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CONTENTS

Research Articles

Journal of Limnology and Freshwater Fisheries Research

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Fish Faunal Diversity and Species Composition in Rupnarayan River, West Bengal, India

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ABSTRACT

A comprehensive fish diversity study in the Rupnarayan River in West Bengal, India, was undertaken for two years, once every month at four separate study locations. We recorded a total of 109 fish species, which were ultimately divided into 19 orders, 44 families and 82 genera. Seventy-one of the total number of fish species were designated as the first to be documented from the waters of the Rupnarayan. The order Cypriniformes has the highest composition (18.26%), followed by Siluriformes (13.80%) and Clupeiformes (13.42%), and so on. Cyprinidae represented 17.02% of the total, followed by Mugilidae (9.40%), Engraulidae (7.90%), and others. In the winter, Station II had the greatest Simpson's index of diversity (0.983), whereas in the summer, Station III had the lowest (0.961). Sorensen's findings reveal strong similarities between stations I and II (0.84) and II and III (0.76), moderate similarities between stations III and IV (0.63), and dissimilarity between stations I and IV (0.26). The current study is an up-to-date documentation of the fish faunal variety and spatial distribution along the entire length of the Rupnarayan River and will certainly provide helpful baseline data for future researchers and fishery planners.

Keywords: Conservation, Cypriniformes, Ichthyofauna, Rupnarayan River, Purba Medinipur

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Introduction

In India, rivers are the single largest source of inland fishing resources, both in terms of size and production potential. The fish fauna simply represents the diversity and number of fish in the river (Zhang et al. 2021). Indian rivers serve the fishing industry by sustaining a diverse range of fish species. Fish species are an important indicator of environmental health (Chovanec et al. 2003). The number and condition of fish will reflect how well the bodies of water are doing. India contributes to about 7.7% of global fish diversity, of which 1,673 are marine and 994 are freshwater (Froese and Pauly 2020) showing a rich diversity within the aquatic ecosystem. According to Muñoz-Mas et al. (2023) approximately 34,800 species of fish had been described as of February 2022. The biodiversity study is a key requirement for river ecosystem management in any riverine ecosystem, but due to a lack of appropriate documentation, it is portrayed in the literature as a minimal contribution (Addy et al. 2014). Fish are a diverse macrofaunal group of vertebrates that offer a rich supply of protein as well as other economic advantages (Aragão et al. 2022). Anthropogenic activities, overfishing, and pollution in river water reduce the diversity of riverine ichthyofauna. Pioneer researchers worked on fish faunal diversity in river water in West Bengal including the River Damodar, Torsa, Kangasabati, Keleghai, and Kapaleswari (Das 2015; Sit et al. 2020; Jana et al. 2021; Kar et al. 2017; Pahari et al. 2017; Saha and Patra 2013; Chanda and Jana, 2021). Das (2015) reported 105 fish species under 29 families and 9 orders from Torsa river; Jana et al. (2021) enlisted 56 fish species belonging to 22 families and 8 orders from Kapaleshwary river ; Kar et al. (2017) reported 45 species under 17 families and 8 orders from Kangsabati river; Pahari et al (2017) enlisted 55 species under 21 families and 9 orders from Keleghai river; Sit et al. (2021) reported 9 species of *Puntius* genus from undivided Medinipur distric of West Bengal; Chanda and Jana, 2021 enlisted 345 species belonging 50 families and 14 orders from Middle east Indian sate (West Bengal & Odisha). The first study on fish fauna of the Rupnarayan river was conducted by Mishra et al.(2003) and reported 17 species of fishes. Following that, studies revealed 27 and 38 fish species at Kolaghat, respectively by Ghorai et al. (2015) and Ghorai (2018). The present study is the first comprehensive study on ichthyofaunal diversity of the Rupnarayan River. Therefore, the current study will be an indicator of the health of the fish biodiversity of the Rupnarayan River and also beneficial tool for the fish researchers of the river.

Materials and Methods

The river has started its journey from Bandarghat of Paschim Medinipur District where the Dwarakeshar and Shilabati rivers meet to form the Rupnarayan, and it ends its journey at Gadiara in Howrah District by meeting with Hoogly River. The 72 km long watershed of Rupnarayan River was divided into four study stations (Table-1, Figure 1) for fish sample collection- Bandar Ghat (SI), Baksi (SII), Kolaghat (SIII), and Gadiara (SIV).

Table 1. Information and Location of all four Sampling stations

Sampling Stations	Latitude & Longitude	Distance from Station-I (km)	Width of river at the Station
Station- I (Bandar Ghat)	22°39’53.68’’N & 87°47’01.21’’E	0 KM	0.09KM (86 m)
Station- II (Baksi)	22°31’34.78’’N & 87°53’32.90’’E	25.4 KM	0.35KM (346 m)
Station- III (Kolaghat)	22°26’50.66’’N & 87°52’27.19’’E	36.6 KM	0.79 KM (789 m)
Station- IV (Gadiara)	22°13’19.48’’N & 88°02’14.76’’E	72.0 KM	1.46 KM (1459 m)

During the study period from March 2019 to February 2021, fish samples were collected every fifteen days during the Pre-monsoon/Summer (March-June), Monsoon/Rainy (July-Oct), and Post-monsoon/Winter (Nov-Feb) seasons from four designated study locations in the morning (5.00A.M.-8.00A.M.) with the assistance of local fishermen using various types of fishing equipment such as gill nets, cast nets, box traps, hooks and lines, seine nets, and others. Some species were taken from local fish markets and landing areas along the river. The fish specimens were photographed and immediately preserved in 10% formalin solution (Joshi and Sreekumar 2015) before being transported to the laboratory of PG Zoology, Raja N. L. Khan Women's College (Autonomous) for further research. Identification was accomplished using available literature (Talwar and Jhingran 1991; Jayaram 1999).

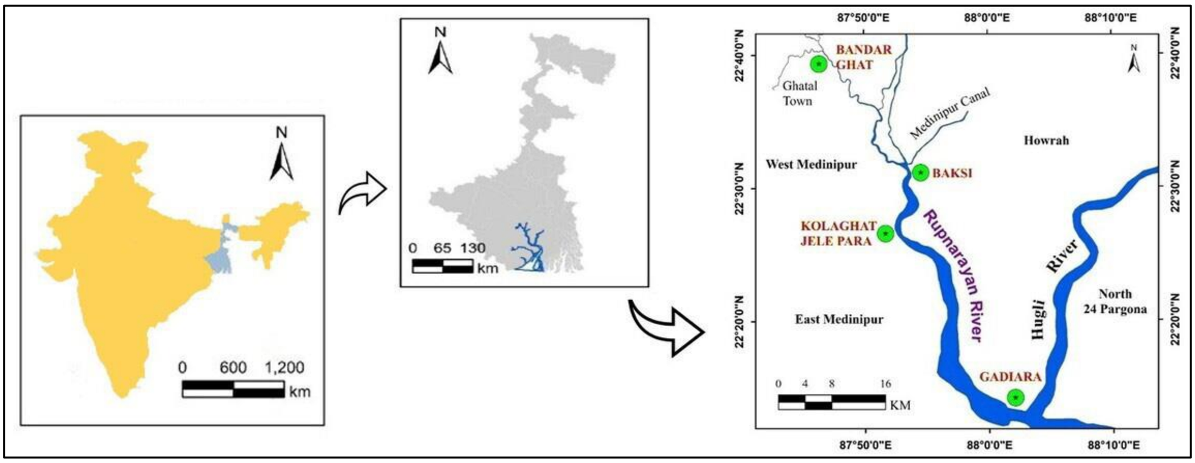

Figure 1. Schematic map showing all four sampling stations (green circles) of the Rupnarayan

Rhinomugil corsula, Terapon jarbua, Ompok bimaculatus and Mastacembelus armatus were identified by Dr. L. Kosygin Singh, Scientist-E, at the Zoological Survey of India in Kolkata. Biodiversity indices like Shannon’s Index, Simpson’s Index, Pielou's Evenness Index, Margalef's Index and different diagram were calculated/formed by using PAST v4.11 software and MS Excel 2016.

Relative Abundance (RA):

$$RA_i = \frac{n_i}{N} \times 100$$

Where,

n_i= number of individuals in i-th species

N= total no. of individuals in whole community

Can only be between 0% and 100%. A 100% indicates presence of only one species.

<1%- Satellite species, <5%- Subdominant species, >5%- Dominant Species. (Trojan, 1992).

Shannon's diversity index 'H' (1948):

$$H = -\sum_{i=1}^{s} P_i ln P_i$$

Where,

P_i= proportion of 'i'-th species upon all individuals in a community.

ln= natural log

s = total species number within community

Value ranges between 1.5 to 3.5.

This index rarely goes greater than 4. Higher 'H' means high species diversity.

H=0 indicates presence of only one species in entire community.

Simpson Index 'D' (1949):

$$D = 1 - \sum_{i=1}^{k} \frac{n_i(n_i - 1)}{N(N-1)}$$

Where,

n_i= individual numbers in 'i'-th species

N= total individuals present in community.

k = number of species within community

'D' ranges between 0 to 1.

When 'D' increases, there is a decrease in diversity.

0=Infinite diversity,

0.1=extremely high diversity,

0.5=moderate diversity,

1=No diversity

Simpson Index of Diversity '1-D' (1949):

$$1 - D = \sum_{i=1}^{k} \frac{n_i(n_i - 1)}{N(N-1)}$$

Where,

n_i= individual numbers in 'i'-th species

N= total individuals present in community.

k = number of species within community

It's range lies between 0 and 1. Greater the value of 1-D, greater diversity

Pielou Evenness Index 'J' (1966):

$$\mathrm{J} = \frac{H}{\ln(S)}$$

Where,

H= Shannon's diversity index

S = richness of a species

It's range lies between 0 and 1. 1=Highest evenness

0=No evenness

Margalef Richness Index 'Ma' (1958):

$$Ma = \frac{(S-1)}{\ln(N)}$$

Where,

S = richness of a species

N= total individuals of existing community.

This richness index is limitless. >4= High species richness

4 to 2.5= medium richness

<2.5 = low species richness

Sorensen's similarity index 'DSC' (1948):

$$DSC = \frac{2C}{s_1 + s_2}$$

Where,

C = number of common species from both communities

s_1= species number in community 1

s_2= species number in community 2

Sorensen's similarity index value varies between 0 and 1.

>0.70= strongly similar species

0.61 to 0.70= moderately similar spies

<0.40= dissimilar species

Results

A total of 109 fish species (Table 2) were identified and categorised using Nelson's scheme of classification (2016). They fall into 19 orders, 44 families, 82 genera. Nineteen fish orders in all were reported from the current study, with Stations II and III having the maximum number of fish orders (16 orders each), and Stations I and IV having the lowest number of fish orders (12 orders each). In terms of seasons, the winter and rainy seasons had higher fish orders than the summer (Table 3). A high number of 19 species have been reported from each of the orders Siluriformes and Cypriniformes. Next, the orders Clupeiformes and Gobiformes have each recorded 10 species, followed by 8 species for the order Perciformes, seven species for the order Acanthuriformes, and six species for the order Anabantiformes. Additionally, four species each belong to the Beloniformes, Carangiformes, Synbranchiformes, and Pleuronectiformes groups of animals. There are three species in each of the two orders, Spariformes and Mugiliformes. Both Osteoglossiformes and Cichlidiformes have two species each. The orders Anguilliformes, Moroniformes, Scombriformes, and Scorpaeniformes all have a single species.

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Amongst the total collected fish species, the dominant group is Cypriniformes (18.26%) with their compositions followed by Siluriformes with 13.80%, Clupeiformes with 13.42%, Gobiformes with 10.49%, Mugiliformes with 9.40%, Perciformes with 7.87%, Anabantiformes with 5.25%, Carangiformes with 3.72%, Spariformes with 3.40%, Acanthuriformes with 3.25%, Pleuronectiformes with 2.97%, Synbranchiformes with 2.22%, Cichlidiformes with 1.78%, Beloniformes with 1.22%. Scorpaeniformes, Osteoglossiformes, Scombriformes, Anguilliformes, and Moroniformes accounted for 0.94%, 0.69%, 0.56%, 0.41%, and 0.37% of the total group, respectively. Cyprinidae, the most abundant and diverse family of fish (Ghimire and Narayan 2021), continued to lead the group with 17.02% of all fish families. With 9.40%, Mugilidae came in second, followed by Engraulidae (7.90%), Clupeidae (5.37%), Bagridae (4.75%), and so on. In contrast, Sisoridae came in last with a proportion of 0.06%, then Pristigasteridae (0.16%), Eleotridae (0.22%), Mullidae (0.31%), Sparidae and Hemiramphidae (0.34%), and so on. The Ven diagram represent fourteen common species that are found in all four stations are *Setipinna taty*, *Setipinna phasa*, *Gudusia chapra*, *Tenualosa ilisha*, *Rhinomugil corsula*, *Mugil cephalus*, *Chelon parsia*, *Lates calcarifer*, *Terapon jarbua*, *Terapon puta*, *Pangasius pangasius*, *Ompok bimaculatus*, *Ompok pabo* and *Mastacembelus armatus.* Fishes namely *Otolithoides biauritus*, *Paranibea semiluctuosa*, *Johnius borneensis*, *Thryssa polybranchialis*, *Coilia ramcarati*, *Coilia dussumieri*, *Drepane longimana*, *Upeneus sulphureus*, *Polydactylus sextarius*, *Pampus argenteus*, and *Osteogeneiosus militaris* are the 11 unique species identified at station-IV; five species namely *Puntius terio*, *Gobiopsis macrostomus*, *Eleotris fusca*, *Rita rita* and *Erethistes hara* are present only at station-II and *Strongylura strongylura* is the sole species of station-I (Figure 2, Table 4).

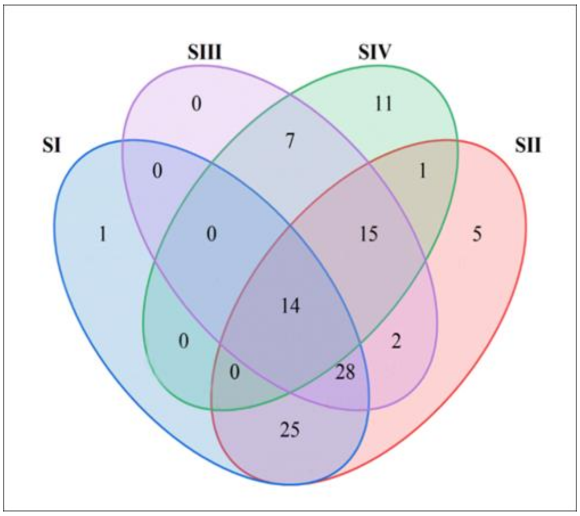

Figure 2. Venn diagram of common species count among all stations.

Table 2. Presentation of fish specimens collected in families and in accordance with orders.

ORDERS	FAMILIES	NAME OF FISH SPECIES
Acanthuriformes	Sciaenidae	*Macrospinosa cuja* (Hamilton, 1822)
		Otolithoides biauritus (Cantor, 1849)
		Paranibea semiluctuosa (Cuvier, 1830)
		Otolithes cuvieri (Trewavas, 1974)
		Johnius dussumieri (Cuvier, 1830)
		Protonibea diacanthus (Lacepède, 1802)
		Johnius borneensis (Bleeker, 1851)
Anabantiformes	Anabantidae	*Anabas testudineus* (Bloch, 1792)
	Osphronemidae	*Trichogaster fasciata* (Bloch & Schneider, 1801)
	Channidae	*Channa gachua* (Hamilton, 1822)
		Channa striata (Bloch, 1793)
		Channa punctata (Bloch, 1793)
	Nandidae	*Nandus nandus* (Hamilton, 1822)

Table 2. Continued

Anguilliformes	Anguilladae	*Anguilla bengalensis* (Gray, 1831)
Beloniformes	Hemiramphidae	*Hyporhamphus limbatus* (Valenciennes, 1847)
	Belonidae	*Xenentodon cancila* (Hamilton, 1822)
		Strongylura leiurus (Bleeker, 1850)
		Strongylura strongylura (Van Hasselt, 1823)
Carangiformes	Carangidae	*Alepes melanoptera* (Swainson, 1839)
		Chloroscombrus chrysurus (Linneaeus, 1766)
		Megalaspis cordyla (Linneaeus, 1758)
		Atropus atropos (Bloch & Schneider, 1801)
Cichlidiformes	Cichlidae	*Oreochromis mossambicus* (Peters, 1852)
		Oreochromis niloticus (Linneaeus, 1758)
Clupeiformes	Pristigasteridae	*Ilisha megaloptera* (Swainson, 1838)
	Engraulidae	*Setipinna phasa* (Hamilton, 1822)
		Setipinna taty (Valenciennes, 1848)
		Thryssa polybranchialis (Wongratana, 1983)
		Coilia dussumieri (Valenciennes, 1848)
		Coilia ramcarati (Hamilton, 1822)
	Clupeidae	*Gudusia chapra* (Hamilton, 1822)
		Hilsa kelee (Cuvier, 1829)
		Tenualosa ilisha (Hamilton, 1822)
		Tenualosa toli (Valenciennes, 1847)
Cypriniformes	Cyprinidae	*Puntius chola* (Hamilton, 1822)
		Puntius sophore (Hamilton, 1822)
		Puntius terio (Hamilton-Buchanon, 1822)
		Systomus sarana (Hamilton, 1822)
		Pethia conchonius (Hamilton, 1822)
		Pethia ticto (Hamilton, 1822)
		Cirrhinus mrigala (Hamilton, 1822)
		Labeo bata (Hamilton, 1822)
		Labeo calbasu (Hamilton, 1822)
		Labeo catla (Hamilton, 1822)
		Labeo rohita (Hamilton, 1822)
		Amblypharyngodon mola (Hamilton, 1822)
		Osteobrama cotio (Hamilton, 1822)
		Salmostoma bacaila (Hamilton, 1822)
		Salmostoma phulo (Hamilton, 1822)
		Cyprinus carpio (Linnaeus, 1758)
		Hypophthalmichthys molitrix (Valenciennes, 1844)
	Cobitidae	*Lepidocephalichthys guntea* (Hamilton, 1822)
		Lepidocephalichthys thermalis (Valenciennes, 1846)

Table 2. Continued

Gobiformes	Gobiidae	*Pseudapocryptes elongatus* (Cuvier, 1816)
		Apocryptes bato (Hamilton, 1822)
		Glossogobius giuris (Hamilton, 1822)
		Gobiopsis macrostomus (Steindachner,1861)
	Odontobutidae	*Odontamblyopus rubicundus* (Hamilton, 1822)
	Eleotridae	*Eleotris fusca* (Bloch & Schneider, 1801)
	Oxudercidae	*Taenioides cirratus* (Blyth, 1860)
	Ambassidae	*Parambassis lala* (Hamilton, 1822)
		Parambassis ranga (Hamilton, 1822)
		Chanda nama (Hamilton, 1822)
Moroniformes	Drepaneidae	*Drepane longimana* (Bloch & Schneider, 1801)
Mugiliformes	Mugilidae	*Rhinomugil corsula* (Hamilton, 1822)
		Mugil cephalus (Linnaeus, 1758)
		Chelon parsia (Hamilton, 1822)
Osteoglossiformes	Notopteridae	*Notopterus notopterus* (Pallas, 1769)
		Chitala chitala (Hamilton, 1822)
Perciformes	Haemulidae	*Pomadasys maculatus* (Bloch, 1793)
	Mullidae	*Upeneus sulphureus* (Cuvier, 1829)
	Latidae	*Lates calcarifer* (Bloch, 1790)
	Terapontidae	*Terapon jarbua* (Fabricus, 1775)
		Terapon puta (Cuvier, 1829)
	Polynemidae	*Polynemus paradiseus* (Linnaeus, 1758)
		Polydactylus sextarius (Bloch & Schneider, 1801)
		Eleutheronema tetradactylum (Shaw, 1804)
Pleuronectiformes	Soleidae	*Brachirus orientalis* (Bloch & Schneider, 1801)
	Cynoglossidae	*Cynoglossus arel* (Bloch & Schneider, 1801)
		Cynoglossus lingua (Hamilton, 1822)
		Cynoglossus puncticeps (Richardson,1846)
Scombriformes	Stromateidae	*Pampus argenteus* (Euphrasen,1788)
Scorpaeniformes	Platycephalidae	*Platycephalus indicus* (Linnaeus, 1758)
Siluriformes	Bagridae	*Rita rita* (Hamilton, 1822)
		Sperata seenghala (Sykes, 1839)
		Mystus bleekeri (Day, 1877)
		Mystus cavasius (Hamilton, 1822)
		Mystus gulio (Hamilton, 1822)
		Mystus vittatus (Bloch, 1794)
	Ariidae	*Osteogeneiosus militaris* (Linnaeus, 1758)
		Arius gagora (Hamilton, 1822)
		Arius platystomus (Day, 1877)
		Gagata cenia (Hamilton, 1822)
	Sisoridae	*Erethistes hara* (Hamilton, 1822)
	Ailiidae	*Clupisoma garua* (Hamilton, 1822)

Table 2. Continued

Siluriformes	Pangasidae	*Pangasius pangasius* (Hamilton, 1822)
	Heteropneustidae	*Heteropneustes fossilis* (Bloch, 1794)
	Clariidae	*Clarias batrachus* (Linneaeus,1758)
	Siluridae	*Wallago attu* (Bloch&Schneider, 1801)
		Ompok bimaculatus (Bloch,1794)
		Ompok pabda (Hamilton, 1822)
		Ompok pabo (Hamilton, 1822)
Spariformes	Sillaginidae	*Sillaginopsis domina* (Cuvier, 1816)
		Sillago sihama (Fabricius,1775)
	Sparidae	*Acanthopagrus latus* (Houttuyn,1782)
Synbranchiformes	Mastacembelidae	*Macrognathus aral* (Bloch & Schneider, 1801)
		Macrognathus pancalus (Hamilton, 1822)
		Mastacembelus armatus (Lacepede, 1800)
	Synbranchidae	*Ophichthys cuchia* (Hamilton, 1822)
19 Orders	**44** Families	**109** Fish species

Table 3. Abundance by fish orders

Sl. No.	Order	Spatial Abundance				Seasonal Abundance		
		S-I	S-II	S-III	S-IV	S	R	W
1	Acanthuriformes	0	7	23	74	12	30	62
2	Anabantiformes	71	75	22	0	43	49	76
3	Anguilliformes	5	5	3	0	5	1	7
4	Beloniformes	20	14	5	0	11	7	21
5	Carangiformes	0	0	35	84	22	38	59
6	Cichlidiformes	27	28	2	0	10	27	20
7	Clupeiformes	50	95	112	173	78	160	192
8	Cypriniformes	237	302	46	0	95	250	240
9	Gobiformes	127	153	56	0	90	117	129
10	Moroniformes	0	0	0	12	0	5	7
11	Mugiliformes	36	94	75	96	65	112	124
12	Osteoglossiformes	11	11	0	0	3	8	11
13	Perciformes	14	44	61	133	33	85	134
14	Pleuronectiformes	0	31	39	25	28	24	43
15	Scombriformes	0	0	0	18	4	9	5
16	Scorpaeniformes	0	17	5	8	6	16	8
17	Siluriformes	119	192	79	52	91	148	203
18	Spariformes	0	38	31	40	24	36	49
19	Synbranchiformes	20	31	18	2	29	11	31
No. of Orders Present		**12**	**16**	**16**	**12**	**18**	**19**	**19**

S-I=Site -I, S-II=Site-II, S-III=Site-III, S-IV=Site-IV, S=Summer, R=Monsoon, W=Winter

Table 4. Data on fish specimens is based on location and season.

