



PERIPHYTIC ALGAE AS INDICATORS OF WATER QUALITY IN SOME TROPICAL LOTIC SYSTEMS IN NORTHERN, NIGERIA

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Abstract

River Kaduna is the main source of potable water in the Kaduna metropolis, home to 1.3 million people. Periphytic algae and water samples were collected from January 2013 to December 2014 in two drains, one receiving mainly brewery effluent and the second receiving effluents from an urban market; and River Kaduna into which both drains empty their waters. The main objective of this study is to evaluate the efficacy of periphytic algae as water quality indicators using diverse ecological metrics in River Kaduna and two urban drains that discharge wastewater into it. Indicator species analysis, Canonical Correspondence Analysis, and Nonmetric Multidimensional Scaling were used to establish the linkages between periphytic algae and water quality. The sampling stations conveying brewery effluent were observed to be of a "very poor water quality" index (WQI) and were found to be associated with *Achnanthes hungarica*, *Aulacoseira ambigua*, *Epithemia* sp., *Gyrosigma* sp., *Melosira calognosa*, *M. sulcata*, *M. sp.*, *Suriella augusta*, *Oscillatoria limosa*, and *Botryococcus* sp. While the sampling stations on the drain conveying wastewater from the urban market and residential areas were observed to be of 'poor water quality status was characterized by *Nitzschia* sp., *Nostoc* sp., *Oscillatoria brevis*, *Oscillatoria tenuis*, *Euglena* sp., *Anomoneis* sp., *Aulacoseira granulata*, *Coconeis placentula*, *Frustulia rhomboides*, *Gyrosigma accumulata*, *Melosira distans*, *Pinnularia viridis*, *Synedra ulna*, *Coelastrum* sp., *Closterium* spp., *Scenedesmus* spp., *Staurastrum* sp., *Merismopedia glauca*, *Merismopedia elegans* and *Oscillatoria lacustris*. Water quality of all the sampling stations on river Kaduna were also observed to be of poor water quality status include *Aulacoseira varians*, *Aulacoseira granulata*, *Melosira sulcata*, *Melosira numuloides*, *Pleurosigma* sp., *Frustulia rhomboides*, *Navicula* sp. 1,2 and 3, *Synedra ulna*, *Nitzschia* sp., *Suriella augusta*, *Cosmarium marigatus*, *Oscillatoria tenuis*, *O. brevis*, *O. lacustris*, *Nostoc* sp. and *Euglena* sp. and *Phacus* sp. The varied response of periphytic algae to water quality confirms their reliability as water quality indicators.

Keywords: Periphytic algae, water quality, wastewaters, River Kaduna

Therefore great innovative approaches are needed to strike a balance between human needs and ecological integrity in these characteristic and dynamic environmentally heterogeneous systems (Pace *et al.*, 2012). Ecological principles have now been found to be very important in the management of lotic systems (Salmaso *et al.*, 2014).

The rapid increase in population densities and increase in industrial and agricultural activities expose most hydrographic basins to negative environmental impacts especially to pollution by domestic and industrial waste residues (Geurts *et al.*, 2009; Salomoni *et al.*, 2011; Chen *et al.*, 2016). The ever-increasing influence of anthropogenic activities on lotic environments as a consequence of an

INTRODUCTION

Anthropogenic activities such as agricultural, industrial, and domestic processes generate discharges that have contributed to the deterioration of freshwater lotic systems (Ansari *et al.*, 2014; Van Dover, 2014; Johannessen *et al.*, 2015). Pollutants from these activities are released either directly into lotic systems in the form of wastewater discharges, oil spillages, or agricultural run-offs (Adeyemo *et al.*, 2002; Hassan *et al.*, 2014b and Dalton *et al.*, 2015), or indirectly through deposition from soil or air within the catchment of such water bodies (Bako *et al.*, 2014; Teittinen *et al.*, 2015).

Freshwater lotic systems are important components of the biogeochemical cycles, at local, regional, or global levels (Li *et al.*, 2010; Bere, 2011). They are used for transportation; serve as sources of drinking water; are used for fisheries and irrigation; waste removal systems; and are of enormous aesthetic value. A great deal of interaction occurs among physical, chemical, and biological processes in lotic systems (Wehr and Descy, 1998; Pace *et al.*, 2012). In lotic systems, activities that alter water quality at upstream locations affect processes and organisms downstream, making the management of these systems very difficult (Nagorski *et al.*, 2014).

A longitudinal difference in the time scales of chemical and biological processes is characteristic of these systems, rendering it difficult to design policies and assess the results of management actions (Fan and Shibata, 2015).

increase in civilization has captured public interest due to the deterioration of water quality and its associated problems (Salvia *et al.*, 1999; Bere, 2007; Chukwu *et al.*, 2012; Chiogna *et al.*, 2016).

Periphytic algae are algal species found growing on surfaces such as sediment material, stones, living or dead plant material have been reported in both polluted and unpolluted waters, and they are very sensitive to variations in physical and chemical characteristics of the water body in which they are found (Jafari and Gunale, 2006; Bere *et al.*, 2013). In addition, they are easy and comparatively less expensive to collect and analyse, thus making them widely used as indicators of water quality (Verlencar and Desai, 2004; Li *et al.*, 2010).

