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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Pakistan Journal of Biological Sciences

ISSN 1028-8880
DOI: 10.3923/pjbs.2021.507.515

Research Article
Anthropogenic Influences on Physico-Chemical Quality, Fish and Macrophyte Diversities of River Adofi, Southern Nigeria

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Abstract

Background and Objective: Freshwater systems support agriculture, industry and even human existence. Pollution due to human activities affect the quality of water bodies thereby threatening biodiversity. This study, therefore, investigated the anthropogenic influences on physico-chemical quality, fish and macrophyte diversities of River Adofi. **Materials and Methods:** Three sampling stations along River Adofi at Ejeme-Aniogor (Station 1), Utagba-Uno (Station 2) and Umuleke-Ossissa (Station 3) were selected based on ecological features and the presence of human activities. Water samples were collected fortnightly for 6 months and water quality was determined. Fish and macrophyte species were collected and diversity indices were calculated. **Results:** Physico-chemical parameters were significantly different ($p<0.05$) in all three stations except for magnesium, calcium and nitrate. Temperature, total dissolved solids, conductivity, COD, total alkalinity and magnesium were higher ($p<0.05$) in Station 2 at Utagba-Uno where a rubber factory effluent discharges into the river. Out of 15 families, 18 genera and 26 species of fish collected *Oreochromis* species were more abundant, followed by *Gymnarchus niloticus*. Mokochidae and Clariidae had higher diversities than other families. Macrophytes recorded were 53 taxa from 21 families and 33 genera with emergent and submerged life forms dominating. Poaceae dominated with nine species. Shannon index increased with increasing species richness and evenness with both fish and macrophytes evenly distributed. **Conclusion:** Lower diversity of fish species observed in Station 2 may be due to influences of effluent discharges into the river while domestic and agricultural activities enhanced abundance and diversity of fish and macrophytes at Station 3.

Key words: Aquatic, quality, diversity, fish, macrophytes, human, pollution

Citation: Nwabueze, A.A. and J.K. Ekelemu, 2021. Anthropogenic influences on physico-chemical quality, fish and macrophyte diversities of River Adofi, Southern Nigeria. Pak. J. Biol. Sci., 24: 507-515.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Aquatic ecosystems are vast and rich in plant and animal lives which contribute to the aquatic food chain. Freshwater systems also support agriculture, industry and even human existence. Optimum water quality is therefore essential for ecological balance and economic development. However, freshwater bodies are increasingly being contaminated with domestic, agricultural, industrial wastes and runoffs as these and other pollutants are washed directly into streams and rivers[1]. River pollution has now become a major problem facing most developing nations. Anthropogenic influences around the river banks and its environment are known sources of water pollution and increasing exploitation of water resources[2-4]. Anthropogenic activities have been reported to directly or indirectly affect water quality and quantity in lakes and rivers thereby threatening fish diversity[5]. It affects water quality, destroy habitats and alter the diversity of fish and other aquatics[6].

The physical and chemical qualities of water are very important for fish growth and production as fish depends on water to carry out activities such as breeding, movement and respiration[7]. Aquatic macrophytes are large macroscopic photosynthetic plants having at least their vegetative parts growing permanently or periodically in aquatic habitat[8,9]. Freshwater macrophytes play important roles in structuring aquatic communities by providing physical structure, food, shelter, increased habitat complexity and heterogeneity affecting various organisms like invertebrates, fishes which are protected against currents and predators[10-12]. The depth, density, diversity and types of macrophytes indicate the health condition of the water system since they have a heavy influence on habitat structure, fish species composition, recreational and nutrient dynamics[11,13]. An absence of macrophytes therefore may indicate water quality problems while an overabundance resulting from high nutrient levels may affect ecosystem health negatively.

River Adofi is an important source of water supply in parts of rural southern Nigeria. Communities located near and along the river depend on its water for domestic and agricultural use. An assessment of the water quality as it affects the diversity of fish and macrophytes can be used to determine its sustainability for rural development.

This study aimed to investigate the influence of anthropogenic activities on physico-chemical quality and diversity of fish species and aquatic macrophytes in River Adofi, Nigeria.

MATERIALS AND METHODS

Study area: River Adofi is located in the Delta North Agricultural Zone of Delta State, Southern Nigeria. The river lies between 5°45' N and 6°00'N, 6°17'E and 6°34'E within the tropical rain forest of the Niger Delta area, Southern Nigeria having a mean annual temperature of 28°C and mean annual relative humidity of 85% (Fig. 1). The source of the river is at Owa-Alidinma and Ejeme-Aniogor water-shed from where the river flows southwards towards Ossissa in Ndokwa-East Local Government Area of Delta State before it empties its water in River Niger[14]. Three sampling stations along River Adofi at Ejeme-Aniogor (Station 1), Utagba-Uno (Station 2) and Umuleke-Ossissa (Station 3) were selected based on ecological features and the presence of human activities. Station 1 had little or no human activity (mainly religious) and with dense vegetation. Station 2 was 100 m from point of effluent discharge of the Michelin Rubber Factory and Station 3 was under the road bridge at Umuleke-Ossissa with high human activities such as farming along the river banks, bathing, washing of clothes, vehicles, motorbikes in the river and commercial activities like sales of fresh fish. This research was conducted from April-September, 2019.