Name of Fish Species	Station I				Station II				Station III				Station IV				Total Abun	Re.Abun (%)
	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun		
M. cuja	0	0	0	**0**	0	0	0	**0**	0	0	5	**5**	2	5	7	**14**	**19**	0.59
O. biauritus	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	4	3	9	**16**	**16**	0.50
P. semiluctuosa	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	2	3	**5**	**5**	0.16
O. cuvieri	0	0	0	**0**	0	0	3	**3**	0	3	2	**5**	3	4	6	**13**	**21**	0.65
J. dussumieri	0	0	0	**0**	0	0	2	**2**	0	4	5	**9**	0	5	7	**12**	**23**	0.72
P. diacanthus	0	0	0	**0**	0	0	2	**2**	0	1	3	**4**	1	2	4	**7**	**13**	0.40
J. borneensis	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	2	1	4	**7**	**7**	0.22
A. testudineus	3	2	6	**11**	2	4	5	**11**	0	0	5	**5**	0	0	0	**0**	**27**	0.84
T. fasciata	6	8	9	**23**	5	9	9	**23**	4	0	3	**7**	0	0	0	**0**	**53**	1.65
C. striata	1	0	2	**3**	2	0	3	**5**	3	0	0	**3**	0	0	0	**0**	**11**	0.34
C. punctata	3	3	7	**13**	4	8	7	**19**	3	0	2	**5**	0	0	0	**0**	**37**	1.15
C. gachua	2	2	4	**8**	0	2	3	**5**	0	0	0	**0**	0	0	0	**0**	**13**	0.40
N. nandus	3	4	6	**13**	2	5	5	**12**	0	2	0	**2**	0	0	0	**0**	**27**	0.84
A. bengalensis	2	1	2	**5**	2	0	3	**5**	1	0	2	**3**	0	0	0	**0**	**13**	0.40
H. limbatus	4	2	2	**8**	1	0	2	**3**	0	0	0	**0**	0	0	0	**0**	**11**	0.34
X. cancila	2	0	3	**5**	3	1	5	**9**	0	2	3	**5**	0	0	0	**0**	**19**	0.59
S. leiurus	0	1	2	**3**	0	0	2	**2**	0	0	0	**0**	0	0	0	**0**	**5**	0.16
S. strongylura	1	1	2	**4**	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	**4**	0.12
A. melanoptera	0	0	0	**0**	0	0	0	**0**	0	2	4	**6**	5	7	9	**21**	**27**	0.84
C. chrysurus	0	0	0	**0**	0	0	0	**0**	0	0	3	**3**	6	8	11	**25**	**28**	0.87
M. cordyla	0	0	0	**0**	0	0	0	**0**	0	2	5	**7**	3	4	7	**14**	**21**	0.65
A. atropos	0	0	0	**0**	0	0	0	**0**	3	7	9	**19**	5	8	11	**24**	**43**	1.34
O. mossambicus	4	7	7	**18**	2	9	8	**19**	0	2	0	**2**	0	0	0	**0**	**39**	1.22
O. niloticus	2	5	2	**9**	2	4	3	**9**	0	0	0	**0**	0	0	0	**0**	**18**	0.56
I. megaloptera	0	0	0	**0**	0	0	0	**0**	0	1	1	**2**	0	1	2	**3**	**5**	0.16
S. taty	4	7	9	**20**	7	10	12	**29**	7	9	11	**27**	4	6	10	**20**	**96**	3.00
S. phasa	2	5	8	**15**	5	11	13	**29**	6	12	15	**33**	4	9	11	**24**	**101**	3.15
T. polybranchialis	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	3	3	**6**	**6**	0.19
C. ramcarati	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	6	8	7	**21**	**21**	0.65
C. dussumieri	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	4	10	15	**29**	**29**	0.90
G. chapra	0	4	7	**11**	6	9	14	**29**	6	8	15	**29**	8	11	15	**34**	**103**	3.21
H. kelee	0	0	0	**0**	0	1	0	**1**	0	2	3	**5**	2	5	3	**10**	**16**	0.50
T. ilisha	0	2	2	**4**	0	4	3	**7**	3	6	5	**14**	3	8	8	**19**	**44**	1.37
T. toli	0	0	0	**0**	0	0	0	**0**	0	2	0	**2**	1	6	0	**7**	**9**	0.28
P. terio	0	0	0	**0**	0	5	3	**8**	0	0	0	**0**	0	0	0	**0**	**8**	0.25
S. sarana	6	11	8	**25**	5	12	7	**24**	0	0	0	**0**	0	0	0	**0**	**49**	1.53
P. conchonius	0	5	5	**10**	3	8	5	**16**	0	0	0	**0**	0	0	0	**0**	**26**	0.81
P. ticto	3	5	5	**13**	0	6	5	**11**	0	0	3	**3**	0	0	0	**0**	**27**	0.84
P. chola	0	7	5	**12**	0	6	9	**15**	0	6	4	**10**	0	0	0	**0**	**37**	1.15
P. sophore	8	10	12	**30**	6	15	9	**30**	0	0	0	**0**	0	0	0	**0**	**60**	1.87
C. mrigala	1	2	0	**3**	0	3	3	**6**	0	0	0	**0**	0	0	0	**0**	**9**	0.28
L. rohita	0	5	0	**5**	0	6	0	**6**	0	0	0	**0**	0	0	0	**0**	**11**	0.34

S, R, W and Re. Abun are abbreviations for Summer, Winter, Rainy and Relative Abundance respectively

Table 4. Continued

Name of Fish Species	Station I				Station II				Station III				Station IV				Total Abun	Re.Abun (%)
	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun		
L. bata	0	4	4	**8**	3	5	8	**16**	0	0	0	**0**	0	0	0	**0**	**24**	0.75
L. calbasu	0	0	3	**3**	0	3	2	**5**	0	0	0	**0**	0	0	0	**0**	**8**	0.25
L. catla	0	2	0	**2**	0	3	0	**3**	0	0	0	**0**	0	0	0	**0**	**5**	0.16
A. mola	10	12	15	**37**	11	14	17	**42**	4	9	12	**25**	0	0	0	**0**	**104**	3.25
O. cotio	0	5	8	**13**	4	7	8	**19**	0	8	0	**8**	0	0	0	**0**	**40**	1.25
S. phulo	8	10	12	**30**	7	11	15	**33**	0	0	0	**0**	0	0	0	**0**	**63**	1.97
S. bacaila	5	7	11	**23**	8	12	14	**34**	0	0	0	**0**	0	0	0	**0**	**57**	1.78
C. carpio	0	0	2	**2**	0	0	5	**5**	0	0	0	**0**	0	0	0	**0**	**7**	0.22
H. molitrix	0	4	0	**4**	0	6	0	**6**	0	0	0	**0**	0	0	0	**0**	**10**	0.31
L. guntea	3	5	7	**15**	0	7	9	**16**	0	0	0	**0**	0	0	0	**0**	**31**	0.97
L. thermalis	0	0	2	**2**	0	4	3	**7**	0	0	0	**0**	0	0	0	**0**	**9**	0.28
P. elongatus	4	4	7	**15**	6	8	9	**23**	0	4	5	**9**	0	0	0	**0**	**47**	1.47
L. bata	0	4	4	**8**	3	5	8	**16**	0	0	0	**0**	0	0	0	**0**	**24**	0.75
L. calbasu	0	0	3	**3**	0	3	2	**5**	0	0	0	**0**	0	0	0	**0**	**8**	0.25
L. catla	0	2	0	**2**	0	3	0	**3**	0	0	0	**0**	0	0	0	**0**	**5**	0.16
A. mola	10	12	15	**37**	11	14	17	**42**	4	9	12	**25**	0	0	0	**0**	**104**	3.25
O. cotio	0	5	8	**13**	4	7	8	**19**	0	8	0	**8**	0	0	0	**0**	**40**	1.25
S. phulo	8	10	12	**30**	7	11	15	**33**	0	0	0	**0**	0	0	0	**0**	**63**	1.97
S. bacaila	5	7	11	**23**	8	12	14	**34**	0	0	0	**0**	0	0	0	**0**	**57**	1.78
C. carpio	0	0	2	**2**	0	0	5	**5**	0	0	0	**0**	0	0	0	**0**	**7**	0.22
H. molitrix	0	4	0	**4**	0	6	0	**6**	0	0	0	**0**	0	0	0	**0**	**10**	0.31
L. guntea	3	5	7	**15**	0	7	9	**16**	0	0	0	**0**	0	0	0	**0**	**31**	0.97
L. thermalis	0	0	2	**2**	0	4	3	**7**	0	0	0	**0**	0	0	0	**0**	**9**	0.28
P. elongatus	4	4	7	**15**	6	8	9	**23**	0	4	5	**9**	0	0	0	**0**	**47**	1.47
A. bato	3	0	4	**7**	6	5	8	**19**	6	0	0	**6**	0	0	0	**0**	**32**	1.00
G. giuris	5	4	8	**17**	4	7	9	**20**	2	0	5	**7**	0	0	0	**0**	**44**	1.37
G. macrostomus	0	0	0	**0**	0	3	0	**3**	0	0	0	**0**	0	0	0	**0**	**3**	0.09
O. rubicundus	12	11	8	**31**	11	8	5	**24**	5	4	4	**13**	0	0	0	**0**	**68**	2.12
E. fusca	0	0	0	**0**	0	3	4	**7**	0	0	0	**0**	0	0	0	**0**	**7**	0.22
T. cirratus	0	4	0	**4**	4	5	0	**9**	0	6	0	**6**	0	0	0	**0**	**19**	0.59
P. lala	2	6	4	**12**	1	3	4	**8**	0	0	0	**0**	0	0	0	**0**	**20**	0.62
P. ranga	3	4	12	**19**	2	5	11	**18**	0	0	0	**0**	0	0	0	**0**	**37**	1.15
C. nama	7	8	7	**22**	5	9	8	**22**	2	6	7	**15**	0	0	0	**0**	**59**	1.84
D. longimana	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	5	7	**12**	**12**	0.37
R. corsula	4	7	8	**19**	11	19	17	**47**	8	12	13	**33**	11	18	15	**44**	**143**	4.46
M. cephalus	0	1	3	**4**	2	3	5	**10**	2	4	5	**11**	5	7	6	**18**	**43**	1.34
C. parsia	0	5	8	**13**	8	13	16	**37**	7	11	13	**31**	7	12	15	**34**	**115**	3.59
N. notopterus	2	4	4	**10**	1	3	5	**9**	0	0	0	**0**	0	0	0	**0**	**19**	0.59
C. chitala	0	1	0	**1**	0	0	2	**2**	0	0	0	**0**	0	0	0	**0**	**3**	0.09
P. maculatus	0	0	0	**0**	0	0	4	**4**	0	0	4	**4**	3	7	9	**19**	**27**	0.84
U. sulphureus	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	3	3	4	**10**	**10**	0.31
L. calcarifer	0	0	2	**2**	1	2	2	**5**	1	2	3	**6**	1	3	4	**8**	**21**	0.65

S, R, W and Re. Abun are abbreviations for Summer, Winter, Rainy and Relative Abundance respectively

Table 4. Continued

Name of Fish Species	Station I				Station II				Station III				Station IV				Total Abun	Re.Abun (%)
	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun	S	R	W	Abun		
T. jarbua	0	2	3	**5**	0	3	5	**8**	2	7	9	**18**	4	6	9	**19**	**50**	1.56
T. puta	0	2	5	**7**	1	4	5	**10**	0	3	5	**8**	0	5	8	**13**	**38**	1.19
P. paradiseus	0	0	0	**0**	0	4	6	**10**	4	8	9	**21**	7	13	17	**37**	**68**	2.12
P. sextarius	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	2	3	6	**11**	**11**	0.34
E. tetradactylum	0	0	0	**0**	0	3	4	**7**	0	0	4	**4**	4	5	7	**16**	**27**	0.84
B. orientalis	0	0	0	**0**	2	0	3	**5**	4	0	4	**8**	0	0	0	**0**	**13**	0.40
C. arel	0	0	0	**0**	2	5	5	**12**	4	3	8	**15**	5	4	7	**16**	**43**	1.34
C. lingua	0	0	0	**0**	4	2	3	**9**	5	3	4	**12**	2	2	5	**9**	**30**	0.94
C. puncticeps	0	0	0	**0**	0	3	2	**5**	0	2	2	**4**	0	0	0	**0**	**9**	0.28
P. argenteus	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	4	9	5	**18**	**18**	0.56
P. indicus	0	0	0	**0**	4	8	5	**17**	0	5	0	**5**	2	3	3	**8**	**30**	0.93
R. rita	0	0	0	**0**	2	1	0	**3**	0	0	0	**0**	0	0	0	**0**	**3**	0.09
S. seenghala	0	2	5	**7**	0	3	8	**11**	0	1	3	**4**	0	0	0	**0**	**22**	0.69
M. gulio	4	0	8	**12**	0	0	6	**6**	0	0	0	**0**	0	0	0	**0**	**18**	0.56
M. vittatus	6	11	9	**26**	7	12	10	**29**	0	2	3	**5**	0	0	0	**0**	**60**	1.87
M. bleekeri	0	2	2	**4**	1	3	4	**8**	0	1	1	**2**	0	0	0	**0**	**14**	0.44
M. cavasius	2	2	4	**8**	3	7	8	**18**	0	4	5	**9**	0	0	0	**0**	**35**	1.09
O. militaris	0	0	0	**0**	0	0	0	**0**	0	0	0	**0**	0	3	3	**6**	**6**	0.19
A. gagora	0	0	0	**0**	2	3	2	**7**	2	3	3	**8**	3	0	0	**3**	**18**	0.56
A. platystomus	0	0	0	**0**	0	2	1	**3**	1	2	2	**5**	2	3	2	**7**	**15**	0.47
G. cenia	0	3	4	**7**	4	5	0	**9**	0	0	0	**0**	0	0	0	**0**	**16**	0.50
E. hara	0	0	0	**0**	2	0	0	**2**	0	0	0	**0**	0	0	0	**0**	**2**	0.06
C. garua	0	0	0	**0**	0	4	6	**10**	2	7	8	**17**	5	8	10	**23**	**50**	1.56
P. pangasius	1	2	1	**4**	1	3	2	**6**	0	2	0	**2**	0	1	0	**1**	**13**	0.40
H. fossilis	3	5	7	**15**	0	6	8	**14**	0	2	0	**2**	0	0	0	**0**	**31**	0.97
C. batrachus	2	5	5	**12**	2	7	3	**12**	0	2	0	**2**	0	0	0	**0**	**26**	0.81
W. attu	0	1	3	**4**	3	0	3	**6**	0	1	0	**1**	0	0	0	**0**	**11**	0.34
O. bimaculatus	0	0	5	**5**	4	2	8	**14**	4	2	5	**11**	3	0	0	**3**	**33**	1.03
O. pabda	2	1	5	**8**	3	4	7	**14**	0	0	4	**4**	0	0	0	**0**	**26**	0.81
O. pabo	2	0	5	**7**	7	5	8	**20**	2	1	4	**7**	4	2	3	**9**	**43**	1.34
S. domina	0	0	0	**0**	8	8	9	**25**	6	7	9	**22**	5	8	11	**24**	**71**	2.22
S. sihama	0	0	0	**0**	0	3	5	**8**	1	3	5	**9**	2	4	4	**10**	**27**	0.84
A. latus	0	0	0	**0**	2	0	3	**5**	0	0	0	**0**	0	3	3	**6**	**11**	0.34
M. pancalus	4	0	5	**9**	5	0	7	**12**	3	0	2	**5**	0	0	0	**0**	**26**	0.81
M. aral	2	0	3	**5**	3	0	3	**6**	0	0	0	**0**	0	0	0	**0**	**11**	0.34
M. armatus	1	2	1	**4**	2	4	2	**8**	1	0	0	**1**	2	0	0	**2**	**15**	0.47
O. cuchia	0	0	2	**2**	1	2	2	**5**	5	3	4	**12**	0	0	0	**0**	**19**	0.59

S, R, W and Re. Abun are abbreviations for Summer, Winter, Rainy and Relative Abundance respectively

Shannon's diversity index *H* climbs above 4.1 (Table 5) during the rainy (4.111) and winter (4.211) seasons at station-II, indicating greater species diversity there (4.230) than at other stations. Compared to the summer (4.164), the winter (4.350) and rainy (4.310) are little more diversified. The Simpson index *D* is much less than 0.1 and ranges from 0.018 (S-II) to 0.030 (S-IV) in terms of station and from 0.016 (winter) to 0.020 (rainy) in terms of season. It would therefore not be an overstatement to say that the river is extremely diverse throughout the year. Pielou's evenness index J (the upper limit of this index is 1, indicating maximum evenness) never falls below 0.923 (S-III) and has even climbed as high as 0.947 (S-IV) across all locations and seasons. It is straightforwardto deduce that station-IV and station-III, respectively, exhibit the highest and lowest evenness. A high species richness is indicated by a Margalef's index (Ma) value exceeding 4. Ma is significantly higher at station-II during the winter (12.920) and lowest at station-III during the summer (6.696). Station-wise, station-II exhibits the highest richness (12.650), while station-IV exhibits the lowest richness (7.147). Figure 3 and 4 are graphical representations of the studied biodiversity indices. The biodiversity indices for the entire river, both spatially and seasonally are shown in Table 6.

Strong similarities are found (Table 7) between stations I & II (0.84) and stations II & III (0.76), according to the dice similarity coefficient. Stations III and IV have species that are moderately similar (0.63). The species compositions are dissimilar between stations I and IV (0.26), which is desirable because station I is freshwater habitat and station IV is esturine in nature. As shown in Figure 5, along with the change in species richness (lnS), a corresponding improvement in Shannon's diversity (H) and Pielou's evenness (lnE) is observed as the volume of fish samples gathered over time increases across the entire river. Overall, there is no evidence of unscientific abrupt variation in the richness, evenness, or diversity of species. The fish species studied in this work have been listed and the degree of conservation determined to be 70% Least Concern (LC), representing 75 fish species of the total data, 11% Not Evaluated (NE), representing 12 fish species of the total data, 9% Near Threatened (NT), representing 10 fish species, 7% Data Deficient (DD), representing 8 fish species, and 3% Vulnerable (VU), representing 4 fish species filling this category (Figure 6). The hierarchical clustering process involved standardizing abundance scores from table 2 (z scores) and computing Pearson's correlation of sum of squares. The group average cluster method demonstrates clustroid similarity (fish orders). Cichlidiformes are the most representative, while Anabantiformes are the least. Interestingly, the third level cluster (shown in Figure 7) ranging from Anabantiformes to Cichlidiformes shares a less-saline habitat.

Discussion

The maximum number of species observed in orders Siluriformes and Cypriniformes as well as the high abundance of these orders is also seen in the Brahamputra River (Galib, 2015) and lotic water in Arunachal Pradesh (Gurumayum et al. 2016). The present observation agree with similar findings reported by Chakraborty et al. (2021), Chapin et al. (2000), Saha and Chakraborty (2021) in the Rajar Beel wetland, West Bengal. Based on Shannon-Wiener Index (H) (Jewel et al. 2018), the Atari River habitat showed more diversity in fish population than the Lakhandaha Wetland habitat in Bangladesh. Higher Shannon index in December while a lower one in April was reported from Meghna River, Bangladesh (Hossain et al. 2012) and Bakkhali River estuary (Rashed-Un-Nabi et al. 2011). Previous work on Rupnarayan River at Kolaghat region received scores of 3.251 for 'H' index, 0.049 for the Simpson's dominance index, and Simpson's index of diversity (1-D) of 0.951, 0.947 and 0.932 (Ghorai et al.2015). The similarity index shows maximum similarity was observed between Hooghly River and surrounded study canals (0.6418) whereas the river and ponds showed moderate similarity (0.6153) in the study (Nath and Patra 2017). The values of Pielou's Evenness Index of sample stations I, II, III and IV were 0.938, 0.940, 0.923 and 0.947 respectively (Table- 5). When the value approaches one, it indicates that the individuals are distributed equally. Here the value is 0.928 (Summer), 0.932 (Rainy), 0.943 (Winter) indicates towards the equitability of the river ecosystem under study. The fish diversity study in Ghaghara River (Kumar et al. 2020) in Northern India showed the evenness index varied from 0.754 to 0.847 in his study. The Margalef value ranges spatially 7.148- 12.650 and highest value encoded in rainy season (Table-5).