The most important factors that affect the distribution, abundance, and diversity of periphytic algae include pH, ionic strength, nutrients, the velocity of water, availability of light, and grazing (Pla *et al.*, 2005; Potapova and Charles, 2005; Bere and Tundisi, 2011a; Stenger-Kovacs *et al.*, 2013). These factors in turn are determined by climate, geology and bedrock topography, and land use (Triest *et al.*, 2012). Many species of algae are ubiquitous; while others appear to be restricted in distribution by climate or geography or may be endemic to some specific water bodies (Potapova and Charles, 2005; Bere *et al.*, 2013). Water chemistry is largely affected by anthropogenic activities, it has been reported to determine the abundance and diversity of periphytic algae (Stenger-Kovacs *et al.*, 2013).

Developed periphytic algae-based water quality indices are mostly from works done in the temperate regions (Bere, 2011), while the few studies from the tropical region may lead to erroneous interpretations of water quality because of overlaps in species composition between regions or variation in ecological characteristics of some key taxa (Pan *et al.*, 1996). An example is the classification of *Gomphonema parvulum* as an indicator species for oligotrophic/mesotrophic environments in Gravatai River, Brazil, by Salomoni *et al.* (2011), which disagrees with the classification of the same species as a tolerant species to organic pollution in Japanese Rivers (Kobayasi and Mayama, 1989; Lobo *et al.*, 2006). The same species was assigned indicative and saprobic values corresponding to highly eutrophic environments when evaluating water quality in English waters (Kelly and Whitton, 1995). These conflicting classifications leave us with a problem on where to place this alga as it is found in Nigeria.

Some species are endemic, thereby making it necessary for the development of an algal index unique to a region to reflect the species present in that locality. New species may be incorporated into biotic indices, which combine ecological information with environmental information through specific indicative rates or values assigned to species from multivariate analysis (Salomoni *et al.*, 2011). The aim of this study is to assess the response of periphytic algae to changes in water quality in some urban lotic systems in Kaduna Town, Nigeria.

MATERIALS AND METHODS

Study Area

Samples were taken from the Tudun Wada main drain, which receives wastewater from an urban residential area and is mainly a residential settlement, and the Sheik Mamud Gumi Central Market; Makera main drain which receives effluent largely from three (3) Textile industries, one (1) Brewing industry, a petrochemical oil depot, and residential areas; and a segment of River Kaduna, at the point where the above drains impact the River. River Kaduna is the major source of potable water in the Kaduna metropolis, it traverses through the urban center in northern Nigeria with a population of 1.33 million

people (Dadi-Mamud *et al.*, 2012). Kaduna has a tropical continental climate with distinct wet and dry seasons. The wet season lasts between May and October and is characterized by torrential rainfall, while the dry season starts in November and ends in April. The natural vegetation cover is tropical grassland of the Northern Guinea Savannah type with short scattered trees interspersed with tall grasses.