Collection of samples: Water samples were collected fortnightly between the hours of 7.00 am and 10.00 am for 6 months of the rainy season spanning April-September in 2019. Parameters determined in-situ were the subsurface temperature of the water using an insulated metal bucket, transparency by secchi disc, depth using weighted graduated rope, current (speed of water) by a timed floater. Water samples were collected for determination of other parameters using sterile 250 mL corked bottles which were transported to the Faculty of Agriculture Research Laboratory of Delta State University for analysis. Conductivity by conductometer (S700, Mettler Toledo, France), pH by pH meter (pH 981, Pec Medical, USA) and standardized with a buffer solution of 7, Total Dissolved Solids (TDS) was determined gravimetrically by evaporating a known volume of water to dryness in a pre-weighed crucible on a steam bath. Chemical parameters determined were pH, Dissolved Oxygen (DO) (using Digital DO meter, USA), biological oxygen demand (BOD) using Hanna BOD meter (H15 421, India), chemical oxygen demand (COD) using COD meter (H183314 Photometer, India), total alkalinity, magnesium, phosphate, calcium and nitrate according to standard methods[15,16].

Fish samples were harvested with the help of fishermen who set traps overnight and also used hook and line from a

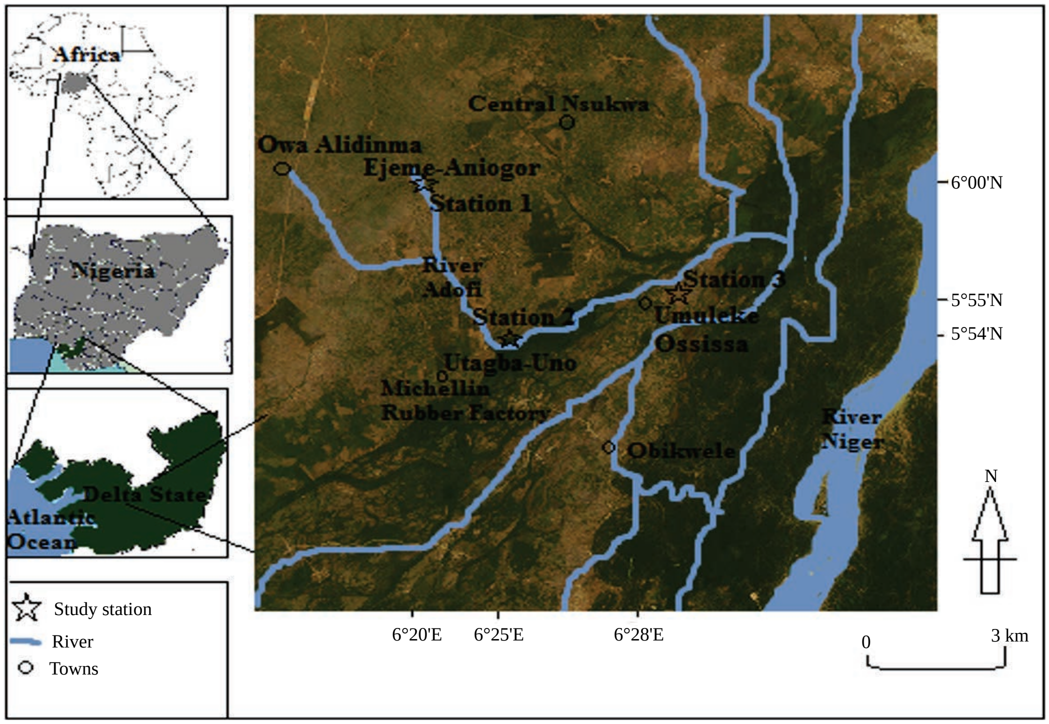

Fig. 1: Map of river Adofi showing study stations at Ejeme-Aniogor, Utagba-Uno and Umuleke-Ossissa
(Adapted from mapcarta.com)

dug-out canoe. Fish samples were preserved in an ice chest and later taken to the Department of Fisheries of Delta State University for identification[17,18]. Different parts of the river in each station were sampled for floating, submerged, emergent and embankment plants by twelve throws of a 1 m by 1 m light wooded quadrant on the river banks and by using rakes from a canoe for submerged, emergent and floating forms while a sieve attached to a long handle was used to collect free-floating species. Aquatic macrophytes collected were washed and kept in air-tight black cellophane to avoid drying up and then taken to the Department of Forestry and Wildlife for identification[19-21].

Biodiversity indices: Diversity indices such as Species richness[22], Shannon-Weaver/Shannon Diversity index[23], Simpson Dominance Index[24] and Species evenness index[25] were used to assess fish and macrophyte species using the following formulae:

- **Species richness (d):**

$$d = \frac{S\text{-}1}{\ln N}$$

where, S is total number of species, N is total number of individuals of all the species. In this study, species richness of fish species was calculated while genus richness for macrophytes was used[26], because of difficulty in separating individual stands due to clonal nature of macrophytes and logistic limitations to measure biomasses in all samples[27].