Table 5. Spatial Indices by Season (utilised application software PAST v4.11)

Biodiversity Indices	Station I			Station II			Station III			Station IV		
	S	R	W	S	R	W	S	R	W	S	R	W
Species (Richness)	42	55	62	58	73	81	33	50	53	39	45	43
Individuals (Abundance)	154	247	336	227	422	488	119	211	282	149	253	315
Shannon's diversity index (H)	3.544	3.800	3.968	3.855	4.111	4.211	3.347	3.681	3.786	3.528	3.625	3.620
Simpson Index (D)	0.034	0.026	0.021	0.025	0.019	0.017	0.039	0.030	0.027	0.033	0.031	0.030
Simpson's Index of Diversity (1-D)	0.966	0.974	0.979	0.975	0.981	0.983	0.961	0.970	0.973	0.967	0.969	0.970
Pielou's Evenness Index (J)	0.948	0.948	0.961	0.949	0.958	0.958	0.957	0.941	0.954	0.963	0.952	0.962
Simpson's Reciprocal Index (1/D)	29.061	38.447	46.773	40.161	52.411	57.937	25.517	33.300	37.341	30.202	32.446	33.333
Margalef's Richness Index (Ma)	8.140	9.801	10.490	10.510	11.910	12.920	6.696	9.156	9.217	7.594	7.952	7.301

Table 6. Biodiversity indices for the entire river, both spatially and seasonally

Biodiversity Indices	Station I	Station II	Station III	Station IV	Summer	Rainy	Winter
Species (Richness)	68	90	66	48	89	102	101
Individuals (Abundance)	737	1137	612	717	649	1133	1421
Shannon's diversity index (H)	3.957	4.230	3.867	3.665	4.164	4.310	4.350
Simpson Index (D)	0.023	0.018	0.027	0.030	0.020	0.017	0.016
Simpson's Index of Diversity (1-D)	0.977	0.982	0.973	0.970	0.980	0.983	0.984
Pielou's Evenness Index (J)	0.938	0.940	0.923	0.947	0.928	0.932	0.943
Simpsons Reciprocal Index (1/D)	43.290	56.243	37.397	33.795	49.702	58.411	62.305
Margalef's Richness Index (Ma)	10.150	12.650	10.130	7.148	13.590	14.360	13.780

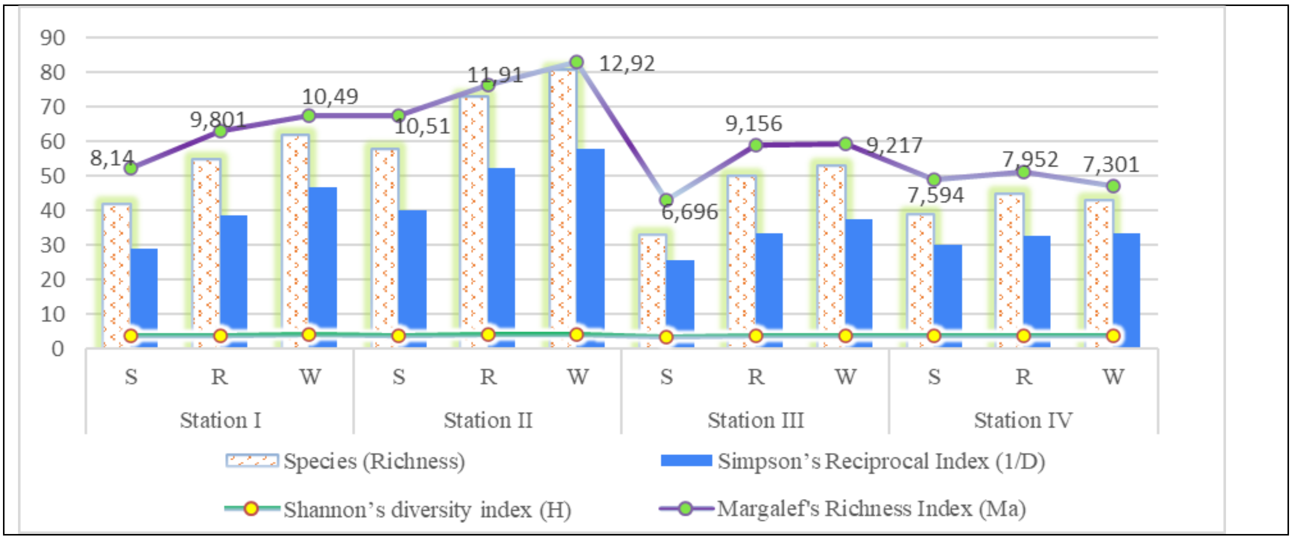

Figure 3. Various indices are compared both in terms of station and seasons as on Table 4. (1 of 2)

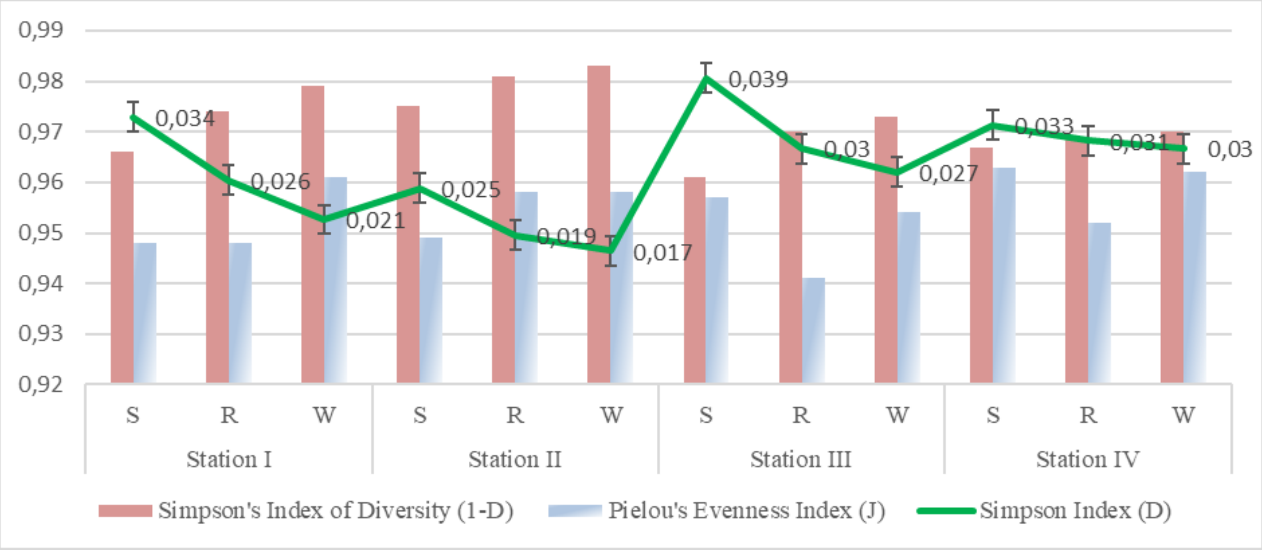

Figure 4. Various indices are compared both in terms of station and seasons as on Table 4. (2 of 2)

Table 7. Sorensen's resemblance Between each pair across the four sampling locations

Between Stations	Species Richness				Common Species	Coefficient (DSC)
	Station I	Station II	Station III	Station IV		
Station -I & Station -II	68	90	-	-	67	0.84
Station -II & Station -III	-	90	66	-	59	0.76
Station -III & Station -IV	-	-	66	48	36	0.63
Station -I & Station -III	68	-	66	-	42	0.63
Station -II & Station -IV	-	90	-	48	30	0.43
Station -I & Station -IV	68	-	-	48	15	0.26

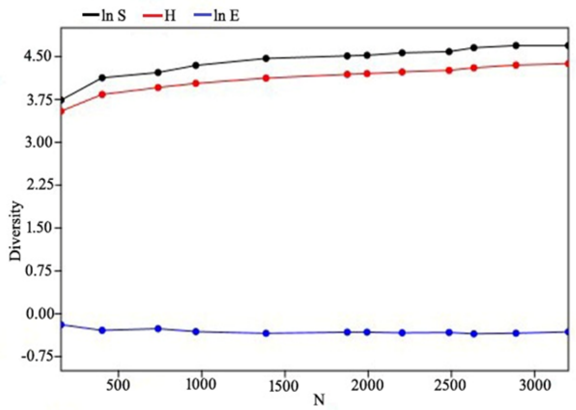

Figure 5. SHE(Richness-Diversity-Evenness) plotting. Each value along X axis from left to right represent SI-Summer, SI-Rainy, SI-Winter, SII Summer, SII-Rainy and so on. (Past v4.11)

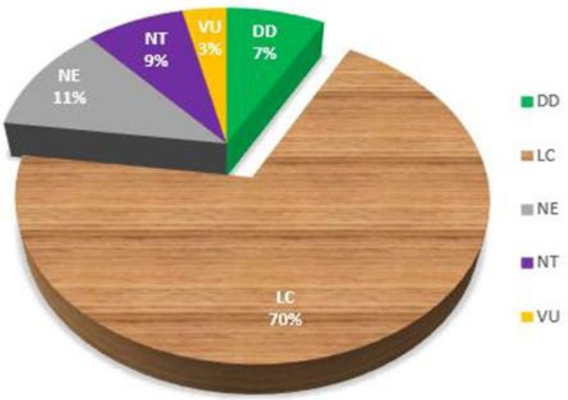

Figure 6. IUCN Status of fish fauna

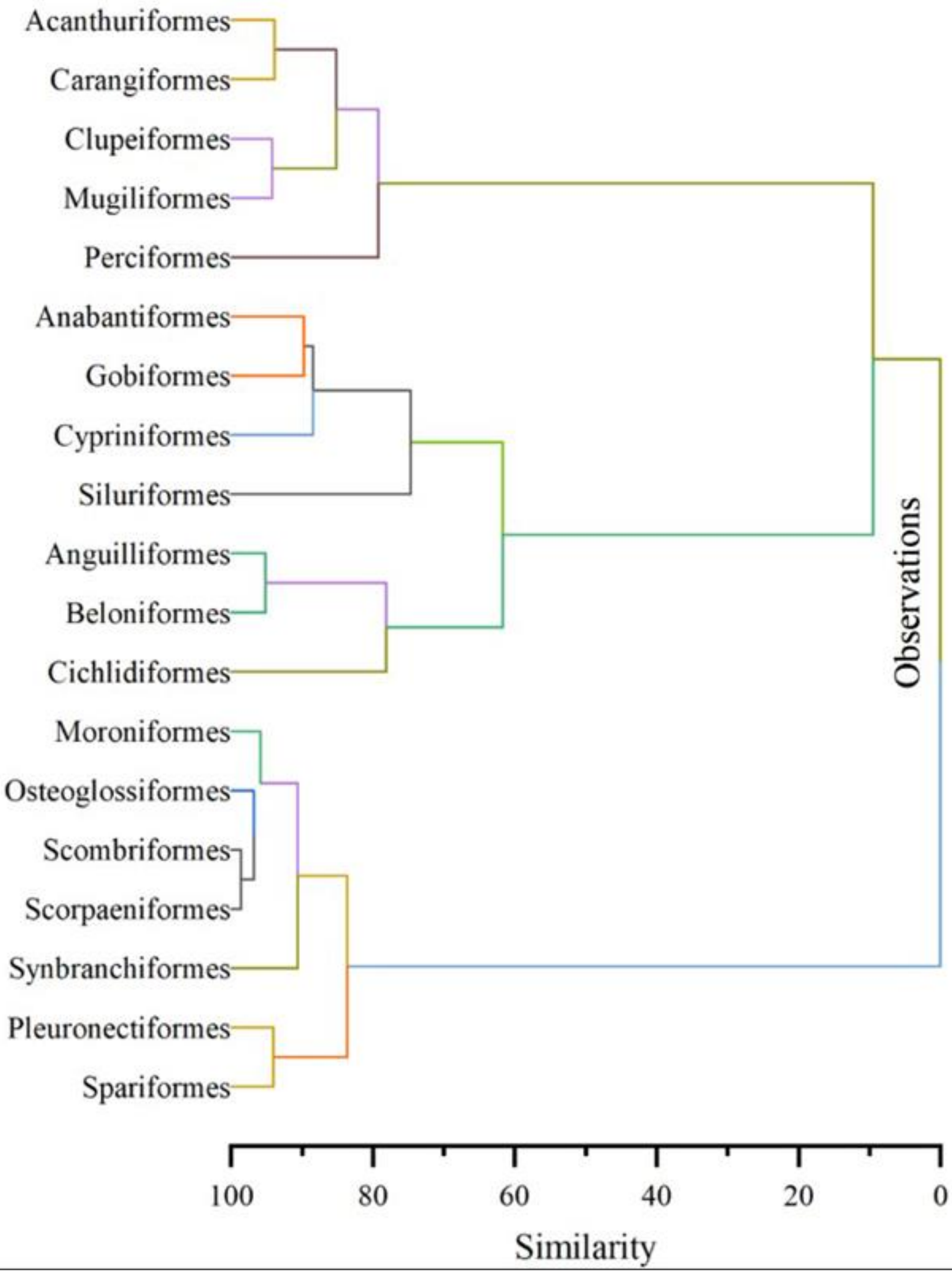

Figure 7. Hierarchical Clustering

This result supported in the previous work on Betwa River (Alam *et al.* 2013), Ponnani Kole wetland in Kerala (Akshad, 2021). The Rupnarayan river flow contains 10 fish species, which make up 9% of the overall richness are close to being vulnerable species i.e., near threatened. They are *P. diacanthus*, *A. bengalensis* (Ban Mach), *O. mossambicus* (Tilapia), *H. molitrix* (Silver Carp), *P. lala* (Chanda), *C. chitala* (Chitol), *W. attu* (Boal), and a three different species of pabda, consisting *O. bimaculatus*, *O. pabda*, and *O. pabo* (Figure 6). These species, including *T. toli*, *S. sarana*, *C. carpio*. and *P. conchonius* have experienced significant losses since the 1980s due to excessive fishing pressure (Adha et al. 2014). Over-exploitation by humans for food and habitat destruction (Hossain et al. 2010), has drastically decreased the population of *S. sarana*, which is mostly found in Asia and is found in Afghanistan, Pakistan, India, Nepal, Bangladesh, and Bhutan (Talwar and Jhingran, 1991) and Sri Lanka (Pethiyagoda and Kottelat 1994). According to Nelson's 2016 classification system, a compilation of earlier research with the current study provides the most recent list of fish species reported from the Rupnarayan River (Table 8). These 122 fish species are found in 94 genera, 47 families, and 19 orders. During the study period (2019–2021), 109 well-documented fish species were catalogued from the Rupnarayan River, of which 71 species (marked with **) were recorded for the first time.

Table 8. Comparative checklist of fish occurrence of Rupnarayan till date

Fish Species	Mishra (2003)	Ghorai (2018)	Present Study
Macrospinosa cuja **	x	x	✓
Otolithoides biauritus **	x	x	✓
Paranibea semiluctuosa **	x	x	✓
Otolithes cuvieri **	x	x	✓
Johnius dussumieri **	x	x	✓
Protonibea diacanthus **	x	x	✓
Johnius borneensis **	x	x	✓
Anabas testudineus **	x	x	✓
Trichogaster chuna	x	✓	X
Trichogaster fasciata	x	✓	✓
Channa striata	x	✓	✓
Channa punctatata	x	✓	✓
Channa gachua **	x	x	✓
Nandus nandus **	x	x	✓
Anguilla bengalensis	✓	✓	✓
Hyporhamphus limbatus **	x	x	✓
Xenentodon cancila	x	✓	✓
Strongylura leiurus **	x	x	✓
Strongylura strongylura **	x	x	✓
Alepes melanoptera **	x	x	✓
Chloroscombrus chrysurus **	x	x	✓
Megalaspis cordyla **	x	x	✓
Atropus atropus**	x	x	✓
Oreochromis mossambicus	x	✓	✓
Oreochromis nilotica **	x	x	✓
Ilisha megaloptera **	x	x	✓
Setipinna taty	✓	x	✓
Setipinna phasa	✓	✓	✓
Thryssa polybranchialis **	x	x	✓
Coilia ramcarati **	x	x	✓
Coilia dussumieri	✓	x	✓
Gudusia chapra	x	✓	✓

Table 8. Continued

Hilsa kelee* *	x	x	✓
Tenualosa ilisha			
Tenualosa toli* *	✓	✓	✓
Puntius terio* *	x	x	✓
Systomus sarana	x	x	✓
Pethia conchonius* *	x	✓	✓
Pethia ticto	x	x	✓
Puntius chola* *	x	✓	✓
Puntius sophore* *	x	x	✓
Puntius vittatus	x	x	✓
Chela cachius	x	✓	X
Cirrhinus mrigala* *	x	✓	X
Labeo rohita* *	x	x	✓
Labeo bata* *	x	x	✓
Labeo calbasu**	x	x	✓
Labeo catla* *	x	x	✓
Ambyphyaringodon mola	x	x	✓
Osteobrama cotio* *	x	✓	✓
Salmostoma phulo**	x	x	✓
Salmostoma bacaila* *	x	x	✓
Cyprinus carpio* *	x	x	✓
Hypophthalmichthys molitrix* *	x	x	✓
Lepidocephalichthys guntea* *	x	x	✓
Lepidocephalichthys thermalis* *	x	x	✓
Pseudapocryptes elongatus	x	x	✓
Apocryptes bato* *	✓	x	✓
Glossogobius giuris	x	x	✓
Gobiopsis macrostoma* *	x	✓	✓
Odontamblyopus rubicundus	x	x	✓
Eleotris fusca	✓	x	✓
Apocryptes cantoris	✓	x	✓
Apocryptes macrolepis	✓	x	X
Taenioides cirratus* *	✓	x	X
Parambasis lala* *	x	x	✓
Parambasis ranga* *	x	x	✓
Chanda nama	x	x	✓
Drepane longimana* *	x	✓	✓
Rhinomugil corsula* *	x	x	✓
Mugil cephalus	x	x	✓
Chelon parsia	x	✓	✓
Notopterus notopterus* *	x	✓	✓
Chitala chitala* *	x	x	✓
Pomadasys maculatus* *	x	x	✓
Upeneus sulphureus* *	x	x	✓
Lates calcarifer	x	x	✓
***Amphipnous* sp.**	x	✓	✓
Terapon jarbua	x	✓	X
Terapon putta* *	✓	x	✓
Pama pama	x	x	✓

Table 8. Continued

Johinus coitor	✓	x	X
Otolithes ruber	x	✓	X
Polynemus paradiseus	✓	x	X
Polydactylus sextarius* *	✓	✓	✓
Eleutheronema tetradactylam	x	x	✓
Cynoglossus arel* *	✓	x	✓
Cynoglossus puncticeps	x	x	✓
Cynoglossus cyanoglossus	✓	x	✓
Cynoglosus lingua	x	✓	X
Euryglossa orientalis* *	✓	x	✓
Pampus argenteus* *	x	x	✓
Platycephalus indicus* *	x	x	✓
Rita rita* *	x	x	✓
Sperata seenghala	x	x	✓
Mystus gulio* *	x	✓	✓
Mystus vittatus	x	x	✓
Mystus bleekeri* *	x	✓	✓
Mystus cavasius	x	x	✓
Mystus tengara	x	✓	✓
Osteogeneiosus militaris* *	x	✓	X
Arius gagora* *	x	x	✓
Arius platystomus* *	x	x	✓
Arius maculatus	x	x	✓
Gagata cenia* *	x	✓	X
Pangasius pangasius	x	x	✓
Clarias batracus	x	✓	✓
Heteropneustes fossilis	x	✓	✓
Clupisoma garua* *	x	✓	✓
Erethistes hara* *	x	x	✓
Wallago attu	x	x	✓
Ompak bimaculatus	x	✓	✓
Ompak pabo* *	x	✓	✓
Ompak pabda	x	x	✓
Silonia silondia	x	✓	✓
Sillaginopsis domina* *	x	✓	X
Sillago sihama* *	x	x	✓
Acanthopagrus latus* *	x	x	✓
Macrognathus pancalus	x	x	✓
Macrognathus aral* *	x	✓	✓
Mastacembelus armatus* *	x	x	✓
Ophichthys cuchia	x	x	✓
	x	✓	✓

**New Records (total 71) during present study period.

The current study serves as a thorough field investigation conducted at four locations for location to research fish biodiversity and the current status of the fish fauna in the Rupnarayan River. This investigation is necessary to ascertain the present status of the fish faunal diversity in the Rupnarayan River. Additionally, seasonal variations in fish diversity within this riverine water body should be noted. The river action plan along with conservation programs from the central and state governments' helps protect the river's environment from widespread anthropogenic activities that harm it.

This study provides an up-to-date documentation of the taxonomic characteristics of the various fish species, which will assist future researchers, decision-makers, taxonomists, and conservation organizations in obtaining the necessary information for future improvement.

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Conflict Of Interests

The authors declare that there are no conflicts of interest.

Ethics Approval

Ethical clearance from Institutional Animal Ethics Committee (IAEC), Approval no. 19/IAEC (05)/RNLKWC/2019, dated-27/07/2019

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Determination of Toxic Effect of Gamma Cyhalothrin in *Dreissena polymorpha* by Some Biomarkers

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ABSTRACT

In this study, the effects of pesticides on the freshwater mussel *Dreissena polymorpha*, a non-target organism, were aimed to be determined through biochemical responses. For this purpose, first, the acute toxicity value (LC50) of Gamma Cyhalothrin (GCH) pesticide on *D. polymorpha* was determined by standard static method and the LC50 value was calculated as 13.64 mg/L using probit analysis. Then, superoxide dismutase (SOD), glutathione peroxidase (GPx), catalase (CAT) activities, malondialdehyde (MDA) and glutathione (GSH) level responses of *D. polymorpha* organism exposed to GCH sublethal concentrations for 24 and 96 hours were determined. In addition to biochemical biomarkers, histopathological responses were evaluated. In conclusion, this study demonstrated the abilities of GCH pesticides to induce oxidative stress. Moreover, MDA, GSH levels, SOD, CAT, GPx activities and histopathological responses could be used as an effective biomarker in *D. polymorpha*.

Keywords: *Dreissena polymorpha*, gamma cyhalothrin, biomarker, oxidative stress, histology

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Gamma Cyhalothrin'in *Dreissena polymorpha*'daki Toksik Etkisinin Bazı Biyobelirteçlerle Belirlenmesi

Öz: Bu çalışmada, pestisitlerin hedef olmayan organizmalar olan tatlı su midyesi *Dreissena polymorpha* üzerindeki etkilerinin biyokimyasal tepkilerle belirlenmesi amaçlandı. Bu amaçla öncelikle Gamma Cyhalothrin (GCH) pestisitinin *D. polymorpha* üzerindeki akut toksisite değeri (LC50) standart statik yöntemle belirlenmiş ve probit analizi ile 13,64 mg/L hesaplanmıştır. Daha sonra 24 ve 96 saat boyunca ölümcül olmayan GCH konsantrasyonlarına maruz kalan *D. polymorpha* türünün süperoksit dismutaz (SOD), glutatyon peroksidaz (GPx), katalaz (CAT) aktiviteleri, malondialdehit (MDA) ve glutatyon (GSH) düzeyi tepkileri belirlendi. Biyokimyasal biyobelirteçlerin yanı sıra histopatolojik yanıtlar da değerlendirildi. Sonuç olarak, bu çalışma GCH pestisitlerinin oksidatif stresi tetikleme yeteneklerini ortaya koydu. Ayrıca MDA, GSH düzeyleri, SOD, CAT, GPx aktiviteleri ve histopatolojik yanıtlar da *D. polymorpha*'da etkili bir biyobelirteç olarak kullanılabilir.

Anahtar kelimeler: *Dreissena polymorpha*, gamma cyhalothrin, biyobelirteç, oksidatif stres, histoloji

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Introduction

The combined impact of the Green Revolution allowed global food production to double over the past 50 years. Since 1960, the human population has more than doubled to approach eight billion people. It is estimated that the population will increase by 30% in 2050 and reach approximately 9.2 billion people (Popp et al. 2013). Demand for food production is expected to increase by 70% due to a growing global population and changing diets for meat and dairy products in developing countries (FAO 2009).