Sampling duration and stations

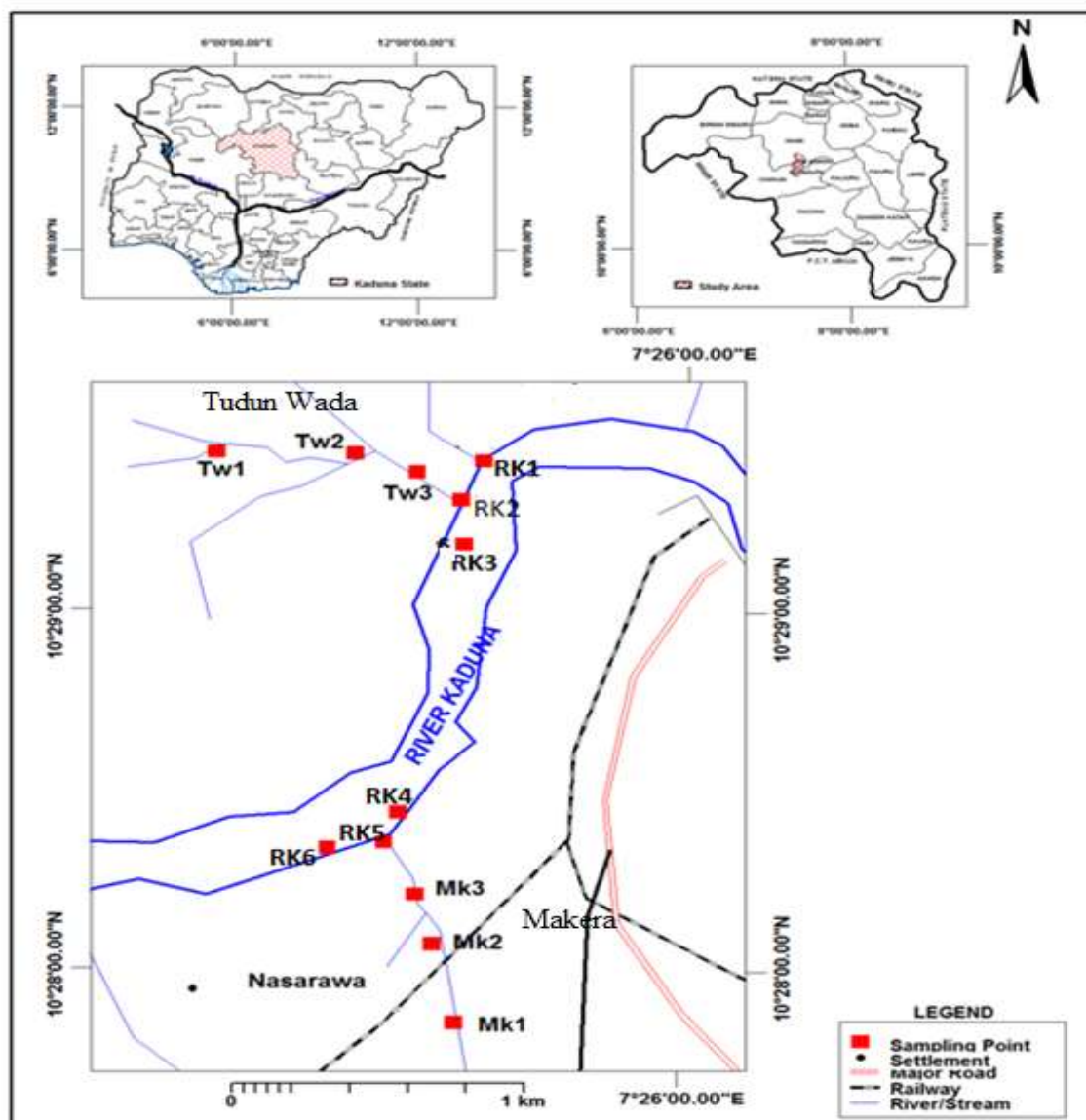
Surface water samples were collected once a month for 24 months, from January 2013 to December 2014. Periphytic algae samples were collected in the dry season of each year (January, February, March, April, November, and December) because they are usually washed away by fast water current in the wet season. Twelve sampling stations were selected for the study. Three (3) stations were located on the Tudun Wada drain across the gradient towards River Kaduna the first, TW1 at the confluence of the drain from the Central Market and the Tudun Wada Kaduna residential area, the second, TW2 by the bridge on the road leading to Kachia road from Tudun Wada, the third station TW3, a hundred meters before the drain discharges into River Kaduna. The first station, RK1 located a few meters upstream of River Kaduna before the drain discharges into the River Kaduna while the second, RK2 is located at the point the water from the drain impacts the River Kaduna, and the third RK3 is located a hundred meters downstream after the point of impact. Three (3) other stations were located on the Makera drain across the gradient towards River Kaduna, Station 1 MK1, after the discharge point of effluent from Nigerian Breweries, Station 2, MK 2 receives effluents from the Kaduna Textile Limited, Station 3, MK 3 receives domestic effluents from residential areas. Three other stations were located on River Kaduna, RK4, a hundred meters upstream before the drain discharges (point of impact) into the River Kaduna, RK5 located at the point the Makera drain impacts the River Kaduna, while RK6 was located downstream after the point of impact (Fig.1).

Determination of surface water Physico-chemical characteristics

The surface water temperature, pH, electrical conductivity, and total dissolved solids were measured *in situ* using a portable HANNA Combo pH/EC/Temp metre model/HI 98129. Nitrogen and phosphorus were determined using the phenoldisulphonic acid and stannous chloride methods, respectively (APHA, 2005). Dissolved Oxygen and Biochemical Oxygen Demand were determined using the azide modification of the Winkler method (APHA, 2005).

Collection and identification of periphytic algae

At each sampling site, epilithic, epiphytic, epipelic, epidemic, and episamic algae were collected separately by scraping the scum on each available substrate and preserved in Lugol's Iodine solution according to methods described by Moulton *et al.* (2000).



Source: Modified From Kaduna Metropolis Map

Figure 1: Map of the study area showing the sampling stations along Makera (MK) drain, Tudun Wada (Tw) drain and a segment of River Kaduna (Rk)

Epilithic algae were collected on at least five pebble-cobble stones at each site, each of which was shaken in stream water to remove any loosely attached sediments and non-epilithic algae, and then a brush was used to remove the epilithic flora. The resulting algal suspension was pooled to form a single sample, which was put in a labelled plastic container and preserved by the addition of 2 to 3 drops of Lugol's iodine solution.

Epiphytic algae were sampled from different species of submerged macrophytes at each sampling site. The whole stalk and leaves were carefully removed from the stream. Periphyton was then removed from the macrophytes by brushing with a toothbrush and adding distilled water. The resulting algal suspension from the selected macrophytes was then pooled into a single sample, which was put in a

labeled plastic container and preserved by the addition of 2 to 3 drops of Lugol's iodine solution.

Epipellic and episamic algae were sampled by pressing a Petri dish lid into the top layer of sand or silt/clay to a depth of 5-7mm followed by sliding a spatula blade under the Petri dish to isolate the contents in the dish, which was then gently brought to the surface. The content was then emptied into a labelled container. Five samples were collected at each site and pooled into a single sample and preserved by the addition of 2 to 3 drops of Lugol's iodine solution.