- **Shannon-Wiener index (H):**

$$H = \frac{N \log N - \sum fi \log fi}{N}$$

where, N is total number of individuals of all the species, fi is number of an individual species.

- **Shannon's index of diversity (H¹):**

$$H^1 = -\sum pi \ln pi$$

where, pi is the proportion of importance value of the ith species (pi = ni/N, ni is the importance value of ith species and N is the Importance Value of all the species).

- **Evenness index (E):**

$$E = \frac{H}{\log S}$$

where, H is Shannon-Wiener diversity index and log S is natural log of the total number of species recorded.

- **Simpson's index of Dominance (D):**

$$D = \sum (pi)2$$

were, pi is the proportion of important value of the ith species (pi = ni/N, ni is the importance value of ith species and N is the Importance Value of all the species).

- **Simpson's Diversity Index (1-D):** represents the probability that two individual organisms randomly selected from a sample will belong to different species

Data analysis: Water quality data collected were subjected to one-way Analysis of Variance (ANOVA) procedures using SPSS version 17 with significant means separated at 5% level of probability using Duncan's Multiple Range Tests. Differences in species/genera diversity were calculated using t-test statistics[28].

RESULTS

All physicochemical parameters determined were significantly different ($p<0.05$) in the three study stations except for calcium and nitrate which were statistically the same in Station 1 and Station 3 (Table 1). Temperature (29.10±0.10°C), total dissolved solids (2.21±0.01 g L^{-1}) conductivity (29.03±0.06 µS cm^{-1}), COD (42.83±0.12 mg L^{-1}), total alkalinity (448.29±0.55 mg L^{-1}) and magnesium (4.92+0.06 mg L^{-1}) were higher ($p<0.05$) in Station 2 at Utagba-Uno where rubber effluent is discharged into the river. Station 1 with less human activities had a higher ($p<0.05$) DO of 8.13±0.02 mg L^{-1} and BOD of 7.26±0.02 mg L^{-1}. Station 3, with most domestic and agricultural activities, had a higher ($p<0.05$) phosphate value of 148.34±0.29 mg L^{-1}.

The abundance and diversity of fish species in study stations along the River Adofi are presented in Table 2. Fifteen families, 18 genera and 26 species of fish were harvested from study stations along River Adofi. *Oreochromis niloticus* and *Oreochromis aureus* were more abundant in terms of the number of individual species, closely followed by *Gymnarchus niloticus.* Whereas fish families of Mokochidae and Clariidae had a higher diversity of species than the other fish families. Out of 53 taxa of species belonging to 21 families and 33 genera of aquatic macrophytes sampled, emergent life forms dominated with 17 emergent, 7 embankments, 11 floatings, 5 free-floating and 13 submerged life forms encountered. Poaceae family dominated with 8 species belonging to 6 taxa namely *Echinochloa stagnina, Echinochloa pyramidalis, Oryza barthi, Phragmites karka, Polygonum lanigerum, Leersia virginica, Leersia oryzoides* and *Vossia cuspidata* found in the study stations.

The data of Table 3 shows the diversity and life forms of macrophytes in the study stations. Figure 2 shows the diversity indices of fish species in the study stations along the River Adofi while Fig. 3 shows the diversity indices of macrophyte species in the study stations along the River Adofi. Shannon index was observed to increase with increasing species

Table 1: Mean physicochemical parameters of river Adofi at study stations

	Station		
Physicochemical parameters	(1) Ejeme-Aniogor	(2) Utagba-Uno	(3) Umuleke Ossissa
Physical			
Temperature (°C)	27.82±0.02^a	29.10±0.10^c	28.89±0.02^b
Transparency (cm)	35.25±0.06^b	12.36±0.08^a	88.67±0.64^c
Depth (cm)	35.25±0.07^a	56.14±0.12^b	128.26±0.23^c
Speed (m sec^{-1})	0.43±0.02^c	0.28±0.01^a	0.35±0.02^b
Chemical			
Total dissolved solids (g L^{-1})	0.62±0.02^a	2.21±0.10^c	1.16±0.01^b
pH	6.60±0.10^b	5.76±0.01^a	6.92±0.01^c
Conductivity (µS cm^{-1})	2.20±0.10^a	29.03±0.06^c	8.42±0.02^b
DO (mg L^{-1})	8.13±0.02^c	2.98±0.01^a	6.84±0.03^b
BOD (mg L^{-1})	7.26±0.02^c	2.23±0.02^a	6.85±0.02^b
COD (mg L^{-1})	2.46±0.02^a	42.83±0.12^c	18.42±0.02^b
Total alkalinity (mg L^{-1})	324.24±0.04^a	448.29±0.55^c	389.80±0.11^b
Phosphate (mg L^{-1})	39.24±0.04^a	80.57±0.15^b	148.34±0.29^c
Magnesium (mg L^{-1})	3.61±0.04^a	4.92±0.06^c	3.84±0.05^a
Calcium (mg L^{-1})	8.33±0.12^a	8.93±0.05^b	8.42±0.01^a
Nitrate (mg L^{-1})	2.77±0.12^a	3.86±0.03^b	2.68±0.02^a

