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RESEARCH PAPER

Exploring the use of Macrophytes as Biological Indicators for Organic Pollution of Chanchaga River in North Central Nigeria

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ABSTRACT
Macrophytes are creatures with low versatility and cannot stay away from any mix of streamflow, nutrient accessibility, and other physical and chemical attributes that impact their survival in the aquatic system. Sampling for macrophytes in Chanchaga River was conducted monthly for a 6-month period (May - October 2019). Sampling stations were selected at approximately equal distance along the streamline, the aquatic vegetation were surveyed, and some environmental variables were analysed using standard methods. Results obtained indicated that temperature ranged from 24.6-28.4°C; pH 6.4 -9.7; Electrical conductivity 28.0-79.0µS cm^{-1}; Total dissolved solids 16-75 mg L^{-1}; Dissolved oxygen(DO) 1.3-5.2 mg L^{-1}; Nitrate 0.217-0.654 mg L^{-1}; Phosphate 0.084-0.211 mg L^{-1}; Biological oxygen demand (BOD) 0.89-5.4 mg L^{-1} and total alkalinity 8.00-11.00 mgL^{-1} for the study period. A total of eleven (11) macrophyte species belonging to ten genera and eight families were identified during the entire study. Variations in terms of families showed that Araliaceae was the most abundant followed by Poaceae, while Cyperaceae had more species throughout the study period. The high frequency of Araliaceae, Cyperaceae, and Poaceae families suggests that the environmental characteristics favour these species. We propose the use of *Cyperus digitatus, Cyperus papyrus* and *Mimosa* spp. as macrophytes indicators of organic pollution in Chanchaga River.
Keywords: Aquatic plants, Araliaceae, Environmental variables, lotic system, Physicochemical parameters

INTRODUCTION

The significance of the aquatic macrophytes community in the aquatic ecosystem cannot be overemphasized; they are mostly essential primary producers because they produce high biomass and add to life forms (Celewicz-Goldyn & Kuczynska-Kippen, 2017). They also have the ability to increase the diversity of ecological niches, thus providing a habitat structure for other groups such as periphyton, macroinvertebrates, fish and birds (Rodrigues et al., 2019; Nouri et al., 2021). The morphological and physiological characteristics of macrophytes may show certain variations which depend on development stage, light conditions and nutrient concentration. Nutrient improvement and the influx of organic pollutant has been known to account for the structural change of macrophytes in running water bodies (Pajević et al., 2003; Bytyqi et al., 2020). Conversely, an increase in certain nutrients and the presence of pollutants are known to have an effect on the distribution of aquatic macrophytes (Onaindia et al., 2005). Therefore, aquatic macrophytes may be very useful in the biological monitoring of aquatic systems since changes in the composition of aquatic vegetation are reliable indicators of the quality of water. They also function as

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integrators of environmental conditions to which they are subjected and thus can be used as long-term indicators with high spatial resolution (Rameshkumar et al., 2019; Sarkar et al., 2020). Besides, aquatic macrophytes have been accounted for to improve water quality (Thiébaut and Muller, 2003), impact algal development (Hu & Hong, 2008) and their remarkable ability to accumulate chemical elements in their tissues (Ansari et al., 2020). By accumulating increased amounts of chemical elements, macrophytes contribute to nutrient cycling and sediment stabilization, thus affecting the extent of eutrophication(Kim et al., 2018). Very important is their role in heavy metal accumulation since heavy metal concentrations in macrophytic tissues may be 106 times as high as their concentrations in an aquatic environment (Rai, 2009).

Many freshwater aquatic plant and animal species are endangered and facing possible extinction in most parts of the world as a result of global warming and pollution. The trend is not different from Africa and Nigeria in particular where flowing water bodies are impacted by industry development, agriculture activities, pesticide use and organic pollution (Arimoro et al., 2021). Therefore, the monitoring of aquatic organisms of these ecosystems and in particular the rivers is of great importance. There is a huge chuck of data on biological monitoring and study of the aquatic ecosystem based on several indicator organisms including macroinvertebrates, plankton and fish in Nigeria (Arimoro et al., 2014; 2018; 2021; Arimoro and Keke, 2021). The use of aquatic macrophytes for biomonitoring in Nigeria waters is sparse (Abubakar et al., 2013) even though their diversity, health and composition are likely to be important determinants of water quality (Balanson *et al*., 2005). They are amongst the least known and least studied components of urban streams and biota flows. Therefore the aim of this research is to assess the ecological status of the Chanchaga River using macrophytes, based on the hypothesis that the water of this river during its course changes in its quality according to the organic pollution and other pollution caused by anthropogenic activities.