Diatom frustules were cleaned using the Hydrogen Peroxide/Potassium Dichromate Oxidation method. To a 5-10 ml subsample of preserved alga placed in a beaker, 50% Hydrogen Peroxide was added and the sample was allowed to oxidize overnight, then a micro spatula of potassium

dichromate was added. When the sample color changed from purple to yellow and the boiling stopped, the beaker was then filled with distilled water and allowed to stand for four (4) hours; the supernatant was then siphoned off (Biggs and Kilroy, 2000). A drop of a small amount of Naphrax (in toluene) fixative was placed onto the centre of a clean glass slide, the slide was then placed onto a hotplate at ~ 120°C and heated until the Naphrax-toluene solution began to bubble gently. A coverslip (with cleaned diatoms facing down) was placed onto the Naphrax-toluene solution and eased down very gently. Heating continued until bubbling subsided then the slide was removed from the hotplate. The cover slip was then gently pressed down with forceps until all air bubbles had been squeezed out. The slide was allowed to cool and then labelled. The slide was examined under oil immersion at x1000 magnification (Biggs and Kilroy, 2000). Three (3) replicate mounts of each specimen were prepared and viewed consecutively under the microscope under oil immersion at x1000 magnification. At least 250-400 cells were counted (depending on the abundance in the sample). The soft-bodied periphytic algae were enumerated and identified using an Improved Neuber bright line haemocytometer. Algal species encountered were identified using guides such as Prescott (1961 and 1977).

2.5 Data analyses

Water Quality Index (WQI) was determined using values of pH, Electrical Conductivity, Total Dissolved Solids, Dissolved, Nitrate, and Phosphate by methods described by Yogendra and Puttaiah (2008). The WQI of a water sample in which n number of parameters (characteristics) have been determined is expressed as a summation of the product of quality rating for the *nth* Water quality parameter (qn) and the unit weight of each parameter (Wn) divided by sum of the unit weights of all the (n) parameters (Wn).

$$\text{Mathematically: } WQI = \sum \left(\frac{qnWn}{\sum Wn} \right) \quad \text{Eq. (1)}$$

qn= quality rating for the *nth* Water quality parameter, corresponding to the *nth* parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standard permissible value and is given by = $100 \frac{Vn - Vio}{Sn - Vio}$
Vn= Estimated value of the *nth* parameter at a given sampling station.

Sn= standard permissible value of the *nth* parameter.
Vio= ideal value of the *nth* parameter in pure water (i.e. 0, for all parameters except pH, 7.0 and Dissolved Oxygen, 14.6 mg/L).
Wn= unit weight of *nth* parameter = K/Sn

Indicator species were determined by the Individual Value index (IndVal index) modified from Dufrêne and Legendre (1997).

$$INDVAL_{ij} = A_{ij} \times B_{ij} \times 100 \quad \text{Eq. (2)}$$

Where INDVAL = Indicator Value of species *i* in substrate *j*

$$A_{ij} (\text{measure of specificity}) = \frac{\text{mean number of individuals of species } i \text{ in sampling Station } j}{\text{mean number of individuals of species } i \text{ across all Sampling Stations}}$$

$$B_{ij} (\text{a measure of fidelity}) = \frac{\text{number of Sampling Stations } j \text{ where species } i \text{ is present}}{\text{the total number of Sampling Stations}}$$

The indicator value of a species (i) for a typology of sites is the largest value of INDVAL_{ij} over all groups (j) of that typology.

Palaeontological Statistics (PAST) software version 1.95 was used for Canonical Corresponding Analysis (CCA).

RESULTS

Surface water Physico-chemical characteristics

The mean of surface water Physico-chemical parameters used for the determination of the Water Quality Index is in Table 1.

All the sampling stations on the Tudun Wada drain (TW₁, TW₂, and TW₃), River Kaduna (RK₁, RK₂, RK₃, RK₄, RK₅, and RK₆), and one on the Makera drain (MK₃) were observed to have a poor water quality status. Whereas two sampling stations on the Makera drain (MK₁ and MK₂) were observed to be of very poor water quality (Fig. 2).

Indicator species analysis of periphytic algae in sampling stations

Periphytic algae species with significant (≥5) indicator values in the Tudun Wada drain (TW₁, TW₂, and TW₃) include *Nitzschia* sp. (17), *Pediastrum* sp3. (8), *Nostoc* sp. (17), *Oscillatoria brevis* (40), *Oscillatoria tenuis* (26), and *Euglena* sp. (25) (Tables 2, 3, and 4).

