), while in downstream sample (SP_3) the trend was the same, the Index of Diversity of Phytoplankton (5.82) was greater than that of Zooplankton (1.37).

Conclusion

Anthropogenic activities altered the diversity of plankton species of Otammiri River, which led to loss of biodiversity, and consequent fluctuations in ecosystem processes and balance.

References

ADELAKUN K.M., MU'AZU M.M., AMALI R.P., OMOTAYO O.L. (2016) Diversity of Phytoplankton Communities in a Tropical River Basin, Nigeria. Hydro Nepal Journal of Water Energy and Environment, 19:52-56. https://doi.org/10.3126/hn.v19i0.15353

APHA - American Public Health Association (1998) Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA/AWWA/WEF, Washington DC.

ATICI T., AHISKA S., ALTINDAG A., AYDIN D. (2008) Ecological effects of some heavy metals (Cd, Pb, Hg, Cr) pollution of phytoplanktonic algae and zooplanktonic organisms in Sarıyar Dam Reservoir in Turkey. African Journal of Biotechnology, 7(12):1972-1979. ISSN:1684-5315

ATICI T., OBALI O., ALTINDAG A., AHISKA S., AYDIN D. (2010) The accumulation of heavy metals (Cd, Pb, Hg, Cr) and their state in phytoplanktonic algae and zooplanktonic organisms in Beysehir Lake and Mogan Lake, Turkey. African Journal of Biotechnology, 9 (4):475-487. ISSN: 1684-5315

BORGES, P., ANDRADE, C. AND FREITAS, M.C. (2002) Dune, Bluff and Beach erosion due to exhaustive sand mining – the case of Santa Barbara Beach, São Miguel (Azores, Portugal). Journal of Coastal Research., (ICS 2002 Proceedings) Special Issue., 36(1):89-95. https://doi.org/10.2112/1551-5036-36

BREITBURG D.L., HONDORP D.W., DAVIAS L.A., DIAZ R.J. (2009) Hypoxia, nitrogen, and fisheries: integrating effects across local and global landscapes. Annual Review of Marine Science, 1:329–349. https://doi.org/10.1146/annurev.marine.010908.163754

DOI: 10.6092/issn.2281-4485/16298

COLES J.F., MCMAHON G., BELL A.H., BROWN L.R., FITZPATRICK F.A., SCUDDER EIKENBERRY B.C., WOODSIDE M.D., CUFFNEY T.F., BRYANT W.L., CAPPIELLA K., FRALEY-MCNEAL L., STACK W.P. (2012) Effects of urban development on stream ecosystems in nine metropolitan study areas across the United States: U.S. Geological Survey Circular 1373, 138 p. Available online at http://pubs.usgs.gov/circ/1373/

CUICUI L., WEIYING F., HAIYAN C., XIAOFENG L., FANHAO S., WENJING G., JOHN P. G., FUHONG S. (2019) Temporal variation in zooplankton and phytoplankton community species composition and the affecting factors in Lake Taihu—a large freshwater lake in China, Environmental Pollution, 245:1050-1057. https://doi.org/10.1016/j.envpol.2018.11.007

EGBORGE A.B.M. (1994) Water Pollution in Nigeria Vol. 1: Biodiversity and Chemistry of Warri River. Ben Miller Books Nig. Ltd, pp. 313.

GUBBAY S. (2003) Marine, aggregate extraction and biodiversity. UK: Wildlife Trusts, WWF-UK.

HUISMAN J., MATTHIJS C.P., VISSER P.M. (2005) Harmful cyanobacteria. Springer, The Netherlands. https://doi.org/10.1007/1-4020-3022-3

ISADA T., HIRAWAKE T., SAITOH S.I. (2017) Influence of hydrography on the spatiotemporal variability of phytoplankton assemblages and primary productivity in Funka Bay and the Tsugaru Strait. Estuarine Coastal And Shelf Science, 188:199-211. https://doi.org/10.1016/j.ecss.2017.02.019

JEJE C.Y., FERNANDO C.H. (1986) A practical guide to the identification of Nigerian zooplankton (Cladocera, copepoda and rotifera). Kainji Lake Research Institute, Nigeria.

JOLLIFFE I. T., CADIMA, J. (2016). Principal component analysis: a review and recent developments. Philosophical transactions. Series A, Mathematical, physical, and engineering sciences, 374(2065):20150202. https://doi.org/10.1098/rsta.2015.0202

KELLER B., WOLINSKA J., MANKA M., SPAAK P. (2008) Spatial, environmental and anthropogenic effects on the taxon composition of hybridizing Daphnia. Philosophical Transactions of the Royal Society B: Biological Sciences, 363:2943-2952. https://doi.org/10.1098/rstb.2008.0044

KIZHAKKE P. A., ANET A., SHILPA O., RESHMA R., SHANTHALA M., HUNASANAHALLY P. G. (2023) An Outlook on Marine Sponges and Associated Biodiversity Addressing Conservation Strategies, Conservation and Sustainable Utilization of Bioresources, 15:373-389. https://doi.org/10.1007/978-981-19-5841-0

KOEHNKEN L., RINTOUL M.S., GOICHOT M., TICKNER D., LOFTUS A-C., ACREMAN M.C. (2020) Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research. River Research and Applications, 36(3):362-370. https://doi.org/10.1002/rra.3586