Means (+SD) on the same row with different letters are significantly different at o<0.05, (Field survey, 2019)

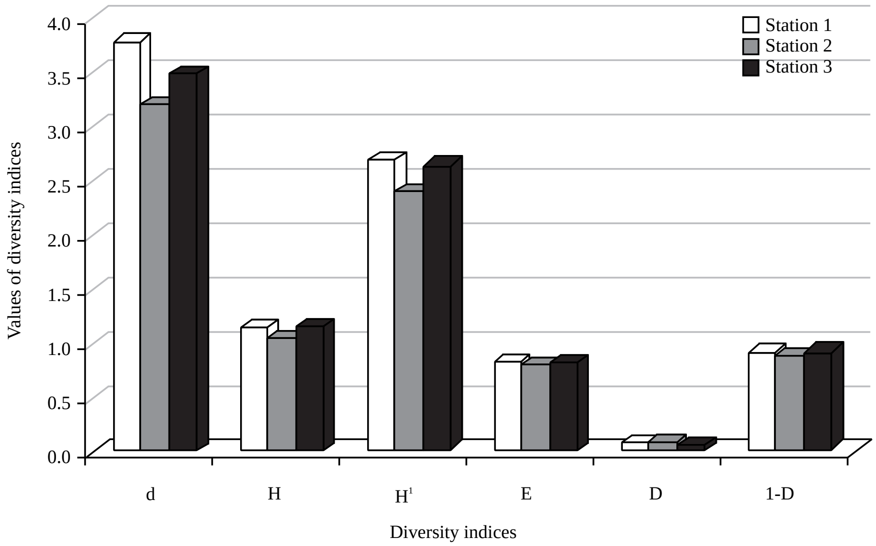

Fig. 2: Diversity indices of fish species from study stations along River Adofi

d = Species Richness, H = Shannon-Wiener Index; H1; Shannon's Index; E = Evenness Index; D = Simpson's Dominance Index; 1-D = Simpson's Diversity index

Table 2: Abundance and Diversity of fish species in study stations along River Adofi

Fish species	Family	Station 1	Station 2	Station 3
Oreochromis niloticus	Cichlidae	87	55	124
Oreochromis aureus	Cichlidae	62	24	96
Bagrus bayad	Bagridae	23	20	34
Bagrus docmak	Bagridae	11	2	10
Synodontis ocellifer	Mochokidae	84	18	28
Synodontis clarias	Mochokidae	14	6	12
Synodontis filamentosus	Mochokidae	23	6	17
Synodontis nigrita	Mochokidae	18	2	7
Clarotes laticeps	Bagridae	0	0	3
Parachanna obscura	Channidae	5	0	2
Hyperopisus bebes	Mormyridae	3	0	19
Gymnarchus niloticus	Gymnarchidae	14	22	83
Lates niloticus	Centropomidae	12	10	16
Heterotis niloticus	Osteoglossidae	25	27	48
Clarias gariepinus	Clariidae	39	74	55
Clarias anguillaris	Clariidae	28	33	21
Labeo senegalensis	Cyprinidae	12	10	13
Labeo coubie	Cyprinidae	6	8	18
Hydrocynus forskalii	Characidae	14	1	20
Distichodus rostratus	Characidae	30	21	46
Schilbe mystus	Schilbeidae	15	12	16
Citharinus citharus	Citharinidae	5	0	0
Heterobranchus bidorsalis	Clariidae	20	12	15
Heterobranchus longifilis	Clariidae	4	0	0
Malapterurus electricus	Malapteruridae	4	1	2
Protopterus annectens	Protopterdae	3	0	6
Number of species		25	20	24
Number of individuals		561	364	711

Field survey, 2019

richness and evenness. Shannon-Weiner Index for fish in Station 1 (1.16) was significantly higher ($p<0.05$) than the index for Station 2 (1.05). Also, values obtained for evenness shows that both fish and macrophyte species were evenly distributed in the study stations. Simpson's Dominance Index was found to be low in both fish species and macrophytes. Stations 1 and 3 had higher diversity and abundance of both fish and macrophytes species. A high level of agricultural activities in Station 3 and the undisturbed nature of Station 1 may have contributed to the high diversity.