Table 1: Mean surface water physico-chemical characteristics in Tudun Wada (TW)- Makera (MK) drains and River Kaduna (RK)

	TW1	TW2	TW3	RK1	RK2	RK3	MK1	MK2	MK3	RK4	RK5	RK6
pH	7.64	7.61	7.56	7.54	7.65	7.56	8.35	8.29	7.99	7.73	7.46	7.88
TD (ppm)	361.68	364.12	375.76	63.92	183.72	106.87	579.27	580.62	578.03	55.78	67.67	47.35
EC	722.04	730.36	750.08	133.08	367.40	213.83	1161.50	1161.50	1155.00	111.78	135.70	94.16
DO(mg/L)	1.23	1.05	1.10	1.61	1.29	1.51	1.35	1.47	1.32	1.66	1.78	1.67
BOD(mg/L)	3.31	3.78	2.95	3.27	2.26	2.70	4.46	6.33	4.34	3.47	4.26	3.54
P-P(mg/L)	0.17	0.13	0.13	0.16	0.11	0.15	0.37	0.36	0.35	0.22	0.18	0.24
N-N (mg/L)	2.38	2.36	2.63	2.24	2.31	2.29	3.07	2.85	3.31	2.80	2.78	2.66

Key: TDS = Total Dissolved Solids, EC = Electrical Conductivity, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, P-P = Phosphate – Phosphorus, N-N = Nitrate – Nitrogen

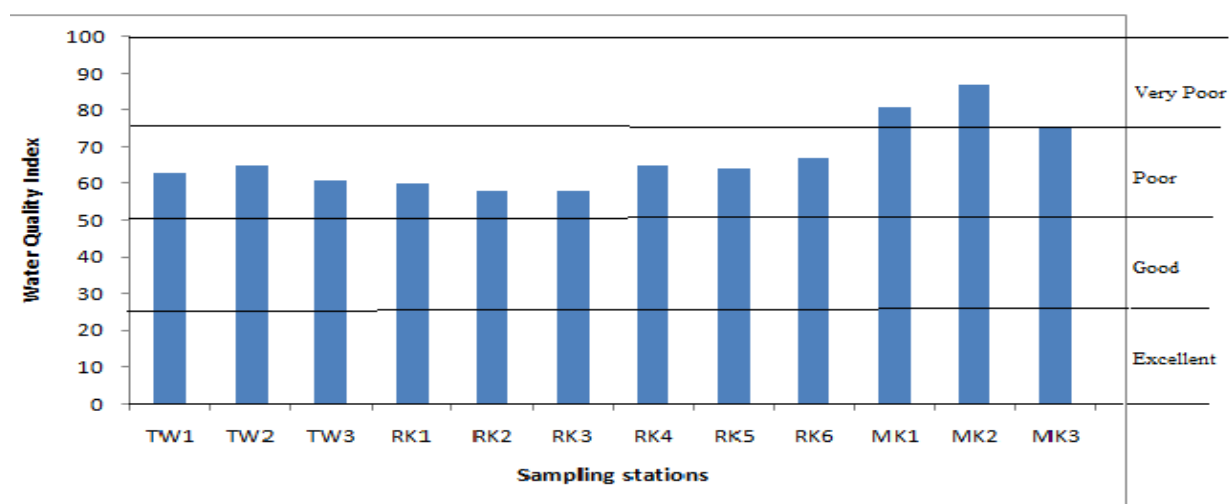


Fig. 2: Water Quality Index (WQI) of sampling stations in Tudun Wada-Makera drains-River Kaduna lotic systems

Table 2 :Indicator values for periphytic diatoms among sampling stations in Tudun Wada-Makera-River Kaduna Lotic systems

Bacillariophyta		TW 1,2,3	MK 1,2,3	RK1	RK2	RK3	RK4	RK5	RK6
1	<i>Achnanthes hungarica</i> Grun.	0	17	0	0	0	0	0	0
2	<i>Anomoneis</i> sp.	0	0	0	0	0	17	0	17
3	<i>Aulacoseira ambigua</i> (Grunow) Simonsen	0	15	0	0	0	1	0	1
4	<i>Aulacoseira granulata</i> (Grunow) Simonsen	0	12	0	0	0	3	32	3
5	<i>Aulacoseira</i> sp.	0	0	0	0	0	0	0	17
6	<i>Aulacoseira varians</i> (Grunow) Simonsen	0	13	0	0	0	8	0	13
7	<i>Coconeis placetula</i>	0	0	0	0	0	8	0	8
8	<i>Cymbella cistula</i> Ehr. (Ehr.)Kirchener	0	3	0	0	0	9	0	22
9	<i>Epithemia</i> sp.	0	17	0	0	0	0	0	0
10	<i>Epithemia zebra</i>	0	0	0	0	0	8	0	8
11	<i>Frustulia rhomboides</i>	0	1	21	0	21	0	0	7
12	<i>Gyrosigma</i> sp.	0	16	0	0	0	8	0	10
13	<i>Gyrosigma acuminatum</i> (Ehr.)Smith	0	0	0	0	0	0	17	0
14	<i>Melosira calognosa</i>	0	17	0	0	0	0	0	0
15	<i>Melosira distans</i> Ehr.	0	2	0	0	0	5	0	27
16	<i>Melosira</i> sp.	0	34	0	0	0	7	1	8
17	<i>Melosira sulcata</i> Ehr	0	33	0	0	0	0	0	0
18	<i>Nitzschia</i> sp.	17	0	0	0	0	0	0	0
19	<i>Pinularia</i> sp.	0	0	0	0	0	0	0	17
20	<i>Pleurosigma</i> sp.	0	0	8	0	8	0	0	0
21	<i>Surirella augusta</i> kg.	0	41	0	0	0	4	0	5
22	<i>Synedra ulna</i> (Nitzsch) Chr	0	0	0	0	0	2	9	22