Globally, an average of 35% of potential crop yields are lost due to preharvest pests (Oerke 2005). In addition to pre-harvest losses, food chain losses are also relatively high. At the same time, agriculture meets the growing demand for food, feed, fiber, biofuels, and other bio-based products globally. The provision of additional farmland is limited, as agricultural expansion will often have to take place at the expense of forests and natural habitats of wildlife, wild relatives of crops, and natural enemies of crop pests (Altıkat et al. 2009). Given these limitations, sustainable production and increased productivity on existing land are by far the better choice. The use of pesticides is inevitable for sustainable agriculture, the highest product yield per unit area, and the fight against pests. The increase in production has occurred simultaneously with a changing and increasingly unpredictable climate changing and becoming less predictable, cutting greenhouse gas emissions from agriculture, and shrinking or deteriorating soil and water resources (Popp et al. 2013). Reducing current yield losses caused by pests, pathogens, and weeds is the biggest challenge for agricultural production. The intensity of crop protection has increased significantly, as exemplified by a 15-20-fold increase in the number of pesticides used worldwide (Oerke 2005). While the use of pesticides increases agricultural production on the one hand, they also cause human and environmental health problems directly or indirectly as a result of unconscious and incorrect use. They can cause acute or chronic poisoning in people fed with foods containing high doses of pesticide residues and other living things in the environment, and they can cause aroma and quality changes, especially in some products. Widespread pesticide applications in agriculture and industry's pollution of the natural environment have a negative impact on living organisms. Pesticides that are withdrawn from use but remain in the environment produce serious and still unresolved ecotoxicological effects (Lew et al. 2009).

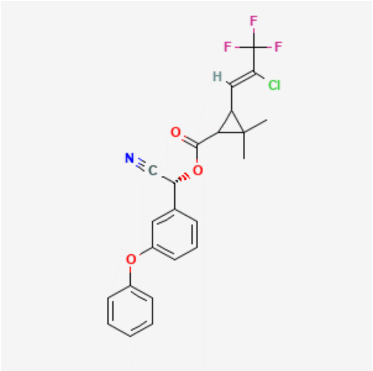
These agricultural pesticide products may reach water bodies due to drift, runoff, rainwater, and seepage (Geoffroy et al. 2004). Some organisms could be used as biological indicators for the presence of pollutants in the environment (Costa et al. 2008). To provide a basis for these assessments, organisms representing various levels of the food chain are used in acute and chronic toxicity experiments. These studies are easy-to-use materials and provide results on the possible ecotoxicological effects of pesticides on non-target organisms in aquatic environments (Florencio et al. 2014).

Aquatic invertebrates involve the effects of multiple stressors, potentially involving complex mixtures of pollutants, particularly affecting organism-sensitive developmental life stages such as growth, development, and reproduction (Oros and Werner 2005; Geist 2011; Brooks et al. 2012; Connon et al. 2012).

Pesticides entering the aquatic ecosystem can cause the reduction of aquatic organisms, such as shrimps, frogs, turtles, waterfowl, and fish in form of pathology or death. Aquatic animals are the main source of natural food chains. If other animals and humans consume these creatures, pesticides affect them. Using pesticides disadvantages people, animals, beneficial plants, and the persistence of some of these chemicals in the environment (long life) poses a serious danger to both human health and the environment (Lakhani 2015).

Gamma Cyhalothrin (GCH) is an insecticide used in agriculture in various fields such as apple, pear, quince, pistachio, tomato, hazelnut, cabbage, corn, cotton, potato, olive, and vineyard.

- **GCH Structure;**



- **GCH Molecular Formula;** $C_{23}H_{19}ClF_3NO_3$
- **Synonyms;**
  - GAMA-CYHALOTHRIN
  - 91465-08-6
  - Cyclopropanecarboxylic acid,3-[(1Z)-2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethyl-,(R)-cyano(3-phenoxyphenyl)methyl ester, (1S,3S)-rel-
  - CHEMBL2270530
  - SCHEMBL13408920
- **Molecular Weight;** 449.8 g/mol (National Center for Biotechnology Information 2024)

There are some organisms that are used as indicators to determine the pollution and pollutants in the waters. Among these indicators, mussels have an important place due to their non-selective feeding and sessile life.

Zebra mussel (*Dreissena polymorpha*) is economically damaging to the structures in the aquatic environment due to its nutritional characteristics, sessile (host) growth and high reproductive characteristics and can cause changes in the freshwater environment. Due to its water filtering feature, zebra mussels cause a decrease in phytoplankton in the environment. *D. polymorpha* may cause the imbalance of the very sensitive food chain to deteriorate and the aquatic ecosystem may be adversely affected by them (Serdar 2021). In addition, the need for mussels to stick to hard surfaces causes problems. Clogging of pipes, coating of piers, corrosion of steel and concrete, in addition rotting mussels cause bad odor on beaches (Pet İhtiyaç 2013).

The longevity of freshwater mussels, limited mobility and filter feeding, and biomarkers enable their widespread and reliable use in toxicological studies in the examination of pollution in aquatic ecosystems (Serdar et al. 2021). Since *D. polymorpha* has a strong oxidative defense and a relatively high resistance to xenobiotics, it is widely used to conduct ecotoxicological experiments (Faria et al. 2009).

In this study, the effect of SOD, CAT, GPx, TBARS and GSH biomarkers on *D. polymorpha* exposed to pesticides with GCH active ingredient was investigated.

Materials and Methods

D. polymorpha individuals were collected from the Euphrates River (38º 48' 25 ”N, 38º 43' 51” E). Samples taken from the Euphrates River were brought to Munzur University, Aquaculture Research Center in plastic bottles and placed in stock tanks. Before being used in the experiments, they were fed microalgae for at least 15 days for adaptation during to laboratory conditions. Then stocked in 500 L ventilated tanks with a temperature adjusted to 18 ºC, in a 12:12 hour light:dark cycle in an environment similar to natural living conditions. Healthy organisms (living things that perform siphoning) at similar developmental stages were selected for the study and were not fed during the experimental study (Serdar et al. 2021).

Gamma Cyhalothrin was obtained from a company selling agricultural chemicals with the number GCH CAS 76703-62-3 and a molecular weight of 449.8 g/mol.

A standard test value was used to determine LC_{50}. For this purpose, interval determination tests were applied. After range testing, *D. polymorpha* individuals were exposed to five determined concentrations of GCH (0.0 (control), 0.05, 0.25, 1.25, 6.25, 31.25 mg/L) for 24, 48, 72, and 96 hours. In acute toxicity experiments, organisms were checked every 24 hours and dead individuals were noted and excluded from the experimental groups. Acute toxicity (LC_{50}) values were calculated by performing probit analysis with the data obtained. Sublethal trial concentrations were established in proportion to the calculated LC_{50} values (1/8, 1/4, and 1/2). The following experimental groups were formed to expose *D. polymorpha* to GCH sublethal concentrations at the mentioned concentrations at 24 and 96 hours.

Control - 24 Group: Group not exposed to any treatment for 24 hours,

Control - 96 Group: Group not exposed to any treatment for 96 hours,

C1 - 24 Group: 24-hour exposure to GCH active ingredient at the rate of 1/8 of the LC_{50} value,

C1 - 96 Group: 96-hour exposure to GCH active ingredient at the rate of 1/8 of the LC_{50} value,

C2 - 24 Group: 24-hour exposure to GCH active ingredient at 1/4 of the LC_{50} value,

C2 - 96 Group: 96-hour exposure to GCH active ingredient at 1/4 of the LC_{50} value,

C3 - 24 Group: 24-hour exposure to GCH active ingredient at the rate of 1/2 of the LC_{50} value,

C3 - 96 Group: 96-hour exposure to GCH active ingredient at 1/2 of the LC_{50} value.

Biochemical response

All application experiments were carried out in 3 repetitions and 7 pieces of *D. polymorpha* were used for each experimental group. The samples, whose trial phase was finished, were kept at -80 degrees until analysis (Aydın and Serdar 2024a). To determine the biochemical response, SOD (Catalog No 706002), CAT (Catalog No 707002), and GPx (Catalog No 703102) enzyme activities, MDA (Catalog No 10009055) and GSH (Catalog No 703002) levels were determined in a microplate reader. Assay kits were purchased from CAYMAN Chemical Company.

Dissection procedures and preparation of supernatants

Test organism individuals were the shells were separated with a scalpel and the body tissue inside the shell was taken. 0.5 g of organisms was weighed and homogenized. Using an iced homogenizer, PBS (phosphate buffered saline) buffer was added. These homogenized samples were centrifuged at 17000 rpm for 15 minutes in a chilled environment. The resulting supernatants were kept in a -80 ºC freezer until measurement (Aydın and Serdar 2024b).

Histopathological evaluation

D. polymorpha samples left in the Bouin's tissue fixation solution were fixed for 24 hours. Afterward, the samples passed through 50 %, 70 %, 80 %, 96 I %, 96 % II, 100 % I, and 100 % II alcohol series (ethyl alcohol) were passed through xylol I, xylol II and xylol III series and kept in a xylol-paraffin mixture in a 45 ºC oven for 1 night (Parlak Ak et al. 2022). Following this, paraffin blocks were prepared by keeping them in three different paraffin series for one hour. Samples were embedded in paraffin. Serial sections were taken from the prepared paraffin blocks on a microtome on 4 µm thick. These sections were dried at room temperature for 24 hours or more. *D. polymorpha* sections were stained according to Hematoxylin-Eosin staining method and examined under a light microscope (Olympus BX-51, Olympus Optical Co., Ltd., Tokyo, Japan) for histological examinations Histopathological changes in the samples were scored according to a four-stage semi-quantitative assessment (0; normal appearance, 1; mild changes, 2; moderate changes, 3; severe changes) (Mantecca et al. 2006).

Statistical analysis

The LC_{50} value was calculated using SPSS 24.0 package program probit analysis. SPSS 24.0 package program one-way ANOVA was used for the evaluation of biochemical analyzes (Serdar et al. 2024).

The statistical analysis of the biochemical data was performed using SPSS 24.0 package programs. Changes in values of GCH in the biochemical parameters of the control and exposure groups were tested by Duncan's ($p<0.05$) multiple range test. Application times were compared using a two-way analysis of variance (ONEWAY–ANOVA) and independent ($p<0.05$) t-tests (Aydın et al. 2022).

Results

Determination of acute (LC_{50}) value

LC_{50} values obtained by applying standard static acute toxicity tests were calculated as 13.64 mg/L by the SPSS package program probit analysis.

Determination of biochemical response

MDA level

It was determined that the MDA level in the test organism exposed to GCH at different concentrations and durations increased statistically significantly ($p<0.05$) compared to the control group (Figure 1).

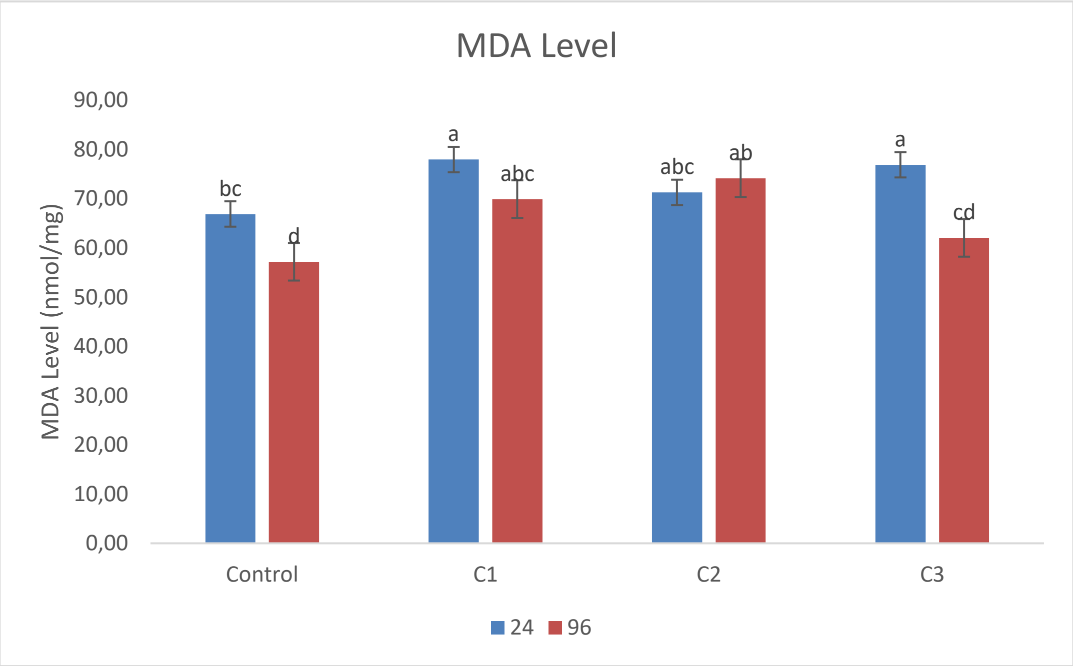


Figure 1. Changes in MDA (pg/mL) enzyme activity in *D. polymorpha* treated with different doses of GCH. Different letters on the bars indicate a statistically significant difference between groups in the same treatment period, $^{abc}p<0.05$ (according to Duncan's multiple comparison test) shows the statistical difference between 24th and 96th hours in the same treatment group (Independent T-test).

GSH level

It was determined that the GSH level in the test organism exposed to GCH at different concentrations and durations increased statistically significantly ($p<0.05$) compared to the control group (Figure 2).

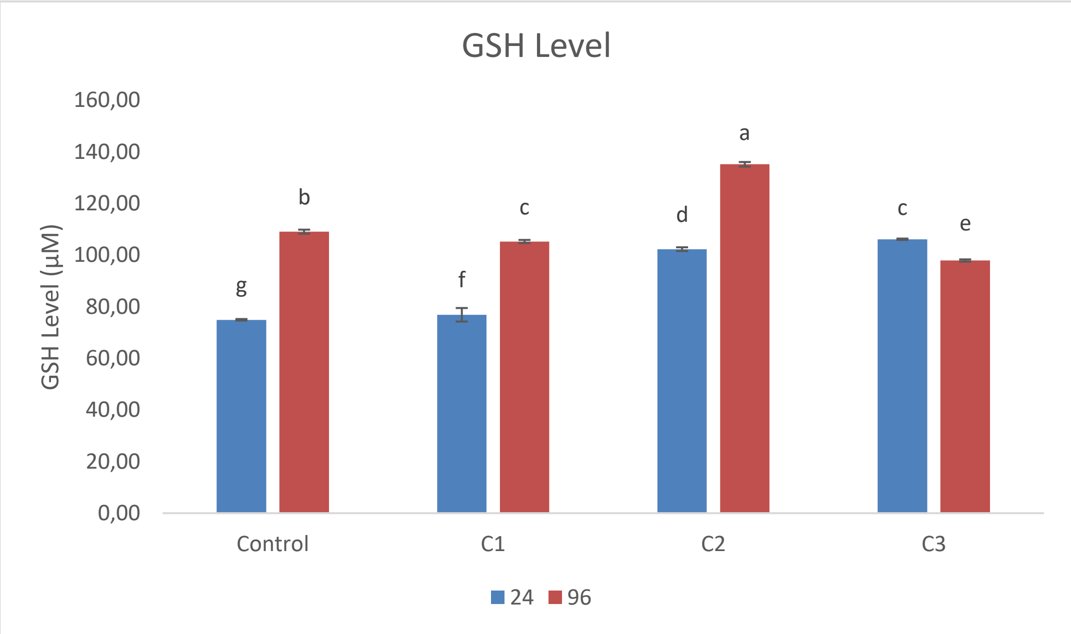


Figure 2. Changes in GSH (pg/mL) enzyme activity in *D. polymorpha* treated with different doses of GCH. Different letters on the bars indicate a statistically significant difference between groups in the same treatment period, $^{abc}p<0.05$ (according to Duncan's multiple comparison test) shows statistical difference between 24th and 96th hours in the same treatment group (Independent T-test).

CAT activity

It was determined that the CAT activity in the test organism exposed to GCH at different concentrations and durations decreased statistically significantly ($p<0.05$) compared to the control group (Figure 3).

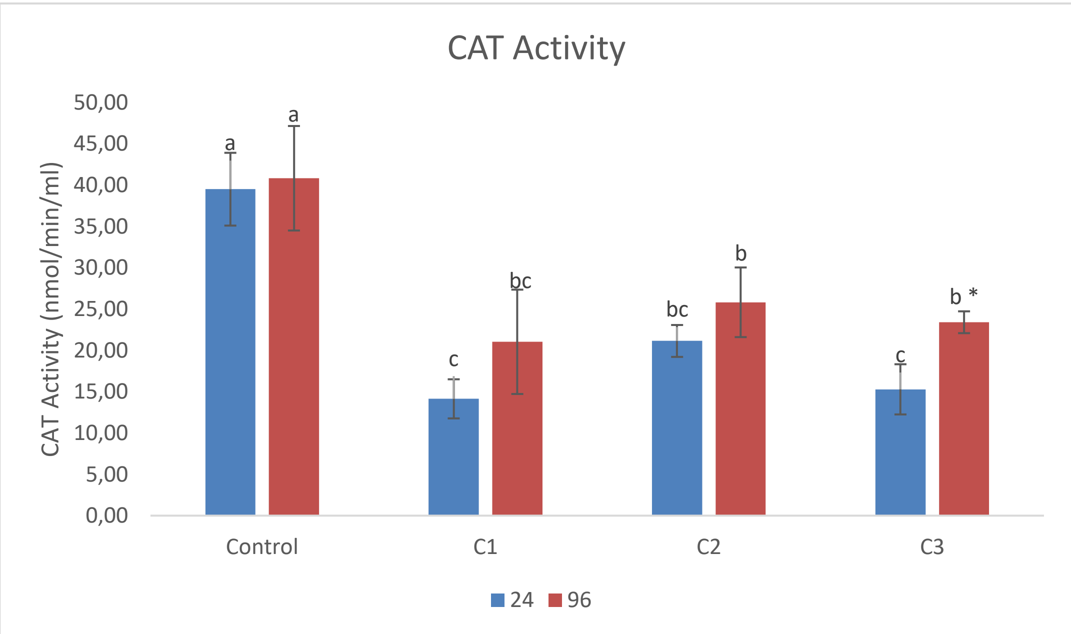


Figure 3. Changes in CAT (pg/mL) enzyme activity in *D. polymorpha* treated with different doses of GCH. Different letters on the bars indicate a statistically significant difference between groups in the same treatment period, $^{abc}p<0.05$ (according to Duncan's multiple comparison test) shows the statistical difference between 24th and 96th hours in the same treatment group (Independent T-test).

SOD activity

It was determined that the SOD activity in the test organism exposed to GCH at different concentrations and durations decreased statistically significantly ($p<0.05$) compared to the control group (Figure 4).

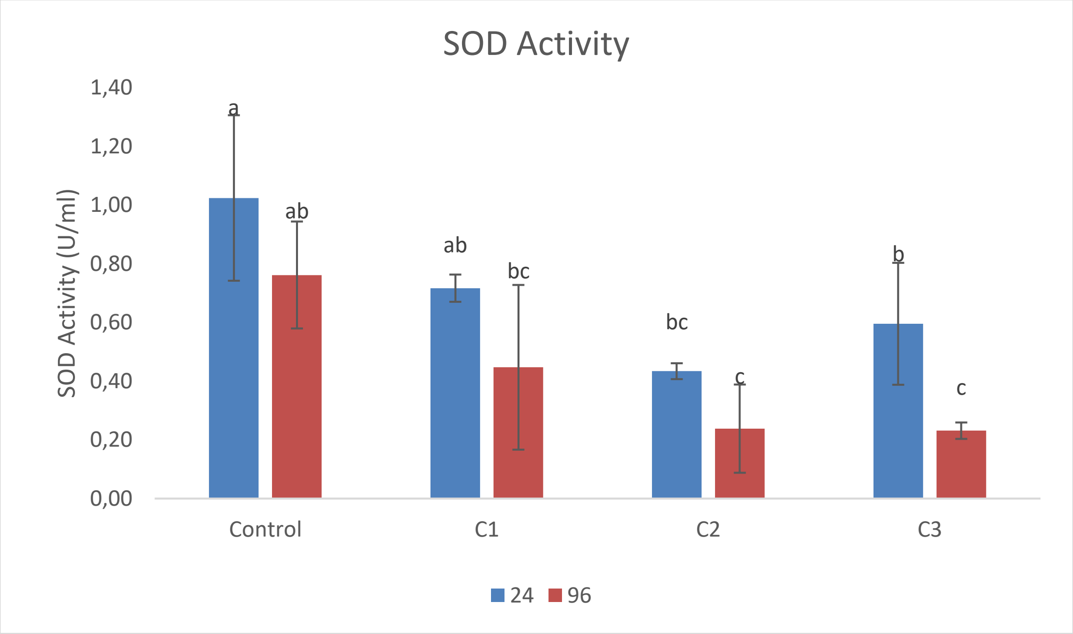


Figure 4. Changes in SOD (pg/mL) enzyme activity in *D. polymorpha* treated with different doses of GCH. Different letters on the bars indicate a statistically significant difference

GPx activity

It was determined that GPx activity in the test organism exposed to GCH at different concentrations and durations increased statistically significantly ($p<0.05$) at the 24th hour compared to the control group (Figure 5).

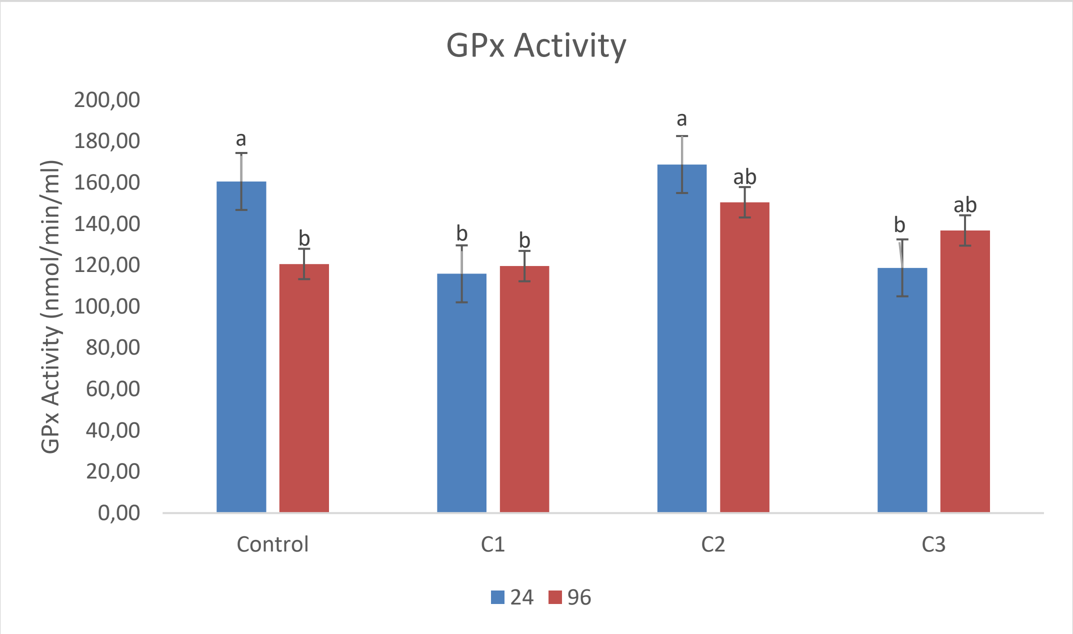


Figure 5. Changes in GPx (pg/mL) enzyme activity in *D. polymorpha* treated with different doses of GCH. Different letters on the bars indicate a statistically significant difference between groups in the same treatment period, $^{abc}p<0.05$ (according to Duncan's multiple comparison test) shows statistical difference between 24th and 96th hours in the same treatment group (Independent T-test).