MATERIALS AND METHODS

Chanchaga River is located within the Sudan Savannah zone of Nigeria (9º 0'5'N; 6°23'20'E) with two distinct seasons (wet and dry seasons). The wet season lasts from May to October, and dry season runs from November to April. The river is situated near Chanchaga village of Chanchaga Local Government Area of Niger State. For the pursuant of this research, the study area was divided into three stations along the river course, which is based on the ecological setting of the sampling area. Station 1, (N12° 16'07", E 8° 31'06") located approximately 15km from the head water. Human activities such as games and irrigation activities, take place during the dry season. Vegetations are subjected to chemicals input from fertilizer application. Station 2 (N12° 17'32", E 8° 31'07") is approximately 50m underneath the motorable and pedestrian bridge and about 1km away from Station 1. The activities in this station include; irrigation by block industry, washing of clothes, and bathing. Station 3 (N12°18'28", E 8°30'40"), human activities like washing and bathing take place. The station is estimated 50m away from the motorable bridge.

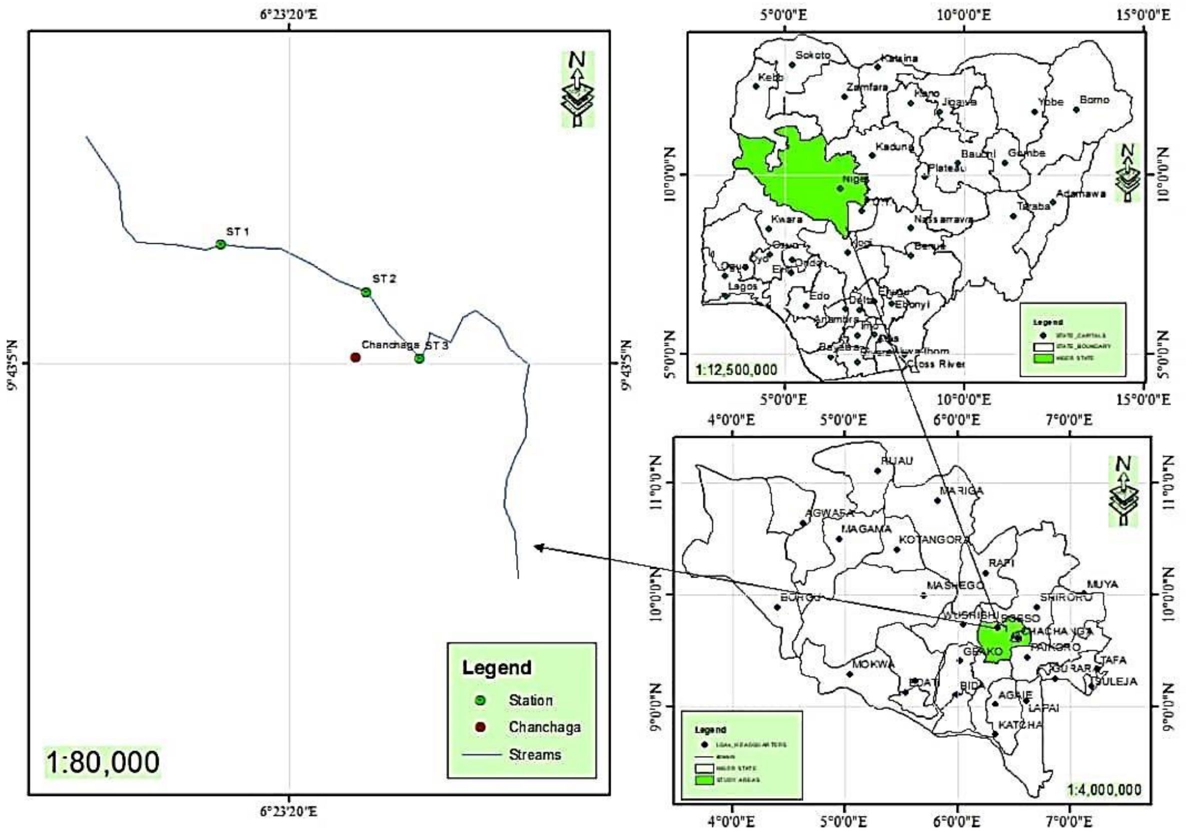

Figure 1. Map of the study site (Chanchaga River) in Niger State, Nigeria
Source: The Department of Geography, Federal University of Technology Minna.
Centre for Remote Sensing (2019).