Table 3: Indicator values for periphytic chlorophyta among sampling stations in Tudun Wada-Makera-River Kaduna Lotic systems

S/ No.	Species	TW 1,2,3	MK 1,2,3	RK1	RK2	RK3	RK4	RK5	RK6
1	<i>Botryococcus</i> sp.	0	17	0	0	0	0	0	0
2	<i>Closterium aerosum</i>								
3	<i>Closterium moniliferum</i>	0	0	0	0	0	0	0	17
4	<i>Closterium lonula</i>	0	2	24	0	24	0	0	0
5	<i>Closterium</i> sp.1	0	0	16	0	16	0	0	2
6	<i>Closterium</i> sp.2	0	0	14	0	14	0	0	5
7	<i>Closterium</i> sp3	0	0	0	0	0	0	0	17
8	<i>Closterium</i> sp4	0	0	0	0	0	0	0	17
9	<i>Coelastrum intermedium</i> (Bohl) Kros	0	0	0	0	0	0	0	17
10	<i>Cosmarium botrytis</i>	0	0	0	0	0	8	0	8
11	<i>Cosmarium margariferum</i>	0	0	0	0	0	0	0	17
12	<i>Cosmarium marigatum</i>	0	0	0	0	0	0	0	33
13	<i>Cosmarium quasillus</i>	0	0	8	0	8	0	0	0
14	<i>Cosmarium</i> sp.1	0	0	0	0	0	0	0	17
15	<i>Cosmarium</i> sp.2	0	0	0	0	0	0	0	17
16	<i>Pediastrum duplex</i> Smith	0	0	8	0	8	0	0	17
17	<i>Pediastrum simplex</i> (Meyen) Lemmerman	0	0	0	0	0	8	0	8
18	<i>Pediastrum duplex</i> var. <i>regulosum</i> Raciborski	0	0	0	0	0	0	0	17
19	<i>Pediastrum duplex</i> var. <i>reticulatum</i> Largerhein	8	0	0	0	0	0	0	8
20	<i>Penium</i> sp.	0	0	0	0	0	0	0	17
21	<i>Scenedesmus acumunatus</i> (Lag) Chodat	0	0	0	0	0	8	0	8
22	<i>Scenedesmus acutus</i> Meyen	0	0	0	0	0	0	0	17
23	<i>Scenedesmus bijuga</i> Turp Legerhem	0	0	0	0	0	3	3	28
24	<i>Scenedesmus bijuga</i> var. (Reinsch) Hansgird	0	0	0	0	0	0	0	17
25	<i>Scenedesmus obliquus</i>	0	0	0	0	0	6	0	11
26	<i>Scenedesmus opolinensis</i> P. Richt 1896	0	0	0	0	0	0	0	17
27	<i>Scenedesmus quadricauda</i> Smith	0	0	0	0	0	0	0	17
28	<i>Scenedesmus incrasatulus</i> Bohlin	0	0	0	0	0	8	0	8
29	<i>Scenedesmus</i> sp.	0	0	0	0	0	8	0	8
30	<i>Scenedesmus dimorphus</i> (Turp) Kg.	0	0	0	0	0	0	0	16
31	<i>Spirogyra</i> sp.	4	0	4	0	4	0	17	4
32	<i>Staurostrum</i> sp.	0	0	0	0	0	8	0	8
33	<i>Stigeoclonium pachydermum</i> Prescott	0	0	0	0	0	8	0	8
34	Ui	0	0	0	0	0	8	0	8

Table 4: Indicator values for periphytic cyanobacteria and euglenophyta among sampling stations in Tudun Wada-Makera-River Kaduna Lotic systems

	TW1,2,3	MK1,2,3	RK1	RK2	RK3	RK4	RK5	RK6
Cyanobacteria								
<i>Merismopedia glauca</i>	0	0	0	0	0	4	0	12
<i>M. elegance</i>	0	0	0	0	0	0	17	0
<i>Nostoc</i> sp.	17	0	0	0	0	0	0	0
<i>Oscillatoria brevis</i>	40	26	0	0	0	0	1	0
<i>Oscillatoria lacustris</i>	0	0	0	0	0	7	12	14
<i>Oscillatoria limosa</i>	0	27	0	0	0	1	20	1
<i>Oscillatoria tenuis</i>	26	22	16	0	16	0	3	0
Euglenophyta								
<i>Euglena</i> sp.	25	8	0	0	0	0	0	0

Species with the highest indicator value in the Makera drain (MK1, MK2, and MK3) include *Achnanthes* sp. (17), *Aulacoseira ambigua* (15), *Aulacoseira varians*, *Aulacoseira granulata*, *Epithemia* sp. (17), *Gyrosigma* sp. (16), *Melosira calognosa* (17), *Melosira* sp. (34), *Melosira sulcata* (33), *Surirella augusta* (33), *Botryococcus* sp. (17), *Oscillatoria brevis*, *Oscillatoria limosa* (26) and *Euglena* sp.