Histopathological data

Normal histological appearance was observed in the gill tissues of the Control-24 group (Figure 6a). In addition, mild histopathological changes were observed in the gill tissues of the C1-24 group (Figure 6b), moderate level (Figure 6c) in the C2-24 group, and severe histopathological changes in the C3-24 group (Figure 6d).

Normal morphological appearance was observed in the gill tissues of the Control-96 group (Figure 7a). In addition, mild histopathological changes were observed in the tissues of the C1-96 group (Figure 7b), moderate level (Figure 7c) in the C2-96 group, and severe histopathological changes in the C3-96 group (Figure 7d).

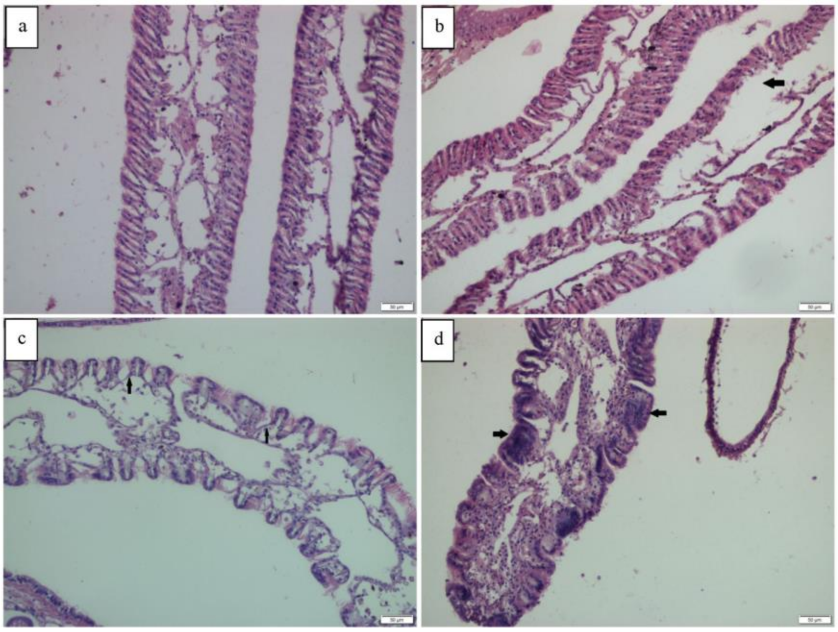


Figure 6. Normal histological structure in the gill tissue of the Control-24 group (a), separation (arrow) in the gill tissue of the C1-24 group (b), epithelial lift (arrows) in the gill tissue of the C2-24 group (c), epithelial hyperplasia in gill tissue of group C3-24 (arrows) (d), H&E.

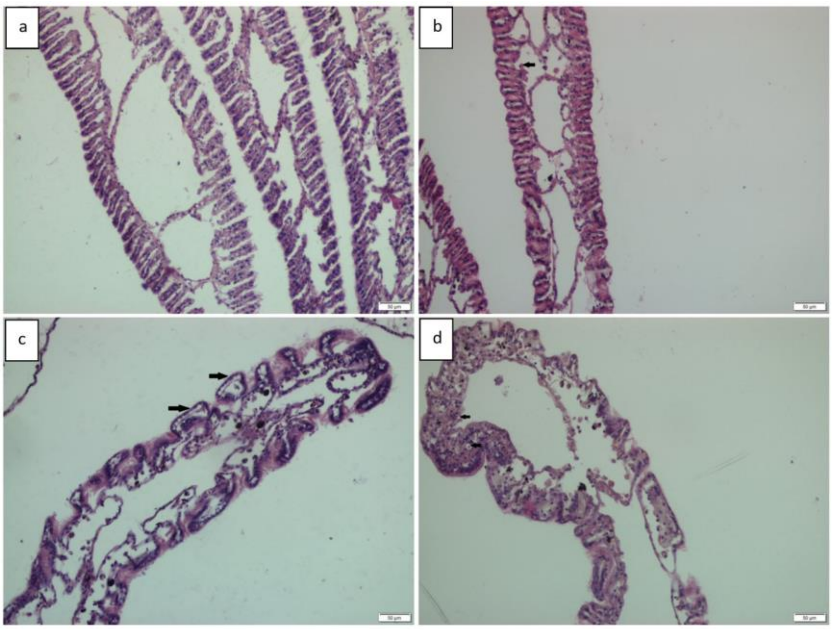


Figure 7. Normal histological structure in the gill tissue of the Control-96 group (a), cellular desquamation (arrow) in the gill tissue of the C1-96 group (b), enlargement of the epithelial layer in the gill tissue of the C2-96 group and missing (arrows) (c), Necrosis of gill tissue from group C3-96 (arrows) (d), H&E.

Discussion

According to various research data, it is stated that oxidative stress is the underlying mechanism of various pollutant-induced cytotoxicity (Yang et al. 2004; Milatovic et al. 2007).

Oxidative stress is defined as the potential for damage to tissues and cellular components with an imbalance between ROS production and removal and is generally accepted in toxicology studies. Pollutants including pesticide pollution, oxidative damage and antioxidant damage caused by the antioxidant defense developed against the formation of oxidative stress in organisms. The sensitivity of the defense to these effects is used to evaluate the toxic effects of these compounds (Valavanidis et al. 2006).

The biological role of superoxide dismutase (SOD) antioxidant defense is to defend cells against the toxic effects of O_2 by catalyzing dismutation reactions (Prasad 2004). Since the SOD-CAT system represents the first line of defense against oxidative stress, an increase in catalase (CAT) and SOD activity is usually observed in response to environmental pollutants (McCord 1996). While the SOD enzyme converts the superoxide anion radical (O_2^-) to hydrogen peroxide (H_2O_2), the CAT enzyme converts the released H_2O_2 to water and molecular oxygen (Pandey et al. 2003). It is also known that CAT and GPX enzymes compete with each other in the detoxification of H_2O_2 (Cheung et al. 2004). Serdar (2021) investigated some biochemical responses of commercial insecticide Cyfluthrin (CFT) in *D. polymorpha* and reported that SOD activity was increased in *D. polymorpha* individuals compared to the control, while CAT activity was inhibited compared to the control. Greco et al. (2011), bivalve *Mya arenaria* living organism in their study, dichlorophenoxyacetic acid (2,4-D), 2-(2-methyl-4-chlorophenoxy) propionic acid (mecoprop), and a formulation containing 3,6-dichloro-2-methoxy benzoic acid. They observed enzyme activities by exposing them to acid (dicamba) herbicides. As a result of the study, they found a decrease in SOD enzyme activities. Tutuş (2016) investigated the effects of organophosphorus insecticide chlorpyrifos (CPF) and avermectin insecticides abamectin (ABM) and emamectin benzoate (EB) on antioxidant parameters and lipid peroxidation in the liver selected as the target organ in *Oreochromis niloticus*. As a result of the study, SOD activity showed a decrease in the effect of all pesticides tested in durations. Xiong et al. (2011), investigated the acute toxicity, oxidative stress, and damage of NPs in *Danio rerio*, the fish were exposed to the effects of TiO_2 and ZnO NPs, and they determined decreases and increases in SOD activity. Yuksel et al. (2020), found reductions in SOD activity in *Gammarus pulex*, where they applied malathion. Florescu et al. (2021), found decreases and increases in SOD activity in the intestines of Sturgeon Fish (*Acipenser stellatus*) fry. Magara et al. (2021), found a decrease in SOD activity in the oxidative stress determination studies of Bronopol and Detarox AP on *Sinanodonta woodiana*. It could be said that the changes in SOD enzyme activities in *D. polymorpha* individuals exposed to GCH application are in agreement with the studies in the literature.

Korkmaz et al. (2018) evaluated the toxic effects of adult zebrafish (*D. rerio*) exposure to organophosphate group pesticides for alone and pyrethroid group pesticides cypermethrin and their mixtures at sublethal doses, and the reversibility of these effects using various biochemical markers. CAT and GPx enzyme parameters were decreased. Hao et al. 2009 investigated the subacute effect of TiO_2-NP on oxidative stress and histopathological variables in *Cyprinus carpio*. Fish were exposed to 10, 50, 100, and 200 mg/L TiO_2-NP for 8 days, and CAT and peroxidase activities and lipid peroxidation levels in the liver, gill, and brain tissues were investigated. As a result of the study, significant decreases were determined in CAT and peroxidase activities in the examined tissues, especially at high ambient concentrations (100 and 200 mg/L) of TiO_2-NP. Tonn et al. (2016), found decreases in CAT values in their study with *Holothuria forskali*. Xiong et al. (2011), observed increases and decreases in CAT levels in their study. Yuksel et al. (2020), found decreases in CAT activity in study. Florescu et al. (2021), detected reductions in CAT activity. Magara et al. (2021), determined reductions in CAT activity. Chen et al. (2020), they investigated the levels of different toxic metals and the extent of oxidative stress responses in *Sinonovacula constricta*. As a result of the research, they observed first increases and then decreases in CAT activity. It could be said that the changes in CAT enzyme activities in *D. polymorpha* individuals exposed to GCH application are in agreement with the studies in the literature.

The decrease in GCLC protein synthesis, which provides the production of SOD, GPX, GST and GSH, leads to a decrease in the antioxidant defense of the cell and thus an increase in the amount of MDA. The CAT enzyme is sensitive to excessive superoxide radical production and its activity decreases under these conditions Kono and Fridovich (1982), this inhibition is also hypothesized to contribute to the increase in MDA levels. Depletion leads to an imbalance in the redox state and ability to cope with organic xenobiotics metabolized by glutathione S-transferase (GST) and glutathione peroxidases (GPx). The effects of various xenobiotics on GPx activity in aquatic organisms have been investigated. Yuksel et al. (2020), observed decreases in GPx values of malathion substance in *G. pulex* in their study. The study of Magara et al. 2021 examined the acute and non-lethal toxicity of Bronopol and Detarox® AP in the crustacean *S. woodiana* and found decreases in GPx levels as a result. Chen et al. (2020), in their study investigated the levels of different toxic metals and the extent of oxidative stress responses in *S. constricta* and reported decreases in GPx levels. Changes in GPx activities in *D. polyhmorpha* exposed to GCH are similar to the literature.

GSH is recognized as a primary line of defense against free oxygen radicals in the antioxidant system (Cnubben et al. 2001; Dickinson and Forman 2002). Chemicals can alter the reduced amounts of GSH Rama (1998). GPx reduces reactive lipid hydroperoxides to prevent malondialdehyde (MDA) formation. Glutathione (GSH) is an important antioxidant that functions as a direct scavenger of oxidants as well as an antioxidant enzyme substrate (Ferrari et al. 2007; Serdar et al. 2021), in their study on *D. polymorpha* individuals, some biochemical responses of the commercial insecticide Beta-Cyfluthrin (β-CF) were investigated in *D. polymorpha*. It was reported increased levels of MDA and GSH in *D. polymorpha* exposed to β-CF compared to control. Kaya et al. (2013) used heavy metals (Cu, Fe, Cd, Pb, Zn and Mn) to analyze the biomarker (Glutathione), which is an indicator of oxidative stress. As a result of the analyzes made, they observed increases in GSH levels. Xiong et al. (2011), in their studies investigating the acute toxicity, oxidative stress, and damage of NPs in *D. rerio*, fish were exposed to TiO_2 and ZnO NPs, radical production and its biochemical effects were investigated. As a result of the research, GSH levels decreased and increased depending on the type of NP and tissues. Yuksel et al. (2020) investigated the oxidative stress and antioxidant levels of malathion pesticides on *G. pulex*. As a result of the study, they observed a decrease in GSH levels. Chen et al. (2020) investigated the levels of different toxic metals and the extent of oxidative stress responses in *S. constricta*. They observed increased GSH levels. In this study, which was conducted to investigate the effect of GCH pesticide on *D. polymorpha* individuals, it is thought that the increase in GSH levels is compatible with the literature.

Florescu et al. (2021) were study on *A. stellatus* also determined increases in MDA levels, Liang et al. (2016), investigated the changes in mRNA expression of genes related to endoplasmic reticulum (ER) stress marker and unfolded protein response (UPR) and redox enzyme and apoptosis in the ammonia of hepatopancreas in pacific white shrimp and observed that MDA increased as a result of their research. Chen et al. (2020) and Magra et al. (2021) observed that the MDA level increased in their study. In this study, it is thought that the changes in MDA levels in *D. polymorpha* individuals are caused by exposure to GCH pesticide.

Histopathology is the examination of changes in organs, tissues, and cells under a microscope using various methods. Information obtained from studies in the field of histopathology sheds light on the microscopic structure of tissues (Vikipedi Özgür Ansiklopedi 2023).

Exposure of organisms to pollutants causes damage to tissues and cells, thus harming the organism. In this study, it is thought that the histological effects in *D. polymorpha* are also dependent on the GCH concentration and time of exposure. Binelli et al. (2004), degenerations were observed with the accumulation of basophilic material in the cell apex of *D. polymorpha*, which they exposed to DDT. Mantecca et al. (2006), examined the histopathological data of *D. polymorpha*, in which they applied the herbicide paraquat (PQ), and as a result, they observed severe lesions such as cellular vacuolation, lysis and germinative epithelial thinness in the digestive gland and testis. Giamberini et al. (1996) investigated histopathological changes in the gills of *D. polymorpha* exposed to a new molluscicide and found serious degenerations in the tissues as a result of the research. Fisher et al. (1991) examined *D. polymorpha*, which they exposed to potassium in their study, and reported that potassium caused deterioration in the gill epithelium. Yancheva et al. (2020), applied cadmium (Cd) and polyaromatic hydrocarbons (PAHs) in *D. polymorpha* in their study and emphasized that Cd and PAHs cause serious damage to the gills of *D. polymorpha*. Shan et al. (2020) exposed *Corbicula fluminea* to imidacloprid and observed significant histopathological changes as a result of degeneration of ciliates, contraction, and adhesion of lymphocytes, and swelling of epithelial cells in the gills and marked degeneration of digestive tubules, hemolytic infiltration of connective tissue, and epithelial cell necrosis. Benjamin et al. (2019) stated in their study that the digestive gland of *C. fluminea*, which they exposed to Bisphenol A (BPA), was the most affected tissue followed by the gill and then the adductor muscles. Baratange et al. (2022), in their study applied carbamazepine and methylmercury to *D. polymorpha* and found that exposure to MeHg caused a high degree of gill fibrosis, deformation, and change as a result of the application: 25-50% of the respiratory surface of the gills changed and 20-40%

of the digestive tubules observed numerous fibrosis such as ongoing and terminal lysis or necrosis and cell changes such as pycnotic nuclei. Hossain et al. 2023 reported that chlorpyrifos caused moderate to severe pathological symptoms in the treatment groups when compared with the control in the gill, muscle and ovary histopathology of *Lamellidens marginalis*. Moreira et al. 2023 reported that mild to severe filament degradation and ciliary deformation occurred in Limnoperna fortunei under the influence of two biocides -MXD-100^{TM} and sodium dichloroisocyanurate (NaDCC). Dethe and Ahire 2023, Toxicity of Imidacloprid, reported histopathological changes in gill, mantle and digestive gland on *L. marginalis*. Histopathological damage to the tissues of *D. polymorpha* individuals is thought to be due to exposure to GCH.

Conclusion

According to the results of the data obtained from the study, the toxic effect of GCH pesticide on *D. polymorpha* was determined. It was concluded that GSH, MDA, SOD, CAT, and GPx are useful biomarkers in investigating the toxic effects of filtered test organism *D. polymorpha*. The results obtained indicate that changes in biomarker levels are dependent on both the concentration and duration of exposure show that the response of the test organism to the toxic substance varies with the concentration of the toxic substance and the duration of administration.

Changes in oxidant-antioxidant levels in aquatic environments may be directly related to pesticide pollution, as well as other environmental stress factors that can act together with pesticides. Environmental factors such as dissolved oxygen level, temperature, salinity, and the presence of organic pollutants can affect the oxidant-antioxidant status of organisms (Livingstone 2003). In future studies, it is recommended to carry out long-term follow-up studies, taking into account these stress factors. As a result of organisms being exposed to pollutants, deterioration occurs in their cells, tissues and organs and histological damage occurs. The magnitude of this damage varies according to the duration and concentration of exposure, and it is thought that the damage increases as the concentration and duration increase.

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Article writing was done by Aquaculture Engineer (MSc) Ayşe Nur AYDIN.

Histopathological analyses were performed by Assoc. Prof. Dr. Tuba PARLAK AK.

There is not conflict of interest between the authors.

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The Relationship between Copper Tolerance and Antibiotic Susceptibility of *Vagococcus salmoninarum* Isolated from Kılavuzlu Dam Lake

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A B S T R A C T

The contamination of aquatic ecosystems by heavy metals has been identified as a significant environmental hazard for aquatic animal species, including fish. The objective of this study was to investigate the tolerance of *Vagococcus salmoninarum* bacteria to copper and the impact of copper exposure on antibiotic susceptibility. The bacterial isolates, comprising six strains, were obtained from rainbow trout reared in cage culture at Kılavuzlu Dam Lake. The initial assessment of antibiotic susceptibility was conducted using the Kirby-Bauer disc diffusion method, which was subsequently validated through the determination of minimum inhibitory concentration (MIC). The broth microdilution method was employed, with the bacterial isolates exposed to concentrations of copper sulphate ranging from 0.1 to 1 mM. The resistance to multiple antibiotics was altered to be significantly altered following exposure to copper sulphate. The minimum inhibitory concentration (MIC) value of copper was observed to be 0.4 mM against *V. salmoninarum*. It was noted that *V. salmoninarum*, which has been exposed to copper in its natural environment, has developed the capacity to withstand stress and has undergone a change in its physiological status.

Keywords: Bacteria, *Vagococcus salmoninarum*, antibiotic resistance, antibiotic susceptibility, copper

A R T I C L E   I N F O

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Kılavuzlu Baraj Gölü'ndeki Alabalık İşletmelerinden İzole Edilen *Vagococcus salmoninarum*'da Bakır Toleransı ve Antibiyotik Duyarlılığı Arasındaki İlişkinin İncelenmesi

Öz: Sucul ekosistemlerin ağır metallerle kirlenmesi, balıklar da dahil olmak üzere sucul hayvan türleri için önemli bir çevresel tehlike olarak tanımlanmıştır. Bu çalışmanın amacı *Vagococcus salmoninarum* bakterisinin bakıra toleransını ve bakıra maruz kalmanın antibiyotik duyarlılığı üzerindeki etkisini araştırmaktır. Altı suştan oluşan bakteri izolatları Kılavuzlu Baraj Gölü'nde kafes kültüründe yetiştirilen gökkuşağı alabalıklarından elde edilmiştir. Antibiyotik duyarlılığının ilk değerlendirmesi Kirby-Bauer disk difüzyon yöntemi kullanılarak yapılmış ve daha sonra minimum inhibitör konsantrasyon (MİK) değeri belirlenerek doğrulanmıştır. Bakteri izolatları 0,1 ila 1 mM arasında değişen bakır sülfat konsantrasyonlarına maruz bırakılarak et suyu mikrodilüsyon yöntemi kullanılmıştır. Bakır sülfata maruz kalmanın ardından çoklu antibiyotik direncinin önemli ölçüde değiştiği bulunmuştur. Bakırın minimum inhibitör konsantrasyon (MİK) değerinin *V. salmoninarum*'a karşı 0,4 mM olduğu gözlenmiştir. Doğal ortamında bakıra maruz kalan *V. salmoninarum*'un strese dayanma kapasitesi geliştirdiği ve fizyolojik durumunda bir değişiklik olduğu kaydedilmiştir.

Anahtar kelimeler: *Vagococcus salmoninarum*, antibiyotik duyarlılık, antibiyotik direnç, bakır

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Introduction

Vagococcus salmoninarum is a Gram-positive coccobacillus that was initially described as a *Lactobacillus* strain in 1968 (Austin and Austin 2016). This strain was subsequently defined as *V. salmoninarum* (Wallbanks et al. 1990; Daly 1999).

V. salmoninarum is the causative agent of coldwater streptococcosis. An infectious disease that has been shown to result in high mortality rates and significant economic losses on fish farms, particularly in rainbow trout and Atlantic salmon (Ghittino et al. 2004; Schmidtke and Carson 1994; Özcan and Barış 2019). However, over the last 30 years, the disease has become established in fish farmed in numerous countries across Europe and the globe (Schmidtke and Carson 1994; Michel et al. 1997; Ghittino et al. 2004; Ruiz-Zarzuela et al. 2005; Salogni et al. 2007; Didinen et al. 2011; Özcan et al. 2014). The mortality rates observed ranged from 20% to 50% per year (Nougayrède et al. 1995; Michel et al. 1997; Ruiz-Zarzuela et al. 2005; Özcan et al. 2016).

There is evidence to suggest that there is a correlation between the tolerance of bacteria to heavy metals and their resistance to antibiotics. This is a global problem that is currently threatening the treatment of infections in plants, animals and humans (Spain and Alm 2003). It is noteworthy that resistance to these metals is mediated by the same plasmid that determines resistance to drugs. The majority of these metals have recently been identified as either established or potential causes of environmental contamination (Nakahara et al. 1977). Furthermore, the presence of heavy metals in the environment has the potential to induce significant alterations in the structure and functionality of microbial communities. It has been demonstrated that both Gram-negative and Gram-positive bacteria may develop resistance to heavy metals. This resistance may serve as an indicator of the extent of contamination and the degree of exposure to bacteria and heavy metals (Kimiran-Erdem et al. 2015). Previous studies have demonstrated the development of antibiotic resistance in bacterial strains due to heavy metal contamination (Calomiris et al. 1984; McArthur and Tuckfield 2000; Stepanauskas et al. 2006; Garhwal et al. 2014).

The objective of this study was to ascertain the antibiotic susceptibility of *V. salmoninarum* isolates following exposure to copper.