Water samples were collected monthly between May and October 2019 at each sampling station between the hours of 8:00 am -11:00 am. A Hanna HI 991300/1 multi-probe meter was used for measuring values of temperature, dissolved oxygen (DO), electrical conductivity, total dissolved solids, and Hydrogen Ion concentration (pH) *in-situ*. Water samples were collected in pre-rinsed 500ml bottles and transported to the laboratory. The water samples were analyzed for biochemical oxygen demand (BOD_5), total alkalinity, nitrate, and phosphate using standard methods for the examination of water and wastewater (APHA et al., 1998).

Each station served as a sampling station and was inventoried by visual estimation from a standpoint. The abundance of aquatic macrophytes was measured through visual estimation of composition and abundance of species to obtain a proper representation of the marshland vegetation. All the aquatic macrophytes were identified using standard protocols published in books and literature (Cook et al., 1974; Obot and Ayeni, 1987; Ita, 1994; Birnin – Yauri, 2010).

The range, the mean, and standard deviation for each parameter and station were calculated. Community attributes (metrics), physical and chemical features of stations were compared using one way ANOVA on log (x + 1) transformed data. Significant ANOVAs ($P < 0.05$) were followed by post hoc {DUNCAN multiple range tests} tests to identify differences between Station means were calculated using the computer BASIC program SP DIVERS (Ludwig and Reynolds, 1988). The relationships between macrophyte species and environmental variables were evaluated with Canonical correspondence analysis (CCA) in PAST statistical package (Hammer et al., 2001). Variables that covaried with other variables such as electrical conductivity and Temperature (Pearson correlation r > 0.80, P < 0.05) were removed from the CCA before analysid. Variables were log transformed {log (x + 1)} before the CCA analysis to prevent extreme values (outlier) from unduly influencing the ordination obtained. The canonical axes extracted were tested for significance with Monte Carlo permutation test using 199 permutations.

RESULTS AND DISCUSSION

The Mean and Standard Error of the environmental variables of the study stations of Chanchaga River are summarized in Table 1. Water temperature ranged from 24.40 °C to 28.40 °C, while the pH values (6.4 to 9.4) was slightly acidic to weak alkaline. The dissolved oxygen (DO) and BOD level ranged between 0.80 and 5.40 mg/L. The levels of Total Dissolved solids (TDS) and --------

Table 1: Physicochemical parameters of Chanchaga River, North Central Nigeria from May – October 2019.

	STATION 1	**STATION 2**	**STATION 3**	**P-VALUE**
pH	7.18±0.47 (6.40-9.50)	7.22±0.44 (6.60-9.40)	7.261±0.49 (6.60-9.70)	0.987
Electrical Conductivity (µS/cm)	44.67±6.78 (29.00-70.00)	49.67±7.75 (33.00-77.00)	48.33±8.65 (28.00-79.00)	0.895
Dissolved oxygen (mg/L)	2.82±0.52 (1.70-5.20)	2.35±0.55 (1.20-3.40)	2.68±0.71 (0.80-5.40)	0.736
Biochemical oxygen demand (mg/L)	2.82±0.42 (1.80-4.11)	2.17±0.36 (1.20-3.40)	2.53±0.76 (0.80-5.40)	0.736
*Total Alkalinity (mg/L)	9.05±0.78[a] (8.00-10.20)	10.01±0.33[b] (9.20-11.05)	9.66±0.15[ab] (9.20-10.00)	0.002
Nitrate (mg/L)	0.29±0.05 (0.22-0.55)	0.31±0.62 (0.23-0.61)	0.32±0.07 (0.23-0.65)	0.930
Phosphate (mg/L)	0.11±0.02 (0.08-0.21)	0.12±0.02 (0.08-0.22)	0.11±0.02 (0.08-0.20)	0.994
*Total dissolved solids (mg/L)	40.83±7.70 [a] (17.00-60.11)	42.00±7.84[a] (16.09-64.01)	55.33±8.62[b] (22.55-74.45)	0.020
Temperature(°C)	26.18±0.62 (24.80-28.40)	26.22±0.61 (24.60-28.30)	26.37±0.33 (24.90-28.40)	0.974