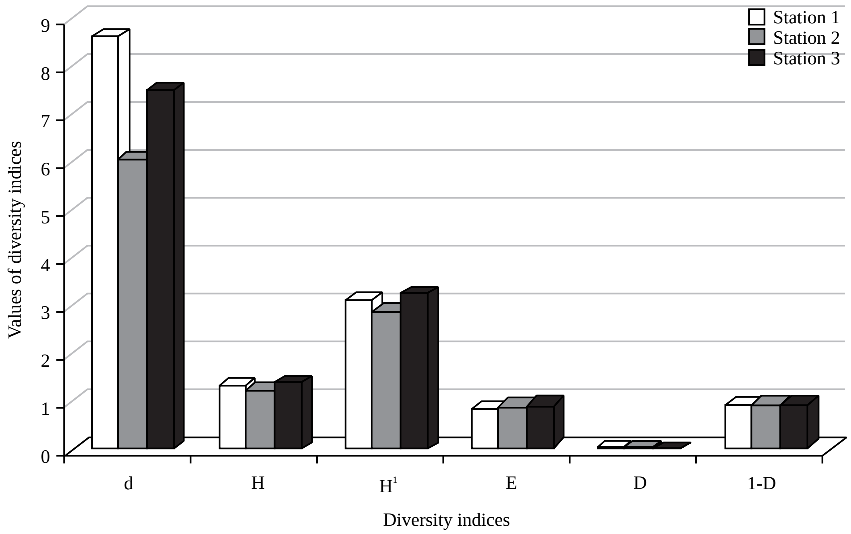

Fig. 3: Diversity indices of aquatic macrophyte species from study stations along River Adofi
(d = Species Richness, H = Shannon-Wiener Index; H1; Shannon's Index; E = Evenness Index; D = Simpson's Dominance Index; 1-D = Simpson's Diversity index)

Table 3: Diversity of macrophytes genera in study stations along River Adofi

Macrophytes (genera)	Family names	Station 1	Station 2	Station 3
Cyperus spp.	Cyperaceae	1	1	2
Eichhornia spp.	Pontederiaceae	2	2	2
Echinochloa spp	Poaceae	2	0	0
Ipomoea spp.	Convolvulaceae	1	0	1
Ludwigia spp.	Onagraceae	1	2	5
Neptunia spp.	Fabaceae	1	0	0
Nephrolepis spp.	Lomariopsidaceae	1	2	1
Oryza spp.	Poaceae	1	1	1
Phragmite spp.	Poaceae	1	1	1
Polygonum spp.	Poaceae	1	1	1
Sagittaria spp.	Alismataceae	1	2	2
Typha spp.	Typhaceae	1	2	2
Alternanthera spp.	Amaranthaceae	1	0	1
Juncus spp.	Juncaceae	1	0	1
Leersia spp.	Poaceae	1	2	2
Sacciolepis spp.	Onagraceae	1	1	1
Lemna spp.	Araceae	1	1	1
Nymphoides spp.	Menyanthaceae	1	2	2
Nymphaea spp.	Nymphaeaceae	2	2	2
Potamogeton spp.	Potamogetonaceae	2	4	4
Pistia spp.	Araceae	1	1	1
Spirodela spp.	Araceae	1	1	1
Salvinia spp.	Salviniaceae	1	1	1
Azolla spp.	Salviniaceae	1	2	2
Wolffia spp.	Araceae	1	1	1
Callitriche spp.	Plantaginaceae	0	0	1
Ceratophyllum spp.	Ceratophyllaceae	1	0	1
Elodea spp.	Hydrocharitaceae	1	0	1
Najas indica	Hydrocharitaceae	1	0	1
Ranunculus spp.	Ruppiaceae	1	2	2
Ruppia spp.	Ruppiaceae	1	2	2
Vossia spp.	Poaceae	1	1	1
Zostera spp.	Zosteraceae	1	0	0
Number of genera		32	23	30
Number of individuals		36	37	47

Field survey, 2019

DISCUSSION

Levels of physicochemical parameters observed in this study were significantly different in all three stations except for magnesium, calcium and nitrate levels which were statistically the same in Stations 1 and 3. Station 2 with higher levels of temperature, total dissolved solids conductivity, COD, total alkalinity and magnesium may have been influenced by the effluent discharge from the rubber factory located at Utagba-Uno, close to the site of sample collection. It has been reported that water quality can be affected by various environmental variables showing wide temporal and spatial differences that may directly or indirectly affect the life of aquatic organisms[29]. The low DO and BOD and higher levels of phosphate and pH observed in Station 3 could be due to high organic pollution due to human activities mostly domestic and agricultural. This agrees with the earlier findings that human activities generate high organic pollution[30-32]. Frankouich *et al.*[33] reported that aquatic macrophyte distribution and growth is associated with nutrient-rich environments particularly nitrate and phosphate. The low level of conductivity observed could be due to the measure of elements in the water column, which is a reflection of the measure of chloride ions in dissolution in the water[34,35]. Though levels of calcium and magnesium obtained in this study were low, levels were within the typical range of 4-100 mg L^{-1} in freshwater bodies as earlier reported[36].