Species with significant (≥ 5) indicator values in sampling stations on the River Kaduna (RK1, RK2, RK3, RK4, RK5, and RK6) include *Frustulia rhomboides*, *Aulacoseira varians*, *Anomoneis* sp., *Aulacoseira granulata*, *Coconeis placentula*, *Gyrosigma* sp., *Gyrosigma acumunatum*, *Melosira distans*, *Pinnularia* sp., *Synedra ulna*, *closterium moniliferum*, *closterium lonula*, *closterium species1*, 2, 3 and 4 *Coelastrum* sp., *Cosmarium marigatum*, *Cosmarium nudum*, *Cosmarium margariferum*, *Cosmarium quasillus*, *Cosmarium* sp.2, *Cosmarium* sp., *Pediastrum simplex*, *pediastrum duplex*, *Pediastrum* sp.2 and 3, *Penium* sp., *Scenedesmus acumunatus*, *Scenedesmus acutus*, *Scenedesmus bijuga*, *Scenedesmus obliquus*, *Scenedesmus opoliensis*, *Scenedesmus quadricauda*, *Scenedesmus* sp. 1, 2, 3, *Spirogyra* sp., *Staurasmus* sp., *Stigeoclonium pachydermum*, *Merismopedia glauca*, *Merismopedia elegans*, *Oscillatoria lacustris* (Tables 2, 3 and 4).

Canonical correspondence analysis (CCA)

Canonical correspondence analysis (CCA) was observed to group periphytic algae species, sampling stations, and surface water Physico-chemical characteristics into two major groups. Species indicative of high pollution such as *Euglena* sp., *Aulacoseira ambigua*, *A. varians*, *Oscillatoria brevis*, and *Surirella augusta* were grouped with heavily polluted sites (TW1, TW3, MK1, MK2, RK1, and RK3) with high EC, TDS, TA, and BOD. The second group is

comprised of species less tolerant to pollution such as *Aulacoseira granulata*, *Navicula cuspidata*, *Nitzschia* sp., *Oscillatoria limosa*, *Cymbella cistula*, *synedra ulna*, *Cosmarium marigatum* and *C. nodum* grouped with less polluted sites RK5, TW2 and RK2.

DISCUSSION

Physico-chemical characteristics

Pollution tolerant species were observed to have the highest indicator species value on the drains. Most of them are observed to be members of the Bacillariophyta, cyanobacteria, and euglenophyta. Indicator species of the Makera drain which are primarily modified by effluent from a brewing industry and secondarily by discharges from residential areas include *Achnanthes hungarica*, *Aulacoseira ambigua*, *Epithemia* sp., *Gyrosigma* sp., *Melosira calognosa*, *Melosira sulcata*, *Melosira* sp., *Surirella augusta*, *Oscillatoria limosa*, and *Botryococcus* sp. Reynolds (2006) classified *Aulacoseira ambigua*, as an indicator of eutrophic waters.

The species indicative of the water quality on the Tudun Wada drain which is modified mainly by effluents from the Kaduna Central Market and residential areas in Tudun Wada included *Nitzschia* sp., *Nostoc* sp., *Oscillatoria brevis*, *Oscillatoria tenuis*, and *Euglena* sp. Species of *Nitzschia*, *Oscillatoria*, and *Euglena* have been reported to have a high tolerance for organic pollution (Bere and Tundisi, 2011a and b; Hosmani, 2013).

Species indicative of water quality in the low polluted stations on River Kaduna which is mainly influenced by the agricultural activities on its banks as well as several discharges from so many other drains include *Anomoneis* sp., *Aulacoseira granulata*, *Coconeis placentula*, *Frustulia rhomboides*, *Gyrosigma acumunata*, *Melosira distans*,