*Data is the Mean ± S.E.M. derived from monthly values with minimum and maximum values in parenthesis. Different lowercase letters in a row show significant differences (P<0.05) indicated by Duncan multiple range tests (DMRT). *Significantly different*

Electrical conductivity recorded ranged between 16.09mg/L to 74.45mg/L and 28.00 µS/cm to 77.00µS/cm, respectively. The values for alkalinity, Phosphate and Nitrates values ranged from 8.00 mg/L to 11.05, 0.08 mg/L to 0.22 mg/L, and 0.22 mg/L to 0.65 mg/L, respectively. Temperature, pH, DO, BOD, TDS, conductivity, phosphates, and nitrates were similar in all stations sampled while total alkalinity differed significantly (P < 0.05) among the stations.

The stretch of the river where this study was undertaken showed that the water quality was comprised at some stations with elevated nutrient levels (i.e. nitrate and phosphate) as a result of the anthropogenic activities occurring there (Edegbene et al., 2019). Local environmental disturbances, natural geological processes, patterns of land use, and other related anthropogenic events can alter the physicochemical parameters of aquatic ecosystems (Sundermann et al., 2013). Water quality is often impacted by either the leakage into a body of water of organic and inorganic components or contaminants with visible alterations in the biotic population and diversity and abundance (Arimoro et al., 2021). Most of the parameters showed that water quality was better at station 1(upstream) as compared to stations 2 and 3 (downstream). This could be linked to reduced anthropogenic influences in station 1 and increased pressure at stations 2 and 3. The temperatures were consistent between the stations, with the minimum and maximum recorded in station 1 and station 3, respectively. Temperature has been described as one of the factors that affect the functioning of the aquatic environment by influencing the growth and distribution of flora and fauna (Tank and Chippa, 2013; Jalal and Sanalkumar, 2012). The temperature recorded in May was the highest indicating that this to be the hottest month in the region of study. The values of temperature recorded in this study are consistent with other studies obtained within the region (Okayi et al., 2012; 2013; Arimoro & Keke, 2021; Arimoro et al., 2021).

The pH of the river water fluctuated between 6.4 and 9.7. At a certain level, the higher pH level can directly impact aquatic life; nevertheless, BIS (2003) recommended an optimal level of 6.5–8.5. The pH is an essential attribute of any aquatic environment as all the biochemical mechanisms and persistence of the water's physical and chemical characteristics change depending on the pH of that same immediate environment (Jalal and Sanalkumar, 2012). Most studies have recommended water samples to be somewhat alkaline attributable to carbonates and bicarbonates (Gopalkrushna, 2011; Tank and Chippa, 2013). Electrical conductivity range of between 28 and and 79µS/cm obtained in the river is an indication that the river potential to transmit electrical current is minimal (Lodh et al., 2014). This river's electrical conductivity comes under Class I category of African waters with an ionic concentration of less than 600 µS/cm. The electrical conductivity values records were similar to that obtained for other water bodies within the region (Arimoro & Keke, 2021; Arimoro et al., 2021).Total dissolved solids (TDS) varied between 16.09 and 77.4mg/L with station 3 having significantly higher values. TDS are soluble substances such as bicarbonate, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions in water. The higher values obtained in station 3 could partly be driven by block industries, agricultural runoff, and residential residues. Present results related to previous studies of Arimoro et al., (2021) for Oiniyi River receiving effluent from cement industry. Dissolved oxygen (DO) fluctuated greatly between 0.80 and 5.40 mg/L. DO refers to the amount of oxygen available in the water body and the quantity used by respiratory species. Because of their major biological and physicochemical features of the surrounding water, they are critical water quality parameters to preserve. As a photosynthetic by-product of aquatic plants, oxygen enters the water through aerial diffusion (Kotadiya Nikesh and Acharya, 2014). The DO changes depending on the water's temperature, salinity, and degree of pollution. The DO rate shows the level of contamination in waterways (Gopalkrushna, 2011). It is necessary to have a minimum DO of 5 mg / l (BIS / ICMR). A slight decrease in dissolved oxygen was observed from June to October in all stations in the present study, although with station recording relatively higher values. Remarkably, the dissolved oxygen levels values were found below the required limit in the present study indicating the organic contents of the water was high. This may be as a result of agricultural activities (including excessive use of inorganic nitrogen fertilizers and manures), sewage disposal (Edegbene et al., 2019) in the area. The crystallization of nitrogen by-products in animal and human droppings, including septic systems, nitrate and phosphates could penetrate both groundwater and surface water leading to depletion of dissolved oxygen and rise in BOD (Arimoro et al., 2021). Also, the values of phosphate at the three stations were above the United States Environmental Protection Agency (USEPA) standard limits of 0.025mg/L in natural aquatic bodies. This could also be linked to the intense agricultural activities in the riparian zone. Relatively, low values of nitrate concentration, which was within the limit acceptable by USEPA and E.U. standard for the aquatic environment, were obtained in all stations. The phosphate and nitrate values were low as compared to that reported by Okayi et al., (2012) in River Benue, Benue State of Nigeria. The fluctuation of these parameters could be due to a change in weather conditions during the study period (Uneke and Okereke, 2015).