Fifteen families, 18 genera and 26 species of fish collected from the study stations shows that *Oreochromis niloticus* and *Oreochromis aureus* were more abundant in number, followed by *Gymnarchus niloticus.* Whereas, fish families of Mokochidae and Clariidae had a higher diversity of species than other families. Earlier studies reported the abundance of Mokochidae[37] and Bagridae[38] fish species in rivers in Nigeria. Emergent and submerged forms of aquatic macrophytes were more in number than an embankment, floating and free-floating forms. The dominance of emergent among other life forms of macrophytes reveals lower productive nature of water bodies and indicates the encroachment of littoral vegetation which reduces the core area of water bodies[26]. Macrophyte species were more abundant and diverse in Station 3, with forest-like vegetation, having more vegetation cover than other stations sampled. Station 2 had the least macrophyte diversity. The abundance of submerged macrophyte at Station 3, could be a pointer to eutrophication. This is because submerged macrophytes are considered to be suitable eutrophication indicators and are sensitive to local environmental conditions[39,40]. Free-floating forms were also present in the study stations. Ghosh and Biswas[26] noted that free-floating and rooted floating leaved species are the most competitive in the aquatic environment for light and usually are dominant macrophytes communities when nutrient levels in the water are sufficiently high.

The use of macrophytes as bioindicators of water quality of rivers have been reported to have high precision, are cost-effective and reliable to detect environmental changes instead of using only water analysis[41-43,26]. The diversity of flora and fauna in aquatic ecosystems and its distribution is directly affected by physical and chemical parameters of the environment where all the life processes take place[44]. The interplay between macrophytes and water quality variables represents a fundamental characteristic of river systems, which has important implications for river flow and ecological functioning[45]. It has been noted that changes in macrophyte community due to enhanced nutrients resulting from anthropogenic activities such as agriculture, forestry operations, constructions activities and urbanization programs are now commonplace in many parts of the world, requiring appropriate attribution of the cause of such changes in the flora, which is vital for management decisions[46-48]. River Adofi was found to have a high abundance and diversity of fish species and macrophytes with members of the family Cichlidae and Poaceae dominating in study stations for fish and macrophyte species respectively. This fact is evidenced in the value of the Shannon index obtained for both fish and macrophytes. Species diversity is a useful parameter for the comparison of communities under the influence of disturbances of any kind or to know the state of succession and stability in the community[49]. Anthropogenic activities in Station 2 may be responsible for the low diversity of fish observed. A significantly lower level of dissolved oxygen was also recorded for Station 2. Changes in the ecosystem including oxygen depletion caused by nutrient enrichment from runoff from agricultural lands can lead to loss of fish diversity[50,5,6,51]. The low dominance obtained in this study shows that there was a high diversity of species. River Adofi can therefore be described as a diversity hotspot for both fish species and aquatic macrophytes.

CONCLUSION

This study concludes that anthropogenic activities at Utagba-Uno, Station 2, had a negative influence on physicochemical parameters probably due to effluent discharge from the rubber factory close to point of sample collection. While domestic and agricultural activities at Stations 1 and 3 enhanced the abundance and diversity of fish species and aquatic macrophytes.

SIGNIFICANCE STATEMENT

This study has shown that anthropogenic activities impacted on biodiversity of fish species and aquatic macrophytes at Utagba-Uno and Umuleke-Ossissa in River Adofi.

This study will help in providing useful baseline information in the management and biomonitoring of the river ecosystems for improved biodiversity and to forestall any future negative impact of human activities in River Adofi, Southern Nigeria.

ACKNOWLEDGMENT

The authors would like to express their appreciation to John Igwe, field scientist of the Department of Fisheries, Delta State University, for his assistance with sample collection.