Materials and Methods

Bacteria

The experiments were conducted using *V. salmoninarum* bacteria isolated from six rainbow trout farms with disease outbreaks in Kılavuzlu Dam Lake in Kahramanmaraş province of Turkey (Figure 1). The strains were stored in trypticase-soy broth (TSB) supplemented with 15% (v/v) sterile glycerol at a temperature of -80ºC. The isolate was identified by means of the polymerase chain reaction (PCR) method described by Ruiz-Zarzuela et al. (2005). For each experiment, the bacteria were inoculated on trypticase-soy agar (TSA), and one to three colonies were transferred into TSB and incubated for 48 hours at 22ºC with shaking. The cells were harvested and washed twice with sterile phosphate-buffered saline (PBS, pH 7.2) by centrifugation at 2500 g for 10 minutes. Following the final centrifugation, the cells were re-suspended in sterile PBS and immediately employed in the experiments. The number of bacteria (expressed as colony forming units, CFU) in the suspension was determined through the implementation of 10-fold serial dilutions and the plate count technique on TSA.

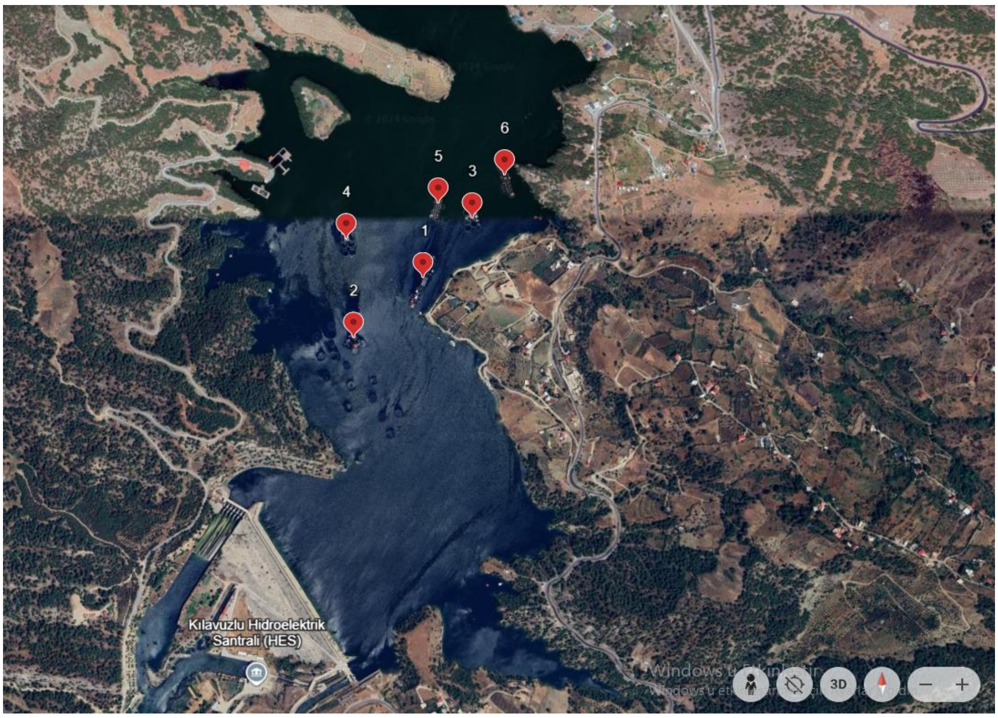

Figure 1. Map of the sampling station

Exposure to copper and minimum inhibitory concentration

To each of the triplicate tubes containing TSB, copper sulphate was added to obtain final concentrations of 0 and 0.1 to 1 mM. A suspension of *V. salmoninarum* (50 µl of $5x10^6$ CFU ml^{-1}) was added to each tube, mixed, and incubated for 48 hours at 22ºC. Following a 48-hour incubation period, 50 µl of sample from each tube was cultured in sterile agar plates containing copper in order to test bacterial recovery. The samples were incubated for 48 hours at 22 degrees Celsius, after which the number of bacterial colonies was counted.

Antibiotic susceptibility testing of the isolates

The antimicrobial susceptibility patterns were determined using Mueller-Hinton medium and commercial antimicrobial disks. The antimicrobial susceptibility patterns were determined using the following antimicrobial disks: kanamycin (30 µg), ampicillin (10 µg), enrofloxacin (10 µg), eritromycin (15 µg), gentamicin (10 µg), neomycin (30 µg), chloramphenicol (30 µg), ciprofloxacin (5 µg), penicillin G (10 IU) and trimetoprim/sulfametaxazol (25 µg). Antimicrobial susceptibility testing was conducted in accordance with the Clinical and Laboratory Standards Institute (CLSI) guidelines using the Kirby-Bauer disc diffusion method (CLSI 2011). The results for the antibiotic susceptibility patterns before and after copper exposure were recorded and subjected to analysis to ascertain any changes in the patterns.

Result

All isolates isolated from rainbow trout in six cage culture farms in Kılavuzlu Dam Lake showed high resistance to copper and the minimum inhibitory concentration (MIC) for copper was 0.4 mM. Following exposure to copper, no change was observed in the organisms' phenotypical properties. However, all isolates exhibited altered antibiotic susceptibility characteristics. Figure 2 depicts the varying inhibition levels of copper against *V. salmoninarum*. After exposure to copper, all antibiotics in this study demonstrated increased resistance in *V. salmoninarum* isolates.

The copper strains demonstrated resistance to furazolidone, gentamicin, and trimethoprim-sulfadiazine. All strains demonstrated sensitivity to kanamycin, ampicillin, neomycin, chloramphenicol, ciprofloxacin, enrofloxacin, erythromycin and penicillin.

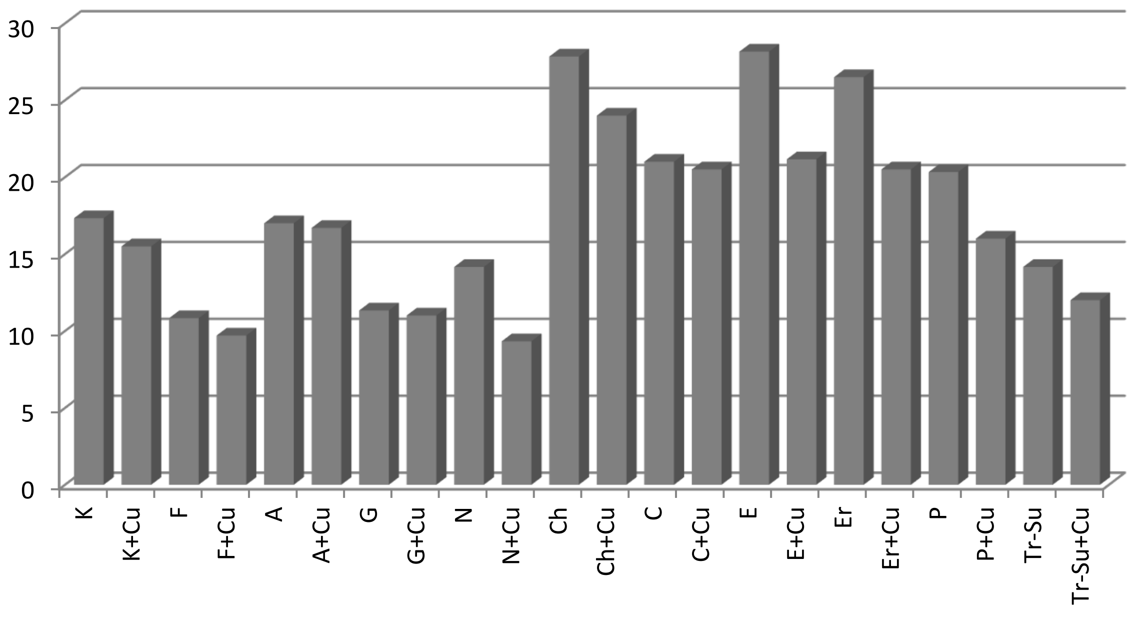

Figure 2. Antibiotic susceptibility of *V. salmoninarum* not exposure and exposure to 0.4 mM copper. K: *Kanamycin*, F: Furazolidon, A: Ampicillin, G: *Gentamicin*, N: *Neomycin*, Ch: Chloramphenikol, C: Ciprofloxacin, E: Enrofloxacin, Er: Eritromisin, P: Penisillin, Tr-Su: Trimethoprim-Sulphadiazine.

Discussion

The phenomenon of antimicrobial resistance has recently been identified as a significant global ecological issue (Levy 2001). The occurrence of antibiotic resistance in the environment may be attributed to the presence of heavy metals and other toxic substances (Schwarz et al. 2004; Baker-Austin et al. 2006).

The present study has demonstrated that kanamycin, ampicillin, neomycin, chloramphenicol, ciprofloxacin, enrofloxacin, erythromycin and penicillin are effective in controlling *V. salmoninarum*. It is therefore recommended that farmers employ these antibiotics for prophylactic and therapeutic purposes in the culture of rainbow trout. As reported by Ruiz-Zarzuella et al. (2005), strains of *V. salmoninarum* isolated from farms in the north-eastern region of Spain demonstrated sensitivity to erythromycin and oxytetracycline. In a further study, Tanrıkul et al. (2014) demonstrated that strains of *V. salmoninarum* isolated from diseased rainbow trout exhibited sensitivity to amoxicillin, ampicillin, enrofloxacin, norfloxacin, oxolinic acid and florfenicol.

In this study, the minimum inhibitory concentration (MIC) values of copper against all strains of *V. salmoninarum* were found to be identical (0.4 mM). As reported by Nies (1999) and Roane and Kellogg (1995), the MIC of copper for *Escherichia coli* was found to be 1 mM and 10 mM, respectively. Zhou et al. (2015) demonstrated that exposure to five heavy metals (Pb, Cu, Zn, Cr (VI) and Hg) resulted in antibiotic susceptibility in *Pseudomonas fluorescens*, with a reported MIC value for copper of 100 mg/ml. The MIC of bacteria resistant to copper exhibited variability between bacterial groups.

Copper has the potential to disrupt cell function in multiple ways, since several mechanisms acting simultaneously may reduce the ability of microorganisms to develop resistance against copper (Michels et al. 2005). In the present study, we also demonstrated that antibiotic susceptibility could provide valuable insights into the exposure of copper. The findings indicated that exposure to varying doses of copper resulted in an elevated level of antibiotic resistance in *V. salmoninarum*. A previous experiment demonstrated that elevated antibiotic resistance levels in bacteria exposed to heavy metals were observed (Garhwal et al. 2014). The analysis of multiple antibiotic-resistant bacteria isolated from a mariculture farm in China revealed a high prevalence of chloramphenicol-resistant isolates (Dang et al. 2006). Similarly, the co-selection of antibiotic resistance by heavy metals in freshwater microcosms and industrially polluted streams has been demonstrated (McArthur and Tuckfield 2000; Stepanauskas et al. 2006). Calomiris et al. (1984) reported a positive correlation between Cu, Pb, and Zn contaminants and multiple antibiotic resistance in bacteria in the drinking water. In the study conducted by Garhwal et al. (2014), 30 clinical isolates of Gram-negative (25 strains) and Gram-positive (5 strains) bacteria were included in the analysis. The antibiotic and lead resistance patterns were studied using the disc diffusion method. Furthermore, lead exposure was found to significantly elevate antibiotic resistance activities in clinical isolates (Garhwal et al. 2014).

In conclusion, the presence of heavy metals in the environment has been identified as a contributing factor in the development of antibiotic resistance among bacterial populations. Furthermore, prolonged exposure to these heavy metal residues may result in the emergence of a heavy metal-resistant bacterial strain. To date, there is a paucity of literature on the heavy metal resistance patterns of bacteria isolated from fish farms. It is therefore recommended that the effects of heavy metals in aquatic systems on bacterial populations be monitored.

Ethical Approval

All animal studies were approved by the Animal Ethics Committee of KSÜZİRHADYEK and Research Institute (Protocol number: 2013/5-1).

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Karakuyu Gölü (Afyonkarahisar) Su Kalitesinin Bazı İndeks ve İstatistiksel Analizler Kullanılarak Belirlenmesi

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Ö Z

Karakuyu Gölü, Göller Yöresi'nde bulunan önemli sulak alanlarımızdan biridir. Nisan 2023 ve Ocak 2024 arasında mevsimsel olarak gerçekleştirilen bu çalışmada Karakuyu Gölü'nün su kalitesinin bazı indeks ve istatistiksel analizler kullanılarak belirlenmesi amaçlanmıştır. Gölden alınan su örneklerinde sıcaklık, pH, elektriksel iletkenlik, çözünmüş oksijen, oksijen doygunluğu, biyolojik oksijen ihtiyacı, klorür, sülfat, ortofosfat, amonyum ve nitrat değerleri ölçülmüştür. Sonuçların değerlendirilmesi için Su Kalite İndeksi (WQI), OneWay Anova, Pearson Korelasyon Testi ve Duncan Çoklu Karşılaştırma Testi yapılmıştır. Sonuçlar ulusal ve uluslararası kuruluşlar tarafından verilen içme suyu ve su kalitesi standart değerleri ile kıyaslanmış ve göl suyunun kalite sınıfları belirlenmiştir. Göl suyunun pH, elektriksel iletkenlik, biyolojik oksijen ihtiyacı, ortofosfat, klorür, nitrat ve amonyum değerleri açısından I. kalite sınıfında, sıcaklık ve sülfat değerlerine göre I. ve II. kalite sınıfında, oksijen miktarına göre kış mevsiminde II. kalite sınıfında, diğer mevsimlerde ise III. kalite sınıfında olduğu saptanmıştır. Göl suyunda ölçülen fizikokimyasal parametrelerin EU, EPA, WHO, TS 266'da belirtilen içme suyu standartlarına göre kabul edilebilir değerler içerisinde olduğu belirlenmiştir. Elde edilen veriler Çevre, Şehircilik ve İklim Değişikliği Bakanlığı tarafından bildirilen Su Kirliliği Kontrolü Yönetmeliği'nde ve Tarım ve Orman Bakanlığı tarafından bildirilen Yerüstü Su Kalitesi Yönetmeliği'nde belirtilen kriterlere göre de değerlendirilmiştir. WQI sonuçlarına göre göl suyunun mükemmel su sınıfında olduğu belirlenmiştir.

Anahtar kelimeler: Su kalitesi, Karakuyu Gölü, su kalitesi indeksi, fizikokimyasal parametreler

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Determination of Water Quality of Karakuyu Lake (Afyonkarahisar) Using Some Indices and Statistical Analysis

Abstract: Karakuyu Lake is one of our important wetlands in the Lakes Region. Since it is in the direction of the migration route of many birds, it has become a natural habitat for various water birds, especially endangered and protected. In this study, which was carried out between April-2023 and January-2024, was aimed to determine the water quality of Karakuyu Lake using some indexes and statistical analyses. Temperature, pH, electrical conductivity, dissolved oxygen, oxygen saturation, biological oxygen demand, chloride, sulfate, ortho-phosphate, ammonium and nitrate values were measured in water samples taken from the lake seasonally. Water Quality Index (WQI), OneWay Anova, Pearson Correlation Test and Duncan Multiple Test were performed to evaluate the results. In addition, the results were compared with the standart values given by national and international organizations and the quality classes of the lake water were determined. It was determined that the lake had class I water quality in terms of pH, electrical conductivity, biological oxygen demand, orthophosphate, chloride, nitrate and ammonium values. According to temperature and sulphate values, Karakuyu Lake had class I or II water quality, based on oxygen values it had class II. quality water in winter while in class III water quality in other seasons. It has been determined that the physicochemical parameters values measured in Karakuyu Lake water are within acceptable values according to the drinking water standarts specified in EU, EPA, WHO and TS 266. The data obtained were also evaluated according to the criteria specified in the Water Pollution Control Regulation reported by the Ministry of Environment, Urbanization and Climate Change and the Surface water Quality Regulation reported by the Ministry of Agriculture and Forestry. According to the WQI results, it was determined that the lake water was in the perfect water class.

Keywords: Water quality, Karakuyu Lake, water quality index, physcio-chemical parameters

Alıntılama
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Giriş

Doğal kaynakların en önemlisi sudur ve günlük ihtiyaçlarımız başta olmak üzere temizlik, yemek, ısınma ve enerji sağlama bakımından mutlaka gerekli olan bir maddedir (Akman vd. 2004). Dünyada bulunan 1,4 milyar km^3 suyun sadece %3'lük kısmını iç sularda bulunan tatlısular meydana getirmektedir. Tatlı suların ise büyük çoğunluğu doğrudan kullanılamayacak şekilde kutuplar ve buzullarda buz şeklinde ya da çok derinlerde yeraltı suyu halinde bulunmaktadır. Ulaşılabilen tatlısuyun ise çok daha az miktarı kullanılabilir kalitededir (Kocataş 2008). Dünyamızda kullanılabilir su miktarı bu kadar az iken nüfus artışı, kentleşme, teknolojik gelişmeler, hayvansal faaliyetler, tarım faaliyetleri, kuraklık, madencilik gibi etkenlerden dolayı tatlı su sistemleri sürekli olarak kirliliğe maruz kalmakta ve bu duruma bağlı olarak suların kalitesi düşmekte ve biyoçeşitliliği azalmaktadır. Ancak diğer taraftan nüfus artışına bağlı olarak kaliteli, güvenli ve temiz suya olan ihtiyaç da artmaktadır (Ouyang 2005; Poonam vd. 2013; Şener vd. 2023). İnsanlar da dahil olmak üzere pek çok organizma hayatta kalma, içme suyu olarak kullanma, balıkçılık, endüstriyel aktiviteler, tarımsal sulama ve rekreasyon gibi ihtiyaçlar ve faaliyetler nedeniyle tatlı suya bağımlıdır (Bhateria ve Jain 2016).

Su kalitesi, farklı amaçlar için kullanılan suyun durumunu göstermektedir. Su kalitesi, suyun kimyasal, fiziksel, hidromorfolojik ve biyolojik özelliklerini ifade eder (Boyd 1990). İçme, kullanma, tarımsal veya endüstriyel amaçla kullanılan kısıtlı miktardaki suların kullanım amacına uygun olması gerekmektedir. Suların kullanıma uygun olup olmadığının tespiti ise su kalitesinin tespiti ile mümkündür. Su kalitesi canlıların popülasyon dinamiğini, bolluk durumlarını ve fizyolojilerini etkileyen önemli bir faktördür (Tepe ve Boyd 2002). Sucul sistemlerin korunması, ekolojik dengenin devamlılığı, sucul sistemin sürdürülebilirliği ve sulardan uzun yıllar verimli bir şekilde faydalanmak için su kalitesinin belirli aralıklarla izlenmesi, geçmiş yıllar ile karşılaştırmalar yapılması ve elde edilen verilere göre gerekli tedbirlerin alınması oldukça önemlidir (Cüce vd. 2020; Gümüş 2021).

Geçmişte, sulak alanlara özellikle göllere atık alanlar olarak bakılmış, hastalık taşıyan, bataklık ve verimsiz alanlar olarak düşünülmüş ve değeri uzun yıllar anlaşılmamıştır (Sülük vd. 2013). Sularda oluşan kirliliğin ve kalitesi düşük suyun canlı sağlığını tehdit etmeye başlamasıyla sulak alanların su kalitesi hem bilim insanlarının hem de yöneticilerin dikkatini çekmiştir. Günümüzde hem ülkemizde hem de Dünya'da sucul sistemlerin su kalitesi ile ilgili araştırmalar giderek önem kazanmaktadır. Bu sebeple özellikle sınırlı miktarda olan tatlı sularda su kalitesine yönelik çalışmaların indekslerle desteklenmesi uluslararası platformda ilgiyle takip edilmektedir.

Su kalite indeksi (WQI), suyun kullanım amacının belirlenmesinde önem arz eden bir derecelendirme sistemidir. İlk olarak ABD'de Horton (1965) ve Brown vd. (1970) tarafından kullanılan su kalite indeksi (WQI), Avrupa, Afrika ve Asya ülkelerinde kabul görmüştür ve kullanımı oldukça yaygındır. ABD Ulusal Sağlık Hizmetleri Kurumu Su Kalite İndeksi (USV SKİ), Kanada Çevre Bakanlığı Konseyi Su Kalite İndeksi (KÇBK SKİ) ve Oregon Su Kalite İndeksi (O SKİ) başta olmak üzere Dünya'da farklı bilim insanları tarafından geliştirilen 35'den fazla su kalite indeksi bulunmaktadır (Brown vd. 1970; Abbasi vd. 2002; Khan vd. 2003; Debels vd. 2005; Abbasi ve Abbasi 2012). Su kalite indeksi (WQI) içme suyu kalitesine etki eden farklı biyolojik ve fiziksel parametrelerin belli bir sistem kullanılarak hesaplanması esasına dayanmaktadır. Elde edilen sonuçlara göre suyun genel kalitesi hakkında fikir veren bir derecelendirme ölçeğidir. Su kalite indeksinin temel amacı, elde edilen fazla miktarda verinin su kalitesini doğru ve güvenilir bir ölçekte temsil edecek tek bir sayıya indirgenmesidir (Taş vd. 2021). Hesaplamalar sonucu bulunan bu rakamsal değer, sonuçların fazla miktarda sayısal veri içeren parametre tablosuna göre daha basit ve anlaşılır olmasını sağlar (Taner 2007). Bu indekslerin hesaplanması ve değerlendirilmesi oldukça kolay, basit ve su kalitesinin değerlendirilmesi açısından faydalıdır (Ustaoğlu 2020). Su kalite indeksi (WQI), farklı araştırmacılar tarafından ülkemizdeki bazı sucul sistemlerin su kalitesini belirlemek amacıyla kullanılmıştır (Imneisi ve Aydın 2016; Alver ve Baştürk 2019; Kükrer ve Mutlu 2019; Taş vd. 2021; Şener ve Şener 2022; Çankaya vd. 2023; Tekin-Özan vd. 2024; Özçelik ve Tekin-Özan 2024). Su kalitesini daha kapsamlı analiz edebilmek için indekslerle istatistiki analizlerin birlikte kullanılması daha etkili olabilir (Şimşek vd. 2022).

Bu çalışmada ülkemizin güneybatısında Afyonkarahisar sınırları içerisinde yer alan Karakuyu Gölü'ne ait bazı fiziksel ve kimyasal parametrelerin ölçülmesi, ölçülen bu parametre değerlerinin indeksler ve istatistiki testler kullanılarak analiz edilmesi ve gölün su kalitesinin belirlenmesi amaçlanmıştır.