A total of 11 species of macrophytes belonging to 8 families were identified throughout the study period. The majority of macrophytes identified were pennywort (*Hydrocotyle leucocephala)* belonging to the Araliaceae family, abundant in Station 1. The Poaceae family constituted the second most common group of macrophytes sampled based on visual biomass observation. The Poaceae family was represented by *Cynodon dactylon*. This species was distributed in all three studied stations. The Cyperaceae family contributed the most diverse family with three species represented, found in stations 2 and 3. The species identified in order of decreasing percentage abundance were; *Cyperus digitatus, C. papyrus,* and *Fuirena ciliaris*, respectively. Family Fabaceae was the second most diverse aquatic macrophyte family represented by two individual species. This family was represented by *Mimosa diplotricha* encountered in station 1 and 2, while *Senna obtusifolia* was only sporadically encountered in station 1.

Table 2: The distribution and abundance of species encountered during the period of study.

Family	Species	Common Name	Abundance		
			ST1	ST2	ST3
Araliaceae	*Hydrocotyle leucocephala*	Pennywort	+++	++	++
Convolvulaceae	*Ipomoea aquatica*	Water Spinach	++	+	
Poaceae	*Cyonodon dactylon*	Bermuda grass	++	++	+
Cyperaceae	*Cyperus digitatus*	Flat sedge		++	+
	Cyperus papyrus	Papyrus sedge		++	+
	Fuirena ciliaris			+	
Capparaceae	*Cleome viscose*	Tick weed		+	
Boraginaceae	*Heliotropium indicum*	Heliotrope	+	+	
Onagraceae	*Ludwigia hyssopifolia*	Water primrose		+	
Fabaceae	*Mimosa diplotricha*	Nilla grass	+	+	
	Senna obtusifolia	Sickle pod		++	

Key: + = present
++ = abundant
+++ = more abundant

Family Convolvulaceae contributed the third most common macrophytes taxa encountered during the study. Station 3 had no individuals of *Ipomoea aquatica,* the highest individuals were visualized in station 1, while the least was visualized in Station 2. Water primrose (*Ludwigia hyssopifolia)* was the second least number of individuals of macrophytes in this study, with just six individuals identified only at Station 2. *L. hyssopifolia* represents the Onagraceae family of aquatic macrophytes during the period of study. The Capparaceae family made of one species (*Cleome viscose*) with only two individuals encountered in the month of May, thoughout the study period restricted to station 2. The macrophyte distribution pattern is primarily determined by the amount of light available to reach the plant and the clarity of the water. Several studies found these to be the most significant factors that govern macrophyte abundance, composition, and distribution (Rameshkumar et al., 2019, Nouri et al., 2021). A total of 11 species of aquatic macrophytes belonging to 8 families were identified during the period of study (May – October 2019) in Chanchaga River. This number is similar to the number of families of macrophytes found in Oyan Lake of Ogun State, Nigeria, as reported by Dienye and Olapade, (2017), but much lower than 13 different aquatic macrophytes families, with 31 species in Kainji and Jebba Lake as opined by Daddy (1993). Relatively, less human impacts in the study stations, in contrast to other water bodies that are used for the dumping of human wastes and other pollution agents, could be responsible for the low abundance (number of individuals) and diversity of macrophytes that were recorded in this study. It has been highlighted that the distribution and growth of aquatic macrophytes are correlated with nutrient-rich environments, mainly nitrate and phosphate, which have been reported as essential nutrients for growth in macrophytes (Frankouich et al., 2006)