KUMAR S., KUMAR S., MOHAPATRA T. (2021) Interaction Between Macro- and Micro-Nutrients in Plants. Frontiers in Plant Science. 12:665583. https://doi.org/10.3389/fpls.2021.665583

KUNLASAK K., CHITMANAT C., WHANGCHAI N., PROMYA J., LEBEL L. (2013). Relationships of Dissolved Oxygen with Chlorophyll-a and Phytoplankton Composition in Tilapia Ponds. International Journal of Geosciences, 4:46-53. https://doi.org/10.4236/ijg.2013.45B008

MBONDE A.S., SITOKI L., KURMAYER R. (2015) Phytoplankton composition and microcystin concentrations in open and closed bays of Lake Victoria, Tanzania Aquatic Ecosystem Health & Management, 18 (2):212–220. https://doi.org/10.1080/14634988.2015.1011030

MIECZAN T., PAWLIK-SKOWROŃSKA B. (2018) Effects of Arcella vulgaris on microbial loop components of peat pools (an experimental approach). Fundamental and Applied Limnology / Archiv für Hydrobiolog. https://doi.org/10.1127/fal/2018/113

DOI: 10.6092/issn.2281-4485/16298

MISHRA S., SARKAR U., TARAPHDER S., DATTA S., SWAIN D., SAIKHOM R., PANDA S., LAISHRAMM. (2017) Principal Component Analysis. International Journal of Livestock Research, 1. https://doi.org/10.5455/ijlr.20170415115235

MORRIS E. K., CARUSO T., BUSCOT F., FISCHER M., HANCOCK C., MAIER T. S., MEINERS T., MULLER C., OBERMAIER E., PRATI D., SOCHER S. A., SONNEMANN I., WASCHKE N., WUBET T., WURST S., RILLIG M.C. (2014) Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. Ecology and Evolution, 4(18):3514–3524. https://doi.org/10.1002/ece3.1155

NESHEIM M. C., ORIA M., YIH P.T. (2015) A Framework for Assessing Effects of the Food System. Committee on a Framework for Assessing the Health, Environmental, and Social Effects of the Food System; Food and Nutrition Board; Board on Agriculture and Natural Resources; Institute of Medicine; National Research Council.

OGBUAGU D.H., AYOADE A.A. (2012). Phytoplankton Assemblage along Gradients of the Imo River in Etche Local Government Area, Nigeria, Annals of Biological Research, 3 (4):1852-1862. ISSN 0976-1233

PECK YEN, T., ROHASLINEY, H. (2013). Status of water quality subject to sand mining in the kelantan river, kelantan. Tropical Life Science Research, 24(1):19-34. PMC3799407

PRASANNA, M. B., RANJAN, P. C. (2010). Physicochemical properties of water collected from Dhamra estuary. International Journal of Environmental Sciences, 1(3):334–343. ISSN:0976-4402

REISINGER A., GIBEAUT J.C., TISSOT P.E. (2017). Estuarine Suspended Sediment Dynamics: Observations Derived from over a Decade of Satellite Data. Front. Mar. Sci. 4:233. https://doi.org/10.3389/fmars.2017.00233

RENAUD P.E., LØKKEN T.S., JØRGENSEN L.L., BERGE J., JOHNSON B.J. (2015). Macroalgal detritus and food-web subsidies along an Arctic fjord depth-gradient. Front. Mar. Sci. 2:31. https://doi.org/10.3389/fmars.2015.00031

SALEM N., HUSSEIN S. (2019) Data dimensional reduction and principal components analysis. Procedia Comput. Sci., 163:292–299. https://doi.org/10.1016/j.procs.2019.12.111

SEDMAK, B AND ELERSEK, T. (2005). Microcystins induce morphological and physiological changes in selected representative phytoplanktons. Microbial Ecology, 50 (2):298-305. https://doi.org/10.1007/s00248-006-9045-9

SHEEBA S. (2009). Biotic environment and sand mining - a case study from Ithikkara River, South West coast of India. Journal of Industrial Pollution Control, 25(2):133-138

SUPRIHARYONO (2004) Effects of sand mining on coral reefs in Riau Islands. Journal of Coastal Development, 7(2):89–100. ISSN: 1410-5217

SURESH B., MANJAPPA S., PUTTAIAH E. T. (2009) The contents of zooplankton of the Tungabhadra River, near Harihar, Karanataka and the saprobiological analysis of water quality. Journal of Ecology and the Natural Environment, 1(9):196-200. ISSN 2006- 9847

SUTHERS I.M., RISSIK D. (2009). A Guide to their Ecology and Monitoring for Water Quality. 2nd edition. CSIRO Publishing, Collingwood Victoria. 272p. ISBN: 97146308798

TER BRAAK C.J.F., SMILAUER P. (2012). CANOCO reference manual and canodraw for windows user's guide: software for Canonical Community Ordination (version 5.0). [accessed 2021 July 15]. www.canoco.com

ZAGHLOUL A., SABER M., GADOW S., AWAD F. (2020) Biological indicators for pollution detection in terrestrial and aquatic ecosystems. Bulletin of the National Research Centre, 44:127. https://doi.org/10.1186/s42269-020-00385-x