Materyal ve Metot

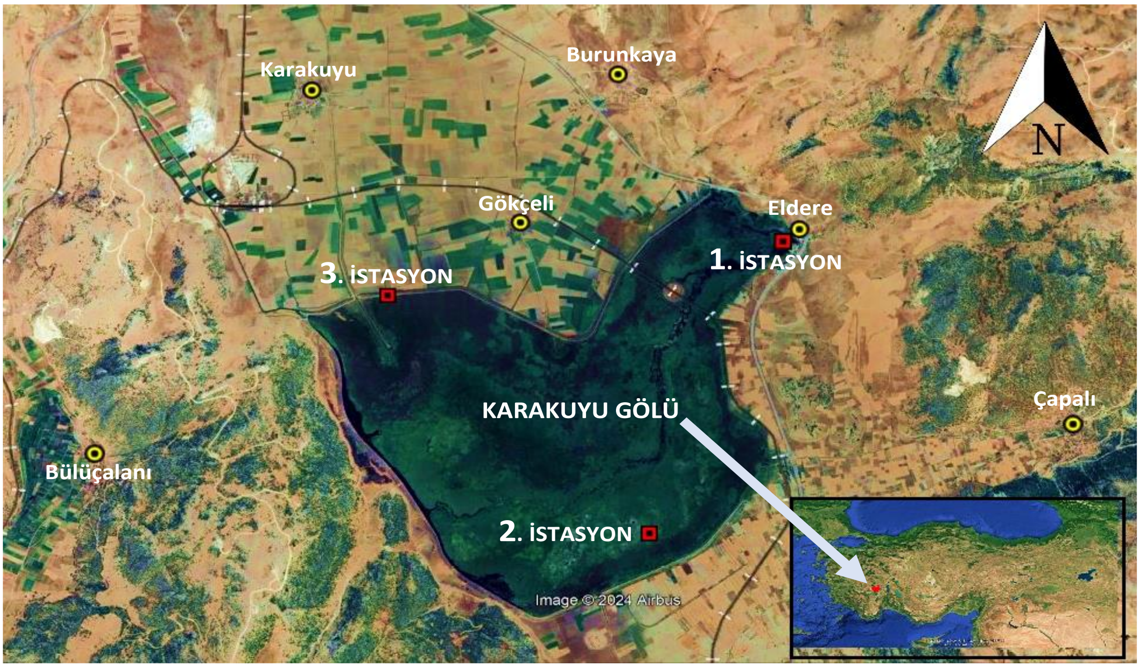
Çalışma alanı ve istasyonlar

Ülkemizin güneybatısında Afyonkarahisar ilinin Dinar ilçesi sınırları içinde bulunan Karakuyu Gölü 38º02′21″-38º04′44″ Kuzey enlemleri ile 30º13′04″-30º16′25″ Doğu boylamları arasında yer almaktadır (Şekil 1). Antalya-Afyon karayoluna paralel güney-kuzey doğrultusunda uzanan bir yapıya sahiptir (Özdemir 2017). Dinar'ın yaklaşık 10 km güneyinde

Dombayova Grabeni içerisinde yer alır. Gölü kuzeydoğuda Eldere Köyü içinden çıkan Ulupınar Deresi, güneyde İncesu Köyü'nden ve kuzeydeki Kumalar Dağı'ndan gelen mevsimsel dereler beslemektedir (Bulut vd. 2016). Bölgedeki en önemli dereler Çay Deresi ve Kumalar Çayı'dır. Kumalar Çayı Sandıklı Ovası'nın güneydoğu bölgesinden doğar ve Karakuyu Gölü'nde dökülür. Gölü besleyen en önemli kaynak ise mevsimsel yağışlar ve yüzey akıntılarıdır (Özdemir 2017).

1979'da DSİ'nin başlattığı proje kapsamında Karakuyu havzasında bulunan tarım alanlarını sulamak ve çevre köylerin içme suyu ihtiyacını karşılamak amacıyla Karakuyu Sazlıkları'nın çevresi 2,0-2,5 m yüksekliğinde, 15 km boyunda bentlerle çevrilmiştir. Bu proje 1990'da tamamlanmış ve sazlık sulama, su taşkınından korunma ve elektrik enerjisi üretimi gibi bölgenin ihtiyaçlarını karşılayan bir baraj gölü haline gelmiştir. Projenin tamamlanmasından sonra bu sazlığa Karakuyu Gölü adı verilmiştir. Bu sulak alan ayrıca; Çapalı Gölü, İncesu Gölü ve Karakuyu Sazlıkları olarak da bilinir (Bulut vd. 2016).

Eğirdir, Burdur ve Işıklı göllerinin arasında kalan bu gölün bir başka özelliği de kaynak sularından fazla beslenmesi sebebiyle kış mevsiminde donmaması ve bu sayede kuşlar için doğal bir sığınma alanı olmasıdır. Koruma altına alınan Karakuyu Gölü'nde ve 300 metrelik koruma şeridi içerisinde balık ve kuş avının yapılması yasaklanmıştır (Bulut vd. 2016). Karakuyu Gölü'nün Göller Yöresi'nde bulunması ve kuşların göç yolu istikametinde olması nedeniyle, nesli tehlikede olup koruma altına alınan çeşitli su kuşları için (dikkuyruk, ördek, turna vb.) doğal yaşam alanı ve güvenli bir sığınak olmuştur (Bulut vd. 2016). Gölün büyük bir kısmı kamış, hasır otu, sazlıklar ve nilüferlerle kaplıdır. Gölün bu özelliği kuşların yuva yapmalarına ve kamufle olmalarına olanak sağlar (Bulut vd. 2016). Karakuyu Gölü sülük avcılığı, hasır otu temini, balık üretimi, kamış üretimi ve rekreasyon amaçlı kullanılmaktadır (Bulut vd. 2016). Karakuyu sazlığı çevresindeki bazı köylerde buğday, arpa, şekerpancarı ve haşhaş ekiminin yapıldığı tarım arazileri de bulunmaktadır (Koçyiğit 2006).



Şekil 1. Çalışma alanı; Karakuyu Gölü ve istasyonlar (https://earth.google.com/)

Figure 1. Study area; Karakuyu Lake and stations

Karakuyu Gölü ve çevresi 1994 yılında "Yaban Hayatı Koruma Alanı" ve "I. Derece Doğal Sit Alanı" olarak ilan edilmiştir ve müdahaleye kapatılmıştır (Dinar Kaymakamlığı 2024; Afyonkarahisar İl Kültür ve Turizm Müdürlüğü 2024). Göl ayrıca 2019'da "Ulusal Öneme Haiz Sulak Alan" olarak ilan edilmiştir (Tarım ve Orman Bakanlığı 2024). Karakuyu Gölü ve çevresindeki 300 m'lik alan saha ve çevre koruması altına alınmış olup balık ve kuşların avlanması yasaklanmıştır (Dinar Kaymakamlığı 2024).

Karakuyu Gölü'nün su kalitesini belirlemek için yapılan bu çalışmada, göl üzerinde 3 farklı istasyon seçilmiştir (Şekil 1.). Birinci istasyon 38º04′31″K-30º16′29″D koordinatlarında olup gölün kuzey doğusunda yer almaktadır. Bu istasyonun yaklaşık olarak 75 m güneyinde Pınarbaşı Lokantası bulunmaktadır. Gölün bu kısmı 1,0-1,5 m derinliğinde olup, gölü besleyen ana kaynak bu alandadır. İkinci istasyon 38º02′44″K-30º15′31″D koordinatlarında, gölün güneyinde, Afyon-Isparta demiryoluna 60 m uzaklıktadır. Derinliği 2,0-2,5 m olup, etrafı hasır otuyla kaplıdır. Üçüncü istasyon 38º04′ 06″ K-30º13′ 37″ D koordinatlarındadır ve gölün kuzey batısında yer almaktadır. Bu istasyona giden yol Karakuyu Köyü'nün içinden geçmektedir. Bu istasyonda gölün zemini oldukça balçıklı bir yapıya sahiptir ve çürümüş bitki kalıntıları mevcuttur. Etrafında çok sayıda kamış otu bulunmaktadır. Yolun diğer tarafında tarım arazileri mevcuttur. Çalışma alanına ait bazı fotoğraflar Şekil 2'de verilmiştir.

Şekil 2. Çalışma alanına ait bazı fotoğraflar

Figure 2. Some views of study area

Arazi çalışmaları ve fizikokimyasal parametreler

Su örnekleri belirlenen istasyonlardan Nisan 2023, Temmuz 2023, Ekim 2023, Ocak 2024 tarihlerinde alınmıştır. Göl suyunun sıcaklık değeri (ºC), pH ve elektriksel iletkenlik değeri (µS/cm) arazide YSI 556 MPS multiparametre cihazı ile ve çözünmüş oksijen değeri (mg/L ve % doygunluk) ise Milwaukee MW600 model oksijenmetre ile yine arazide ölçülmüştür. Arazi çalışmaları sırasında kimyasal analizler için her istasyondan standart metodlara uygun şekilde (TS ISO 5667-4) su örnekleri alınarak 1 litrelik polipropilen kaplara konulmuştur. Bu örnekler, nitrat azotu (NO_3-N mg/L), sülfat (SO_4), amonyum azotu (NH_4-N mg/L), ortofosfat fosforu (PO_4-P mg/L), klorür iyonu (Cl^- mg/L) gibi parametrelerin analizi için Süleyman Demirel Üniversitesi Su, Kayaç ve Mineral Analiz Laboratuvarına getirilmiş ve analizler hizmet alımı yoluyla gerçekleştirilmiştir. Biyolojik oksijen ihtiyacı (BOI_5) (mg O_2/L) ölçümü Süleyman Demirel Üniversitesi Hidrobiyoloji laboratuvarında yapılmıştır.

Su kalite indeksi (WQI)

Su kalite indeksi (WQI) farklı su kalite parametrelerinin bileşik etkisini gösteren bir derecelendirme sistemidir (Sahu ve Sikdar 2008). Suyun kalitesini belirlemek için genel olarak sıcaklık, bulanıklık, pH, fekal koliform, çözünmüş oksijen, biyolojik oksijen ihtiyacı, toplam fosfat, nitrat ve toplam katı madde gibi parametrelerin kullanılması önerilmiştir (Chaturvedi ve Bassin 2009). Ancak WQI için seçilen parametreler; veri mevcudiyetine, uzman görüşüne ve çalışılan suyun çevresel önemine göre değişiklik gösterebilir (Uddin vd. 2021). Debel vd (2005) pek çok WQI modelinde önerilen parametrelerin analiz sonuçlarının olmaması durumunda diğer temel su kalitesi parametrelerinin de WQI hesaplamasında kullanılabileceğini belirtmiştir. Bu çalışmada WQI pH, O_2, E.C., BOI_5, NH_4, NO_3, Cl ve SO_4 parametreleri kullanılarak hesaplanmıştır. Her parametre için atanan ağırlık değerleri ile hesaplanan göreceli ağırlık değerleri Tablo 1'de verilmiştir.

Tablo 1. Her parametrenin ağırlık ve göreceli ağırlık değerleri

Table 1. Weight and relative weight value of each parameter

Parametreler	Standart Değerler	Ağırlık Değeri (wi)	Göreceli Ağırlık Değeri (Wi)
pH	6,5-8,5 (WHO 2022)	4	0,11
O_2	8 (YSKY 2023)	4	0,11
EC	2500 (TSE 266 2005)	5	0,138
BOİ	8 (YSKY 2023)	3	0,083
NH_4	0,50 (TSE 266 2005)	5	0,138
NO_3	50 (WHO 2022)	5	0,138
Cl	250 (WHO 2022)	5	0,138
SO_4	250 (WHO 2022)	5	0,138
		∑wi=36	

WQI aşağıda verilen formüller kullanılarak dört aşamada hesaplanır. İlk olarak su kalitesini etkileyen parametrelerin önem derecesine göre, çalışılan her parametreye göreceli olarak 1 ile 5 arasında bir ağırlık değeri (wi) belirlenir ve aşağıdaki formül kullanılarak göreceli ağırlık (Wi) hesaplanır.

$$Wi=\frac{wi}{\sum_{i=1}^{n} wi}$$

İkinci olarak, ölçümler sonucunda elde edilen veriler (C_i), her parametre için verilen içme suyu standardına (S_i) bölünür, 100 ile çarpılır ve kalite derecelendirilmesi (Q_i) hesaplanır.

$$Q_i=\left(\frac{C_i}{S_i}\right)\times 100$$

Son aşamada ise göreceli ağırlık (*Wi*) ve kalite derecelendirmesi (Q_i) çarpılarak alt-indeksler (*SI*) bulunur. Alt-indeksler toplanarak WQI hesaplanır.

$$SI_i=Wi\times Q_i$$

$$WQI=\Sigma_{i=1}^{n} SI_i$$

WQI değerleri WQI<50 (mükemmel su), 50<WQI<100 (iyi su), 100<WQI<200 (kötü su), 200<WQI<300 (çok kötü su) ve WQI>300 (içme suyu için uygun değil) olmak üzere 5 kategoride sınıflandırılmıştır (Sahu ve Sikdar 2008).

İstatistiksel analizler

Çalışma bölgesindeki 3 farklı istasyondan elde edilen sonuçları mevsimsel olarak değerlendirmek amacıyla sonuçların minimum değeri, maksimum değeri, aritmetik ortalamaları ve standart sapmaları hesaplanmıştır. Ayrıca suda ölçülen fizikokimyasal parametrelerin mevsimsel olarak değişip değişmediğini ortaya koymak ve fizikokimyasal parametrelerin birbirleri ile ilişkilerini belirlemek amacıyla SPPS 22.0 paket programı kullanılarak One Way Anova, Duncan Testi ve Pearson Korelasyon Testi (PCC) yapılmıştır (Pearson 1992; Fisher 1928; Duncan 1955). Duncan Testi 1951 yılında Duncan tarafından geliştirilen ortalamalar arasındaki farkları belirlemek amacıyla kullanılan çoklu karşılaştırma testidir (Tallarida ve Murray 1987; Açıkgöz ve Açıkgöz 2001). PCC ise parametreler arasındaki ilişkiyi belirleyen bir ölçüttür (Gillham 2001). +1 ve -1 aralığında sonuçlar verir. +1 mükemmel pozitif ilişkiyi, -1 mükemmel negatif ilişkiyi ifade ederken 0 parametreler arasında herhangi bir ilişki olmadığını gösterir (Manders vd. 1992). İstatistiksel olarak *p* değerinin 0,05'den küçük olması, ilişkiler arasında anlamlı bir fark olduğunu ifade etmektedir.

Elde edilen sonuçlar Avrupa Birliği (EU)'nin, Dünya Sağlık Örgütü (WHO)'nün, Çevre, Şehircilik ve İklim Değişikliği Bakanlığı'nın, Tarım ve Orman Bakanlığı'nın, ABD Çevre Koruma Ajansı (EPA)'nın ve Türk Standartları Enstitüsü (TS 266)'nün verdiği suda sınıflandırma kriterleri ile kıyaslanmıştır (TSE 2005; EPA 2018; EU 2020; WHO 2022; Tarım ve Orman Bakanlığı 2023; Çevre, Şehircilik ve İklim Değişikliği Bakanlığı 2023).

Bulgular

Fiziksel ve kimyasal parametreler

Karakuyu Gölü'nün su kalitesini belirlemek amacıyla Nisan 2023 - Ocak 2024 tarihleri arasında gölden alınan su örneklerinde yapılan analizler sonucunda elde edilen veriler Tablo 2'de verilmiştir.

Sıcaklık değerleri ilkbaharda mevsiminde 12,94 - 15,18 ºC arasında, yaz mevsiminde 12,50 - 22,74 ºC arasında, sonbaharda 21,59 - 21,77 ºC ve kış mevsiminde 9,30 - 10,09 ºC arasında değişmiştir. Ortalama sıcaklık değerinin mevsimsel olarak sırasıyla sonbahar (21,66 ºC) > yaz (16,88 ºC) > ilkbahar (14,14 ºC) > kış (10,18 ºC) şeklinde olduğu görülmüştür. Sıcaklık değeri açısından tüm mevsimler arasında anlamlı bir farklılık (p<0,05) olduğu belirlenmiştir.

Suda belirlenen pH değerleri ilkbaharda 7,13 - 7,99 arasında, yaz mevsiminde 6,90 - 7,96 arasında, sonbaharda 6,95 - 7,62 arasında ve kış mevsiminde 7,01 - 7,52 arasında değişim göstermiştir. Ortalama pH değerinin mevsimsel olarak sırasıyla ilkbahar (7,58) > sonbahar (7,36) > yaz (7,31) > kış (7,29) şeklinde olduğu belirlenmiştir. pH değeri açısından tüm mevsimler arasında anlamlı bir farklılık (p>0,05) olmadığı belirlenmiştir.

Karakuyu Gölü'nün suyundaki çözünmüş oksijen değeri ilkbaharda 4,95 - 5,85 mg/L arasında, yaz mevsiminde 3,5 - 4,4 mg/L arasında, sonbaharda 3,9 - 5,8 mg/L arasında ve kış mevsiminde 5,9 - 6,7 mg/L arasında değişmiştir. Mevsimler arasında ortalama çözünmüş oksijen değerlerinin sırasıyla kış (6,23 mg/L) > ilkbahar (5,43 mg/L) > sonbahar (4,6 mg/L) > yaz (4 mg/L) şeklinde olduğu saptanmıştır. Çözünmüş oksijen miktarının tüm mevsimler arasında anlamlı bir farklılık (p<0,05) gösterdiği belirlenmiştir.

Oksijen doygunluğu değerinin ilkbaharda %46 - %60 arasında, yaz mevsiminde %39 - %52 arasında, sonbaharda %48 - %70 arasında ve kış mevsiminde %73 - %79 arasında olduğu saptanmıştır. Oksijen doygunluğu ortalama değerinin mevsimsel olarak sırasıyla kış (%75,33) > sonbahar (%56,67) > ilkbahar (% 52,67) > yaz (%46) şeklinde sıralandığı belirlenmiştir. Oksijen doygunluğu değerinin kış mevsiminde değer mevsimlere göre önemli derecede farklılık gösterdiği (p<0,05) tespit edilmiştir.

Tablo 2. Bazı fizikokimyasal parametrelerin mevsimlere göre minimum değerleri, maksimum değerleri, ortalama değerleri ve standart sapmaları

Table 2. Minimum, maximum, mean values and standart deviations of some physicochemical parameters according to seasons

Parametreler	İlkbahar-2023	Yaz-2023	Sonbahar-2023	Kış-2024
Sıcaklık (ºC)	12,94 - 15,18 14,14 ± 1,12[ab]*	12,50 - 22,74 16,88 ± 5,27[bc]	21,59 - 21,77 21,66 ± 0,09[c]	9,30 - 10,90 10,18 ± 0,81[a]
pH	7,13 - 7,99 7,58 ± 0,43[a]	6,90 - 7,96 7,31 ± 0,56[a]	6,95 - 7,62 7,36 ± 0,35[a]	7,01 - 7,52 7,29 ± 0,25[a]
Oksijen (mg/L)	4,95 - 5,85 5,43 ± 0,45[bc]	3,5 - 4,4 4 ± 0,45[a]	3,9 - 5,8 4,6 ± 1,02[ab]	5,9 - 6,7 6,23 ± 0,41[c]
Oksijen doygunluğu (%L)	46 - 60 52,67 ± 7,02[a]	39 - 52 46 ± 6,55[a]	48 - 70 56,67 ± 11,71[a]	73 - 79 75,33 ± 3,21[b]
Elektriksel iletkenlik (µS/cm)	343,2 - 380,5 367,06 ± 20,72[a]	256,4 - 330,3 284,1 ± 40,27[a]	295,9 - 398,4 330,66 ± 58,66[a]	287,7 - 443,2 340,06 ± 89,31[a]
BOI_5 (mgO_2/L)	0,9 - 2 1,36 ± 0,56[a]	0,8 - 1,8 1,36 ± 0,51[a]	0,3 - 1,6 0,9 ± 0,65[a]	0,3 - 0,5 0,4 ± 0,1[a]
Cl^- (mg/L)	2,59 - 10,56 6,41 ± 3,99[a]	2,43 - 2,71 2,53 ± 0,15[a]	1,14 - 2,11 1,78 ± 0,56[a]	2,41 - 11,75 5,62 ± 5,31[a]
SO_4^- (mg/L)	0,1 - 3,45 2,23 ± 1,85[a]	0,09 - 2,98 1,96 ± 1,62[a]	2,97 - 3,22 3,08 ± 0,12[a]	0,33 - 3,26 2,16 ± 1,59[a]
NO_3-N (mg/L)	ALA** - 1,39[a]	ALA - 1,51[a]	ALA - 1,51[a]	ALA - 1,53[a]
PO_4-P (mg/L)	ALA	ALA	ALA	ALA
NH_4-N (mg/L)	ALA - 0,11[c]	0,08 - 0,09 0,08 ± 0,005[bc]	0,07 - 0,09 0,08 ± 0,01[b]	ALA

* Her bir parametre sütununda aynı harfle gösterilen değerler arasındaki fark 0,05 düzeyinde önemsizdir.
** Analiz Limitinin Altında

Biyolojik oksijen ihtiyacı değeri ilkbaharda 0,9 - 2 mg/L arasında, yaz mevsiminde 0,8 - 1,8 mg/L arasında, sonbaharda 0,3 - 1,6 mg/L arasında ve kış mevsiminde 0,3 - 0,5 mg/L arasında değişmiştir. Biyolojik oksijen ihtiyacı değerinin mevsimsel olarak sırasıyla ilkbahar (1,36 mg/L) = yaz (1,36 mg/L) > sonbahar (0,9 mg/L) > kış (0,4 mg/L) şeklinde sıralandığı belirlenmiştir. Biyolojik oksijen ihtiyacı değerinin mevsimler arasındaki değişiminin istatistiki açıdan önemli olmadığı (p>0,05) belirlenmiştir.

Klorür iyonu miktarı ilkbaharda 2,59 - 10,56 mg/L arasında, yaz mevsiminde 2,43 - 2,71 mg/L arasında, sonbaharda 1,14 - 2,11 mg/L arasında ve kış mevsiminde 2,41 - 11,75 mg/L arasında belirlenmiştir. Mevsimler arasında ortalama klorür iyonu miktarı ilkbahar (6,41 mg/L) > kış (5,62 mg/L) > yaz (2,53 mg/L) > sonbahar (1,78 mg/L) şeklinde sıralanmıştır. Klorür iyonu miktarı açısından mevsimler arasında istatistiki açıdan önemli bir fark olmadığı (p>0,05) tespit edilmiştir.

Sülfat iyonu miktarı ilkbaharda 0,1 - 3,45 mg/L arasında, yaz mevsiminde 0,09 - 2,98 mg/L arasında, sonbaharda 2,97 - 3,22 mg/L arasında ve kış mevsiminde 0,33 - 3,26 mg/L arasında değişiklik göstermiştir. Ortalama sülfat iyonu değerlerinin sırasıyla sonbahar (3,08 mg/L) > ilkbahar (2,23 mg/L) > kış (2,16 mg/L) > yaz (1,96 mg/L) şeklinde sıralandığı saptanmıştır. Sülfat iyonu miktarı açısından mevsimler arasında istatistiksel olarak önemli bir fark olmadığı (p>0,05) tespit edilmiştir.