Araliaceae and Poaceae families of aquatic macrophytes were well distributed in all study stations while others were only in 1 or 2 stations during the study period. The family Araliaceae represented by *Hydrocotyle leucocephala* had the highest observable frequency, with more abundance at station 1. This could be that the environmental factors surrounding the Chanchaga River are favorable to the distribution and abundance of *H. leucocephala* and *Cynodon dactylon.* The Poaceae family's *Cynodon dactylon* is a tufted perennial swamp grass up to 10-60 cm tall, rapidly spreading through rhizomes and stolons, as well as through seed dispersal. It is a crucial lowland rice weed, which also occurs in swamps and shallow waters (Ita 1994). This could owe to its distribution. *Cleome viscose* belonging to the Capparaceae family, also called tick weed, the plant is an erect, branched, annual plant with sticky leaves; it can grow 40 – 150cm tall. This plant was the least abundant and was only encountered in May. This could be because of the rise in water volume due to the commencement of a proper rainy season. Human effect on the water quality and natural activities switches the structure of aquatic macrophytes (Rameshkumar et al., 2019). In this study, for all stations, small but noticeable temporary disparities in macrophyte abundance (proportion of individuals) and variety were observed among the respective sampling months. Overall, macrophyte abundances were recorded in May were marginally higher than in the subsequent months. This may probably be a reaction to the reduction of ecological pressures as a consequence of the rainwater dilution and washout implications of the wet season and also the water body's water volume change (Dienye, 2015; Bucior et al., 2021). Exposure to wind and waves largely influences the distribution of aquatic plants in shallow waters (Pankhurst, 2005). Aquatic macrophyte is an essential habitat for fish, which can be fed on, used as breeding station and shelter. It also plays a crucial role in absorbing trapped nutrients from bottom sediments back into the aquatic environment, and organic matter produced by aquatic macrophytes can boost benthic organism development (Thomaz et al., 2009). They also can serve in water treatment systems and aid in Agricultural effluent removal.

The CCA ordination showed a good relationship between macrophytes distribution and measured physicochemical variables (Fig. 2). The strongest explanatory factors were pH, BOD, nitrate and alkalinity. Sixty-four percent of variation in the taxa abundance data was accounted for by the environmental variables measured in axis 1. The macroinvertebrate taxa and the selected set of environmental variables based on the first and sum of all canonical eigenvalues was however not significant (P > 0.05) by Monte Carlo Permutation test. The CCA triplot of macrophytes and physicochemical variables based on the first two axes extracted explained 63.92% of the variation in axis 1 and 38.08% in axis 2. The eigenvalues of axes 1 and 2 were 0.423 and 0.239 respectively (Table 3). CCA axis 1 revealed a gradient primarily concerned with pollution. This was determined by BOD and nitrates (Table 3). Samples taken from stations 2 and 3 are positioned on the left whereas those from station 1 are on the right. According to the CCA ordination (Fig. 2) *Hydrocotyle leucocephala*, *Ipomoea aquatica* and *Senna obtusifolia* were strongly associated with station 1. On the other hand, *Fuirena ciliaris* was strongly associated with station 3 while *Ludwigia hyssopifolia* was strongly associated with station 2. The variations in environmental variables indicate that higher macrophyte abundance at Chanchaga River at station 1 may be attributed to the fairly good water quality and low BOD value. Similar observations was reported by Bucior et al., (2021) in some temperate streams. The CCA also revealed that Phosphate, Nitrate, and TDS were positively correlated with station 2 and these were factors responsible for pollution with the associated taxa (*Cyperus digitatus, Cyperus papyrus* and *Mimosa* sp.). This study therefore indicates that these macrophytes are powerful predictors of water quality and can be used to detect degradation in water and habitat quality due to organic pollution.

Table 3. Axis eigenvalues and weighted intraset correlation between axes and environmental variables following canonical correspondence analysis of macrophyte taxa abundance data in Chanchaga River, Nigeria.