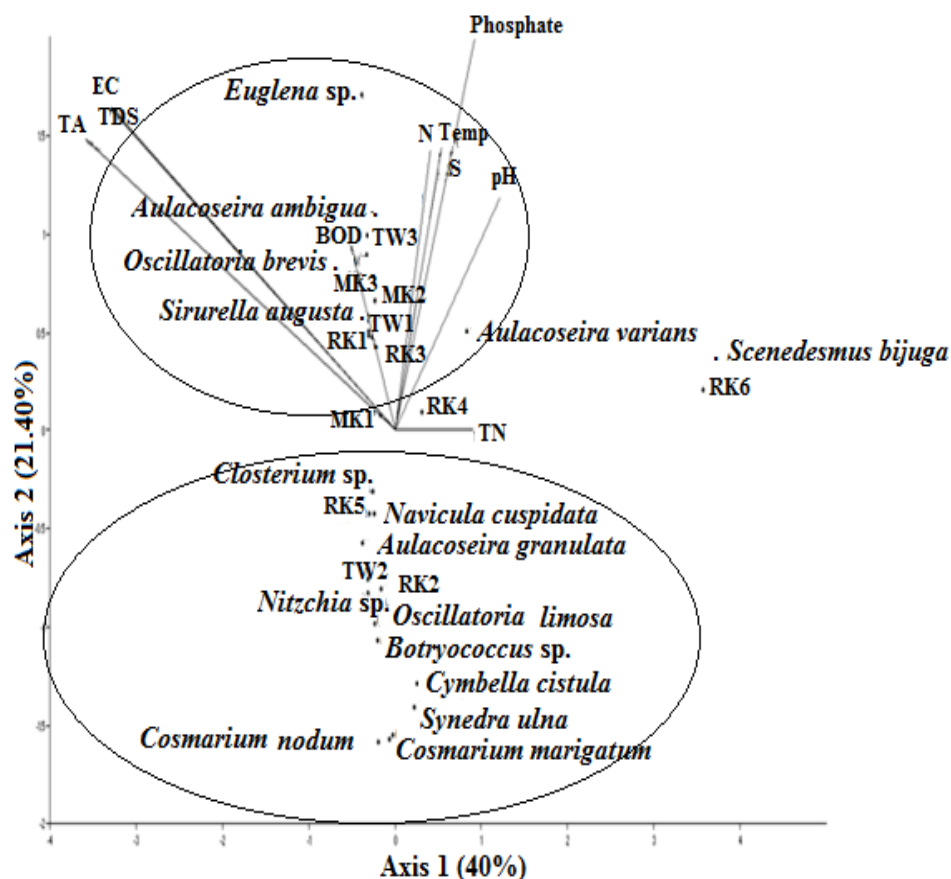


Fig. 3: Canonical correspondence analysis (CCA) triplot for 11 surface water physico-chemical characteristics and most abundant (relative abundance > 5%) periphyton algae species in Tudun Wada-Makera drains and River Kaduna lotic systems (Temp= temperature, TDS= Total Dissolved Solids, EC= Electrical Conductivity, DO= Dissolved Oxygen, BOD= Biochemical Oxygen Demand)

Synedra ulna, *Coelastrum* all species of *Closterium* and *Scenedesmus*, *Staurostrum* sp., *Merismopedia glauca*, *M. elegans* and *Oscillatoria lacustris*. Rawson (1956), classified *Aulacoseira granulata*, to be an indicator of oligotrophic water while Bere and Tundisi (2011a) classified *Synedra ulna* as an indicator of highly polluted waters. The contradiction observed in the case of *Synedra ulna* could be due to the variation in ecological characteristics displayed by the species from one region of the world to another. Salmoni *et al.* (2011) observed similar variations for *Gomphonema parvulum* in Brazil and Japan.

The tolerant species have been reported to be associated with waters with relatively high nutrient load, low dissolved oxygen, high ionic strength, and electrical conductivity (Doung *et al.* 2006). It is also well documented that algae species are usually indicative of the upper limits of the pollution that they can tolerate and not the lower limit (Lange-Bertalot, 1979; Biggs and Kilroy, 2000; Bere and Tundisi, 2011b; Salmaso *et al.*, 2014; Dalu and Bere, 2015). This implies that species that develop well in polluted zones may also be found in clean waters.

Canonical correspondence analysis triplot of periphyton, surface water Physico-chemical and sampling stations separated periphyton species into two major groups. The first comprises species that are positively associated with EC, TDS, Total

alkalinity, and BOD such as *Aulacoseira ambigua*, *Euglena* sp., *Oscillatoria brevis*, and *Surirella ovalis*. Species that are positively associated with these parameters are tolerant to organic pollution and eutrophication (Kshirga, 2013; Hosmani, 2013; Wilson *et al.*, 2014; Beyer *et al.*, 2015).

The second group comprised *Aulacoseira granulata*, *Closterium* sp., *Navicula cuspidata*, *Nitzschia* sp., *Oscillatoria limosa*, *Botryococcus* sp., *Cymbella cistula*, *Synedra ulna*, *Cosmarium marigatum*, and *C. nudum* could be considered indicators of low pollution because of their negative association with this factors total alkalinity, TDS, EC, BOD, NO₃-N, total nitrogen, pH and PO₄-P (Jafari and Gunale, 2006).

The significant positive association observed between Surface water temperature, TDS, EC, total alkalinity, total nitrogen, BOD, SO₄, pH, PO₄-P, NO₃-N with *Oscillatoria brevis* and *Nostoc* sp. indicates that these species thrive in polluted water.

CONCLUSION

The periphytic algae species observed were indicative of the variation in water quality. Indicator species of the Makera drain which conveys effluents from an industrial area, with a 'very poor water quality' status include *Achnanthes hungarica*, *Aulacoseira ambigua*, *Epithemia* sp., *Gyrosigma* sp., *Melosira calognosa*, *M.*

sulcata, *M.sp.*, *Surirella augusta*, *Oscillatoria limosa*, and *Botryococcus* sp.

Whereas Indicator species of the Tudun Wada drain, a drain conveying effluents from an urban market and residential areas are *Nitzschia* sp., *Nostoc* sp., *Oscillatoria brevis*, *Oscillatoria tenuis*, and *Euglena* sp., while those of the stations on River Kaduna include *Anomoneis* sp., *Aulacoseira granulata*, *Coconeis placentula*, *Frustulia rhomboides*, *Gyrosigma accumulata*, *Melosira distans*, *Pinnularia viridis*, *Synedra ulna*, *Coelastrum*, all species of *Closterium*, all species of *Scenedesmus*, *Staurastrum* sp., *Merismopedia glauca*, *M. elegans* and *Oscillatoria lacustris*.

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