REFERENCES

1. Bashir, I., F.A. Lone, R.A. Bhat, S.A. Mir, Z.A. Dar and S.A. Dar, 2020. Concerns and Threats of Contamination on Aquatic Ecosystems. In: Bioremediation and Biotechnology, Hakeem, K., R. Bhat and H. Qadri (Eds.), Springer International Publishing Cham, ISBN: 978-3-030-35691-0 pp: 1-26.
2. Arimoro, F.O., O.N. Odume, S.I. Uhunoma and A.O. Edegbene, 2015. Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream. Environ. Monit. Assess., Vol. 187. 10.1007/s10661-014-4251-2.
3. Adeosun, F.I., T.F. Adams and M.O. Amrevuawho, 2016. Effect of anthropogenic activities on the water quality parameters of federal university of agriculture Abeokuta reservoir. Int. J. Fish. Aquat. Stud., 4: 104-108.
4. Adekanmbi, A.O., O.O. Adelowo, A.I. Okoh and O.E. Fagade, 2019. Metal-resistance encoding gene-fingerprints in some bacteria isolated from wastewaters of selected printeries in Ibadan, South-western Nigeria. J. Taibah Uni. Sci., 13: 266-273.
5. Ali, M.M., 2008. An analysis of the impact of human activities on water quality and ecological responses in the suez irrigation canal. Manage. Env. Qual., 19: 377-401.
6. Bukola, D., A. Zaid, I.O. Eledgbede and A. Falilu, 2015. Consequences of anthropogenic activities on fish and the aquatic environment. Poult. Fish Wildlife Sci., Vol. 3. 10.4172/2375-446X.1000138.
7. Dimowo, B.O., 2013. The phytoplankton species composition and abundance of Ogun River, Abeokuta, Southwestern Nigeria. Int. J. Aquacult., 3: 4-7.
8. Jones, J.I., A.L. Collins, P.S. Naden and D.A. Sear, 2012. The relationship between fine sediment and macrophytes in rivers. Riv. Res. Applic., 28: 1006-1018.
9. Dienye, H.E., O.A. Olopade and G.N. Woke, 2017. The relationship between aquatic macrophytes and water quality in new Calabar River, Niger Delta, Nigeria. Int. J. Res. Agric. For., 4: 1-6.
10. Thomaz, S.M. and E.R.D. Cunha, 2010. The role of macrophytes in habitat structuring in aquatic ecosystems: Methods of measurement, causes and consequences on animal assemblages' composition and biodiversity. Acta Limnol. Brasil., 22: 218-236.
11. Uka, U.N. and K.S. Chukwuka, 2011. Utilization of aquatic macrophytes in Nigerian freshwater ecosystem. J. Fish. Aquat. Sci., 6: 490-498.
12. Kurniawan, R., Triyanto and L. Subehi, 2016. Aquatic macrophytes and fish diversity of various tropical lakes at the main islands in Indonesia. In: Aquatic Biodiversity Conservation and Ecosystem Services, Nakano, S., T. Yahara and T. Nakashizuka (Eds.), Springer, Singapore, ISBN: 978-981-10-0780-4 pp: 3-12.
13. EPA (Environmental Protection Agency) USA, 2017. Indicators: Macrophytes. National Aquatic Resource Surveys. Web Snapshot. https://www.epa.gov/national-aquatic-resource-surveys/indicators-macrophytes
14. Chinyem, F.I., 2017. Geoelectric investigations for groundwater prospects in Ejeme-Aniogor and environs, Aniocha-South local government area, delta state, Nigeria. J. Appl. Sci. Environ. Manage., 21: 682-690.
15. Bustillo-Lecompte, C., M. Mehrvar and E. Quiñones-Bolaños, 2016. Slaughterhouse wastewater characterization and treatment: An economic and public health necessity of the meat processing industry in Ontario, Canada. J. Geosci. Environ. Prot., 04: 175-186.
16. APHA, AWWA and WPCF., 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edn., American Public Health Association, Washington, DC., USA., ISBN-13: 978-0875530475.
17. Idodo-Umeh, G., 2003. Freshwater Fishes of Nigeria: Taxonomy, Ecological Notes, Diet and Utilization. Idodo Umeh Publisher, Benin, Nigeria, ISBN-13: 9789788052012, Pages: 232.
18. Reed, W., J. Burchad, A.J. Hopson, J. Jenness and I. Yaro, 1967. Fish and fisheries of Northern Nigeria. Ministry of Agriculture, Northern Nigeria, pp: 1-226.
19. Schuyler, A., 1984. Classification of life forms and growth forms of aquatic macrophytes. Bartonia, 50: 8-11.
20. Akobundu, I.O. and C.W. Agyakwa, 1987. A Handbook of West African Weeds. International Institute of Tropical Agriculture, Ibadan, Nigeria, ISBN-13: 9789781310140, Pages: 521.
21. Chambers, P.A., P. Lacoul, K.J. Murphy and S.M. Thomaz, 2008. Global diversity of aquatic macrophytes in freshwater. Hydrobiologia, 595: 9-26.
22. Margalef, R., 1968. Perspective in Ecological Theory. University of Chicago Press, Chicago and London, Pages: 111.