	Axis 1	**Axis 2**
Eigenvalue	0.42392	0.23932
%	63.92	36.08
pH	**-0.91439**	0.494541
DO	**0.65267**	**0.688329**
BOD	**0.769654**	**0.558011**
Alkalinity	**-0.88916**	-0.36607
Nitrate	**-0.97442**	0.321375
Phosphate	-0.40483	**-0.86915**
TDS	**-0.77306**	**0.708698**

Note: Significance of the axes by Monte Carlo test is given: P values for Monte Carlo permutation test axis 1: P = 0.3743. Axis 2, P = 0.4921.
Values in bold indicate significant difference at P < 0.05.

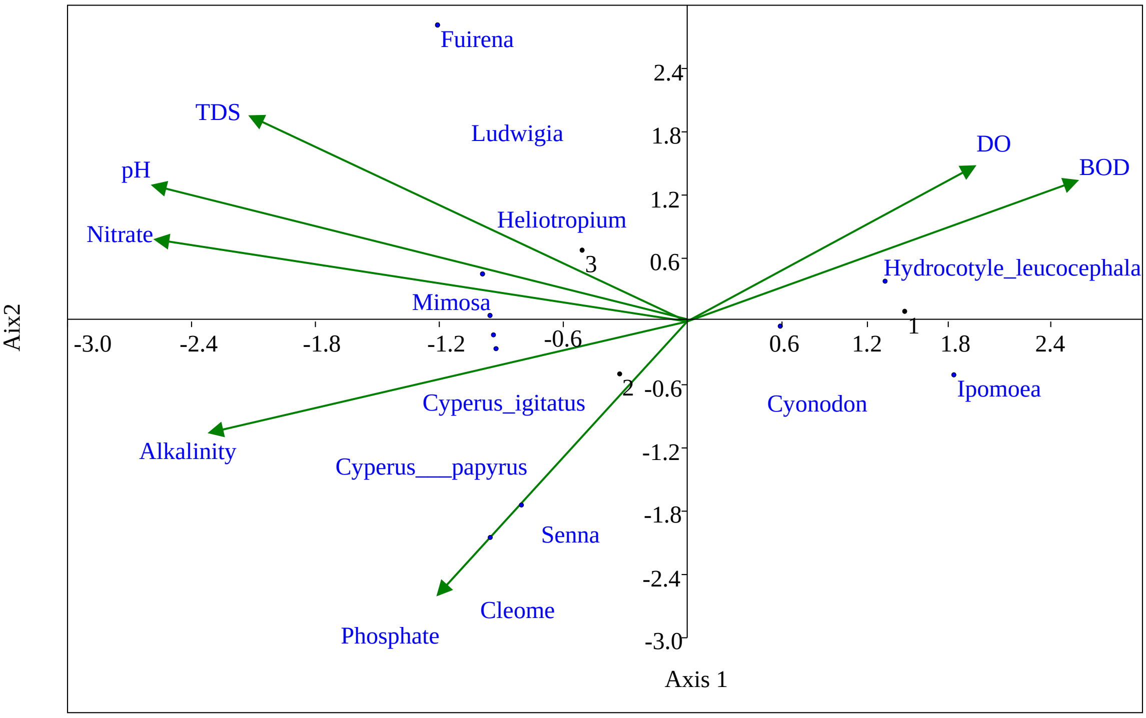

Fig. 2: Triplot of first and second CCA axes of macrophyte taxa, environmental variables and their corresponding sampling stations. The scale in SD units is -3 to 3 for both the macrophyte and environmental variable scores. Key ⇨ environmental variable, (BOD- Biochemical Oxygen demand, DO- dissolved oxygen, TDS-Total dissolved solids)

CONCLUSION

From this study we have been able to find out that Chanchaga River is moderately polluted organically along the river course as a result of several anthropogenic pressures that alter the quality of water and thus the composition and distribution of macrophytes in the river. A total of 11 species comprising 8 families were encountered with the highest species contained in Cyperaceae and Fabaceae families. The region was dominated by *Hydrocotyle leucocephala* and was evenly distributed. Macrophytes grow in presence of water pollution, from which they provide nutrients that enable the growth, hence the most polluted downstream stations of river basin had also the greater number of species. Therefore, based on the results of this research, we recommend the use of macrophytes as biological indicators for water quality classification in all water bodies in Nigeria and beyond. The study also reveals that an increase in water supply and flow due to rainfall would decrease macrophyte diversity and water quality.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of thismanuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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