23. Shannon, C.E. and W. Wiener, 1963. The Mathematical Theory of Communication. University of Illinois Press, Urbana, USA Pages: 125.
24. Simpson, E.H., 1949. Measurement of diversity. Nature, 163: 688-688.
25. Pielou, E.C., 1966. An Introduction to Mathematical Ecology. John Wiley and Sons, Inc., New York, pp: 286.
26. Ghosh, D. and J.K. Biswas, 2015. Biomonitoring macrophytes diversity and abundance or rating aquatic health of an oxbow lake ecosystem in Ganga river Basin. Am. J. Phytomed. Clin. Ther., 3: 602-621.
27. Evangelista, H.B.A., S.M. Thomaz and L.R. Evangelista, 2012. Comparison of diversity indices applied to macrophyte incidence-based data. Braz. Arch. Biol. Technol., 55: 277-282.
28. Hutcheson, K., 1970. A test for comparing diversities based on the Shannon formula. J. Theor. Biol., 29: 151-154.
29. Rameshkumar, S., K. Radhakrishnan, S. Aanand and R. Rajaram, 2019. Influence of physicochemical water quality on aquatic macrophyte diversity in seasonal wetlands. Appl. Water Sci., Vol. 9. 10.1007/s13201-018-0888-2.
30. Wen, Y., G. Schoups and N. van de Giesen, 2017. Organic pollution of rivers: Combined threats of urbanization, livestock farming and global climate change. Sci. Rep., Vol. 7. 10.1038/srep43289.
31. Jalal, F.N. and M.G. Sanalkumar, 2012. Hydrology and water quality assessment of Achencovil river in relation to pilgrimage season. Int. J. Sci. Res. Publ., 2: 1-5.
32. Kotadiya, N.G. and C.A. Acharya, 2014. An assessment of lake water quality index of Manipu Lake of district Ahmedabad, Gujarat. Int. J. Sci. Res., 3: 448-450.
33. Madkour, F.F. and G.A. El-Shoubaky, 2007. Spatial and temporal distribution of epiphytic diatoms on macroalgae inhabiting port said coast, mediterranean sea, Egypt. New Egypt. J. Microbiol., 17: 285-296.
34. Oyem, H.H., I.M. Oyem and D. Ezeweali, 2014. Temperature, pH, electrical conductivity, total dissolved solids and chemical oxygen demand of groundwater in Boji-Boji Agbor/Owa area and immediate suburbs. Res. J. Environ. Sci., 8: 444-450.
35. Peinado-Guevara, H., C. Green-Ruíz, J. Herrera-Barrientos, O. Escolero-Fuentes, O. Delgado-Rodríguez, S. Belmonte-Jiménez and M.L. de Guevara 2012. Relationship between chloride concentration and electrical conductivity in groundwater and its estimation from vertical electrical soundings (VESs) in Guasave, Sinaloa, Mexico. Cien. Inv. Agr., 39: 229-239.
36. Hamaidi-Chergui, F., M.B. Errahmani, F. Benouaklil and M.S. Hamaidi, 2013. Preliminary study on physico-chemical parameters and phytoplankton of chiffa river (Blida, Algeria). J. Ecosyst., 2013: 1-9.
37. Meye, J.A., P.E. Omoruwou and E.D. Mayor, 2008. Food and feeding habits of *Syndontis ocellifer* (Boulenger, 1900) from river Adofi, Southern Nigeria. Trop. Freshwater Biol., 17: 1-12.
38. Jega, I.S., I.M. Daramola and I. Rasaq, 2020. Length-Weight Relationship and Spawning Season of Bagrusbayad (Forsskal, 1775) in Yamama Lake Kebbi State, Nigeria. Oceanogr. Fish. Open Access J., Vol. 12. 10.19080/OFOAJ. 2020.12.555841.
39. Lacoul, P. and B. Freedman, 2006. Environmental influences on aquatic plants in freshwater ecosystems. Environ. Rev., 14: 89-136.
40. Sondergaard, M., L.S. Johansson, T.L. Lauridsen, T.B. Jorgensen, L. Liboriussen and E. Jeppesen, 2010. Submerged macrophytes as indicators of the ecological quality of lakes. Freshwater Biol., 55: 893-908.
41. Gebler, D., D. Kayzer, K. Szoszkiewicz and A. Budka, 2014. Artificial neural network modelling of macrophyte indices based on physico-chemical characteristics of water. Hydrobiologia, 737: 215-224.
42. Ciecierska, H. and A. Kolada, 2014. ESMI: a macrophyte index for assessing the ecological status of lakes. Environ. Monit. Assess., 186: 5501-5517.
43. Bytyqi, P., M. Czikkely, A. Shala-Abazi, O. Fetoshi and M. Ismaili *et al*., 2020. Macrophytes as biological indicators of organic pollution in the Lepenci River Basin in Kosovo. J. Freshwater Ecol., 35: 105-121.
44. Anbarasu, K. and G. Anbuselvan, 2017. Physico-chemical parameter analysis of water in Musiri Taluk, Tamil Nadu, India. World News Natur. Sci., 6: 28-35.
45. Xiao, C., X. Wang, J. Xia and G. Liu, 2010. The effect of temperature, water level and burial depth on seed germination of *Myriophyllum spicatum* and *Potamogeton malaianus*. Aquat. Bot., 92: 28-32.
46. Collins, A.L. and D.E. Walling, 2007. The storage and provenance of fine sediment on the channel bed of two contrasting lowland permeable catchments, UK. Riv. Res. Applic., 23: 429-450.
47. Wang, S., X. Jin, L. Jiao and F. Wu, 2009. Response in root morphology and nutrient contents of *Myriophyllum spicatum* to sediment type. Ecol. Eng., 35: 1264-1270.
48. Alahuhta, J., A. Kanninen and K.M. Vuori, 2012. Response of macrophyte communities and status metrics to natural gradients and land use in boreal lakes. Aquat. Bot., 103: 106-114.
49. Dornelas, M., 2010. Disturbance and change in biodiversity. Phil. Trans. R. Soc. B., 365: 3719-3727.
50. Laurén, D.J. and D. Wails, 2019. Liver structuralalterations accompanying chronic toxicity in fishes: Potential biomarkers of exposure. 1st Edn., CRC Press, Boca Raton, Florida, ISBN: 9781351070263, 41.
51. Ruiz-Navarro, A., M.C. Jackson, D. Almeida and J.R. Britton, 2020. Influence of nutrient enrichment on the growth, recruitment and trophic ecology of a highly invasive freshwater fish. Aquat. Ecol., 54: 1029-1039.