Tablo 2'e göre tüm mevsimlerde en düşük nitrat azotu miktarı analiz limitinin altında (<0,01) çıkmıştır. En yüksek nitrat azotu miktarı (1,53 mg/L) kış mevsiminde ölçülmüştür. Yaz ve sonbahar mevsiminde nitrat azotu miktarının (1,51 mg/L) eşit olduğu belirlenmiştir. Nitrat iyonu miktarı açısından mevsimler arasında önemli bir fark olmadığı (p>0,05) tespit edilmiştir.

Ortofosfat fosforu iyonu değerlerinin tüm mevsimlerde ve tüm istasyonlarda analiz limitinin altında (p<0,05) kaldığı tespit edilmiştir.

İlkbaharda en düşük amonyum azotu miktarı analiz değerinin altında (p <0,05) çıkmıştır. Yaz ve sonbaharda ortalama amonyum azotu miktarının eşit olduğu belirlenmiştir. Kış mevsiminde ise tüm istasyonlarda ölçülen amonyum azotu değerinin analiz limitinin altında (p<0,05) olduğu tespit edilmiştir. Amonyum azotu değerinin mevsimler arasında birbirinden önemli derecede farklı olduğu (p<0,05) belirlenmiştir.

Pearson korelasyon analizi

Bu çalışma sonucunda elde edilen verilerin istatistiki açıdan anlamlı bir ilişkisi olup olmadığını belirlemek için (p<0,05 ya da p<0,01) pearson korelasyon analizi (PCC) testi yapılmıştır. Daha güvenilir sonuçların elde edilebilmesi için tüm mevsim ve istasyonlarda ölçülen verilerin tümü pearson korelasyon analiz testini hesaplarken kullanılmıştır. Belirlenen su kalite parametre verileri arasında kaydedilen anlamlı istatistiki ilişkiler ve korelasyon katsayıları Tablo 3'de verilmiştir.

Buna göre sıcaklık ile pH, elektriksel iletkenlik, çözünmüş oksijen, oksijen doygunluğu, klorür ve sülfat miktarları arasında negatif, sıcaklık ile biyolojik oksijen ihtiyacı, nitrat ve amonyum değerleri arasında ise pozitif bir ilişki olduğu tespit edilmiştir. Bu durum, sıcaklığın artışıyla birlikte biyolojik oksijen ihtiyacı, nitrat ve amonyum değerlerinin artması, pH, elektriksel iletkenlik, çözünmüş oksijen, oksijen doygunluğu, klorür ve sülfat miktarlarının azalması anlamına gelmektedir. pH ile elektriksel iletkenlik ve nitrat değerleri arasında negatif, pH ile diğer parametreler arasında ise pozitif bir ilişki olduğu belirlenmiştir. Bu durum, pH'ın artışıyla beraber çözünmüş oksijen, oksijen doygunluğu, biyolojik oksijen ihtiyacı, klorür, sülfat ve amonyum değerlerinin artması, elektriksel iletkenlik ve nitrat miktarlarının azalması anlamına gelmektedir. Elektriksel iletkenlik ile biyolojik oksijen ihtiyacı, sülfat ve nitrat değerleri arasında negatif, elektriksel iletkenlik ile çözünmüş oksijen, oksijen doygunluğu, klorür ve amonyum miktarları arasında ise pozitif bir ilişki olduğu tespit edilmiştir. Elektriksel iletkenlik miktarının artışıyla çözünmüş oksijen, oksijen doygunluğu, klorür ve amonyum miktarları artarken, biyolojik oksijen ihtiyacı, sülfat ve nitrat miktarlarında ise azalma olmuştur. Çözünmüş oksijen ile biyolojik oksijen ihtiyacı, sülfat, nitrat ve amonyum miktarları arasında negatif, çözünmüş oksijen ile oksijen doygunluğu ve klorür miktarları arasında ise pozitif bir ilişki olduğu tespit edilmiştir. Bu durum, çözünmüş oksijen miktarının artışıyla beraber oksijen doygunluğu ve klorür miktarlarının artması anlamına gelmektedir. Oksijen doygunluğu ile biyolojik oksijen ihtiyacı, sülfat ve amonyum miktarları arasında negatif, oksijen doygunluğu ile klorür ve nitrat miktarları arasında ise pozitif bir ilişki olduğu tespit edilmiştir. Oksijen doygunluğu miktarının artmasıyla beraber klorür ve nitrat miktarları artarken biyolojik oksijen ihtiyacı, sülfat ve amonyum miktarlarında ise azalma olmuştur. Biyolojik oksijen ihtiyacı miktarının artışıyla klor ve amonyum miktarları da artarken, sülfat ve nitrat miktarlarında ise azalma olmuştur. Klorür iyonu ile sülfat ve amonyum miktarı arasında negatif, klorür iyonu ile nitrat miktarı arasında ise pozitif bir ilişki olduğu tespit edilmiştir. Sülfat iyonu miktarının artışıyla nitrat miktarı artarken, amonyum miktarında ise azalma olmuştur. Nitrat ile amonyum miktarı arasında negatif bir ilişki olduğu tespit edilmiştir. Bu durum, nitrat miktarının artışıyla amonyum miktarının artması anlamına gelmektedir.

Oksijen doygunluğu değeri ile çözünmüş oksijen ve amonyum değeri arasında 0,01 düzeyinde önemli farklılıklar tespit edilmiştir. Diğer tüm ilişkiler istatistiki açıdan bir önem arz etmemektedir (p>0,05).

Tablo 3. Karakuyu Gölü'nün suyunda ölçülen bazı fizikokimyasal parametrelerin pearson testine göre belirlenen değerleri

Table 3. The determined values of some physico-chemical parameters of Karakuyu Lake's water according to pearson test

	Sıcaklık (ºC)	pH	E.İ. (µS/cm)	Ç.O. (mg/L)	O_2 doygunluğu (%)	BOI_5 (mg O_2/L)	CI^- (mg/L)	SO_4^- (mg/L)	NO_3 -N (mg/L)	NH_4 -N (mg/L)
Sıcaklık (ºC)	*1*	-0,131	-0,048	-0,526	-0,401	0,342	-0,500	-0,037	0,027	0,442
pH		1	-0,387	0,218	0,090	0,100	0,181	0,342	-0,097	0,073
E.İ. (µS/cm)			1	0,237	0,106	-0,143	0,560	-0,506	-0,174	0,156
Ç.O. (mg/L)				1	0,896**	-0,378	0,329	-0,117	-0,168	-0,491
O_2 doygunluğu (%)					1	-0,535	0,153	-0,102	0,004	-0,757**
$BOİ_5$ (mg O_2/L)						1	0,016	-0,416	-0,147	0,555
CI^- (mg/L)							1	-0,388	0,093	-0,151
SO_4^- (mg/L)								1	0,252	-0,042
NO_3 -N (mg/L)									1	-0,425
NH_4 -N (mg/L)										1

* 0.05 düzeyinde önemli

** 0.01 düzeyinde önemli

Karakuyu Gölü suyunun su kalite kriterlerine göre değerlendirilmesi

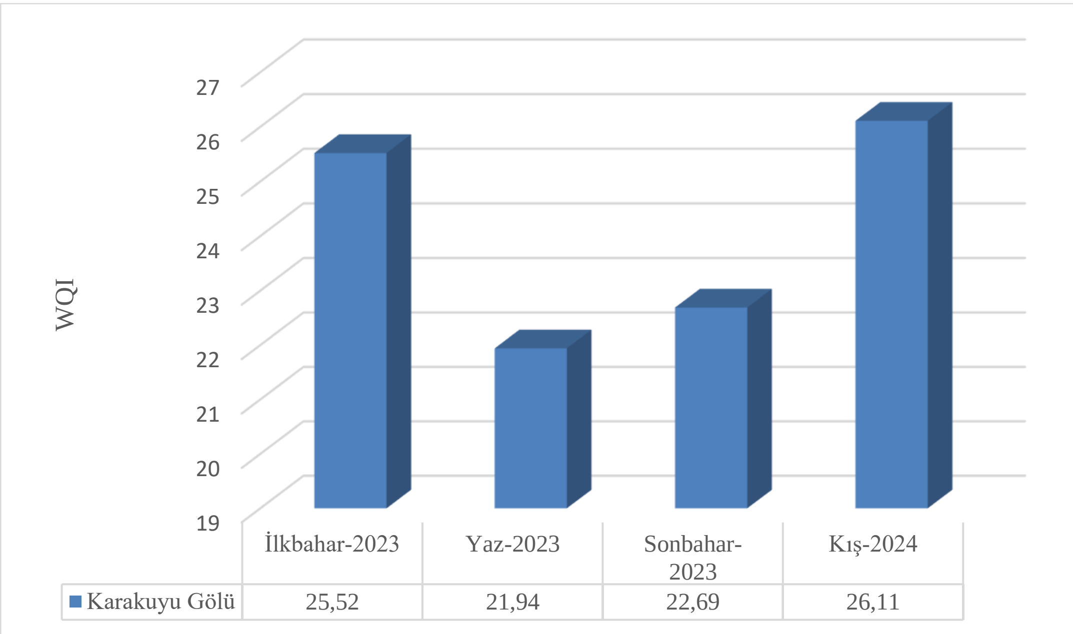
Çalışmamız sonucunda elde ettiğimiz veriler Çevre, Şehircilik ve İklim Değişikliği Bakanlığı (2023) tarafından bildirilen Su Kirliliği Kontrolü Yönetmeliği'nde belirtilen kriterlere göre değerlendirildiğinde, Karakuyu Gölü'nün tüm mevsimlerde su sıcaklığı değerlerine göre I-II. kalite sınıfında olduğu belirlenmiştir. Klorür iyonu değerlerine göre tüm mevsimlerde I. kalite sınıfında yer alırken sülfat iyonu değerlerine göre tüm mevsimlerde I-II. kalite sınıfında olduğu hesaplanmıştır. Oksijen doygunluğu değerine göre kış mevsiminde II. kalite sınıfında, diğer mevsimlerde ise III. kalite sınıfında olduğu saptanmıştır.

Çalışmamız sonucunda elde ettiğimiz diğer veriler Tarım ve Orman Bakanlığı (2023) tarafından bildirilen Yerüstü Su Kalitesi Yönetmeliği'nde belirtilen kriterlere göre değerlendirilmiştir. Buna göre Karakuyu Gölü pH değerlerine göre tüm mevsimlerde I-II-III. kalite sınıfında yer almıştır. Çözünmüş oksijen değerlerine göre kış mevsiminde II. kalite sınıfında, diğer mevsimlerde ise III. kalite sınıfında olduğu tespit edilmiştir. Elektriksel iletkenlik bakımından ise tüm mevsimlerde I. kalite sınıfında yer almıştır. Biyolojik oksijen ihtiyacı değerlerine göre tüm mevsimlerde I. kalite sınıfında olduğu belirlenmiştir. Çalışmada ölçülen ortofosfat fosforu değerleri analiz limitlerinin altında (p<0,05) tespit edilmiş ve tüm mevsimlerde I. kalite sınıfında yer almıştır. Nitrat azotu ve amonyum azotu değerlerine göre Karakuyu Gölü tüm mevsimlerde I. kalite sınıfında olduğu belirlenmiştir.

Karakuyu Gölü suyunda ölçülen bazı fizikokimyasal parametre değerlerinin EU, EPA, WHO VE TS 266'da belirtilen içme suyu standartlarına göre kabul edilebilir değerler içerisinde yer aldıkları belirlenmiştir (TSE 2005; WHO 2022; EPA 2018; EU 2020).

WQI kullanılarak su kalitesinin değerlendirilmesi

Karakuyu Gölü suyu WQI değerleri Şekil 3'de gösterilmiştir. Belirlenen WQI değerlerine göre Karakuyu Gölü tüm mevsimlerde mükemmel su kalitesi kategorisinde bulunmaktaktadır. WQI değerlerinin ilkbaharda 25,52, yaz mevsiminde 21,94, sonbaharda 22,69 ve kış mevsiminde ise 26,11 olduğu belirlenmiştir.



Şekil 3. Karakuyu Gölü'nün mevsimlere göre WQI değerleri

Figure 3. WQI values of Karakuyu Lake according to seasons

Tartışma ve Sonuç

Sıcaklık yüzeysel suların kalitesini belirlemede kullanılan en önemli değişkenlerden biridir (Nazar 2018). Sudaki kimyasal ve biyolojik reaksiyonların hızlarını etkilemektedir. (Kutanis 2010). Suda yaşayan canlıların büyüme ve üreme hızları su sıcaklığına bağlı olarak değişiklik gösterir (Barlas ve Kiriş 2004). Sıcaklık canlıların sudaki dağılımını ve tüm yaşamsal faaliyetlerini de etkileyerek fizyolojilerinin değişmesine neden olur

(Özakkoyuncu 2007). İklim, atmosfer şartları, deniz seviyesinden yükseklik, su yatağının yapısı, mevcut bitki örtüsü, coğrafi konum gibi nedenlere bağlı olarak göl sularının sıcaklığı değişir (Özakkoyuncu 2007). Suyun sıcaklığı suyun oksijen seviyesini, bitkilerin fotosentez hızını, organizmaların zehirli atıklara, hastalıklara ve parazitlere karşı olan hassasiyetlerini etkiler (Bhateria ve Jain 2016). Karakuyu Gölü'nde su sıcaklığı kış mevsiminde en düşük seviyede iken sonbaharda en yüksek düzeye ulaşmıştır. Ortalama sıcaklık değerinin mevsimsel olarak sırasıyla sonbahar (21,66 ºC) > yaz (16,88 ºC) > ilkbahar (14,14 ºC) > kış (10,18 ºC) şeklinde olduğu görülmüştür. Sıcaklık değeri açısından tüm mevsimler arasında anlamlı bir farklılık (<0,05) olduğu belirlenmiştir. Gümüş ve Akköz (2020) Eber Gölü'nde yaptığı çalışmada su sıcaklığının kışın en düşük, yazın ise en yüksek değere ulaştığını bildirmiştir. Karataş Gölü'nde su sıcaklığı ortalama olarak 2,37 ºC (kış) ve 30,28 ºC (yaz) arasında değişiklik göstermiştir (Tekin-Özan vd. 2024). Aşıkkutlu vd. (2014), Çavuşcu Gölü'ndeki ortalama su sıcaklığını 18,0 ºC olarak tespit etmiştir. Sucul sistemlerde su sıcaklığının yaz aylarında artması beklenen bir durumdur. Ancak çalışmamızda su sıcaklığının sonbaharda en yüksek düzeye ulaştığı görülmüştür. Bu durum 2023 yılının meteorolojik verileri ile desteklenmektedir. Karakuyu Gölü'nün bağlı olduğu bölgenin Haziran 2023'de 144,2 mm yağış aldığı ve bu miktarın 2023 yılı için ay bazında en yüksek yağış miktarı olduğu bildirilmiştir. Ayrıca Haziran ayında ortalama hava sıcaklığı 19,6 ºC olarak ölçülmüş, maksimum hava sıcaklığı 27,3 ºC ile Ağustos ayında tespit edilmiştir (Anonim 2024). Sucul sistemlerdeki su sıcaklığı bölgenin meteorolojik verilerine bağlı olduğundan göldeki su sıcaklığının yaz mevsiminde maksimum düzeyde olmaması 2023 yılının haziran ayının aşırı yağışlı geçmesinden kaynaklanmış olabilir.

Göllerin pH değeri 6-9 aralığında değişiklik gösterir. Ancak kireçli bölgelerdeki, buharlaşmanın yüksek olduğu göllerde, volkanik göllerde ve maden yataklarına yakın göllerde bu değer daha yüksek veya daha düşük olabilir (Tanyolaç 2009). pH sucul sistemlerde, canlıların hayatını etkileyen ve pek çok biyolojik ve kimyasal olayda etken olan en önemli parametrelerden biridir (İkinci 2016; Gümüş ve Akköz 2020). Çalışma süresince pH değerleri 6,90 - 7,99 arasında değişim göstermiş ve en yüksek düzeye ilkbaharda, en düşük düzeye ise kış mevsiminde ulaşmıştır. Ülkemizde yapılan diğer çalışmalarda da pH değerleri Işıklı Gölü'nde 6,79 - 9,57 arasında (Tekin-Özan ve Aktan 2012), Eber Gölü'nde 7,72 - 9,72 arasında (Gümüş ve Akköz 2020) ve Karataş Gölü'nde 7,25 - 9,96 arasında (Tekin-Özan vd. 2024) belirlenmiştir. Karakuyu Gölü ve çevresinde yapılan diğer çalışmalarda ise suyun pH değerinin 7,30 - 7,8 ve 7,01 - 7,85 arasında değiştiği bildirilmiştir (Bulut vd. 2011; Şener ve Özdemir 2017). Kovada Gölü'nde (Sancer ve Tekin-Özan 2016) ve Eğirdir Gölü'nde (Özçelik 2022) pH değerinin yaz mevsiminde arttığı ve kış mevsiminde azaldığı tespit edilmiştir. Karakuyu Gölü'nün bazik karakterde olduğu belirlenmiştir. Gümüş ve Akköz (2020), Eber Gölü'nün bazik karakterde olduğunu belirtmiş ve bu durumu gölün sığ olması ve fitoplankton gelişimin fazla olması ile açıklamışlardır. Karakuyu Gölü de oldukça sığ ve makrofit gelişiminin fazla olduğu bir göldür. Genel olarak göllerdeki pH seviyesinin yaz mevsiminde arttığı bilinmektedir. Ancak çalışmamızda pH seviyesinin ilkbaharda maksimum olduğu, yaz mevsiminde ise bir miktar düştüğü belirlenmiştir. Bu düşüşün Haziran 2023'deki aşırı yağış miktarı ile birlikte su miktarının artışına bağlı olduğu düşünülmektedir. Ayrıca göllerde pH miktarı gölün jeolojik özelliklerine, karbonat-bikarbonat dengesine, göldeki biyolojik reaksiyonlara göre değişiklik göstermektedir (Garg vd. 2010; Bhateria ve Jain 2016; Gümüş ve Akköz 2020).

Su kalitesinin en önemli parametrelerinden birisi çözünmüş oksijendir ve aynı zamanda ortamdaki metabolik olayların düzenleyicisidir (Tanyolaç 2009). Suyun sıcaklığı, tuzluluğu ve atmosfer basıncı havadaki oksijenin suda çözünebilirliğine etki eder ve atmosfer basıncı arttıkça çözünürlük artar (Atay ve Pulatsü 2000). Bu çalışmada Karakuyu Gölü'ndeki oksijen değerleri 3,5 - 6,7 mg/L arasında değişim göstermiştir. Oksijen miktarı kış mevsiminde maksimum iken yaz mevsiminde ise minimum düzeye ulaşmıştır. Oksijen doygunluğu değeri ise %39 - %73 arasında değişirken %45 ile yaz mevsiminde en düşük, %75,33 ile kış mevsiminde en yüksek değere ulaşmıştır. Yabanlı vd. (2011) Bafa Gölü'nde ortalama oksijen değerini 5,5 mg/L olarak belirlemişlerdir. Öztürk ve Akköz (2014) Apa Baraj Gölü'nde en düşük çözünmüş oksijen değerini yaz mevsiminde (4,36 mg/L), Tekin-Özan vd. (2024), Karataş Gölü'nde en düşük değeri yaz mevsiminde (3,98 mg/L), en yüksek değeri kış mevsiminde (5,95 mg/L), Özçelik (2022), Eğirdir Gölü'nde en düşük değeri yaz mevsiminde (2,94 mg/L), en yüksek değeri ise kış mevsiminde (5,65 mg/L) tespit etmişlerdir. Bulut vd. (2011) 2004-2005 yıllarında Karakuyu Gölü'nde yaptıkları çalışmada en düşük çözünmüş oksijen miktarını ekim ayında 3,30 mg/L ve en yüksek değeri ise haziran ayında 7,18 mg/L olarak belirlemişlerdir. Çalışmamızın sonuçları ile kıyaslandığında göldeki oksijen seviyesinin genel olarak aynı seviyede kaldığı söylenebilir. Thurston vd. (1979)'a göre, yaşamın sürekliliği için gereken oksijen miktarının suda bulunması gerekir. Tatlı su yaşamı için gerekli en düşük çözünmüş oksijen miktarı 5,0 mg/L olmalıdır (Göksu 2014). Oksijen değerinin yaz mevsiminde azalması su sıcaklığının artmasına bağlı olarak oksijen çözünürlüğünün azalmasından ve sudaki canlıların metabolizma hızlarının artışına bağlı olarak oksijen gereksinimlerinin artmasından kaynaklanmış olabilir (Wetzel 2001). Bahar ve kış aylarında göle kar ve yağmur şeklinde su girişinin fazla olması ve rüzgarlar nedeniyle sudaki hareketliliğin artması oksijen seviyesinin artmasına neden olabilir. Karakuyu Gölü'nün oksijen değerlerinin genel olarak yaşamı tehdit edecek düzeylere indiği ya da sınır değerlerde olduğu görülmektedir. Çözünmüş oksijen değerlerine göre kış mevsiminde II. kalite sınıfında, diğer mevsimlerde ise III. kalite sınıfında olması da oksijen açısından göle atık suların karıştığını, organik madde yükünün fazla olduğunu, sirkülasyonun az olduğunu düşündürmektedir. Kirletici faktörlerin yoğun olduğu, suda organik madde miktarının fazla olduğu, alglerin aşırı çoğaldığı sucul sistemlerde çözünmüş oksijenin düşük değerde olması olası bir durumdur (Barlas vd. 2000; Göksu 2014).

Karakuyu Gölü'nde elektriksel iletkenlik değeri 256,4 - 443,2 µS/cm arasında tespit edilmiştir. İlkbaharda en yüksek düzeye ulaşırken, yaz mevsiminde ise en düşük seviyede olduğu tespit edilmiştir. Şener ve Özdemir (2017) Karakuyu Gölü ve çevresinde yaptıkları çalışmada su örneklerinin elektriksel iletkenlik değerinin 347 - 521 µmho/cm arasında değiştiğini tespit etmişlerdir. Kükrer ve Mutlu (2019) Saraydüzü Baraj Gölü'nde en yüksek elektriksel iletkenlik değerini Ekim ayında (307,28 µS/cm), en düşük değeri ise Mart ayında (152,81 µS/cm) belirlemiştir. Eğirdir Gölü'nde en yüksek elektriksel iletkenlik değeri 502,6 µS/cm olarak yaz mevsiminde ve en düşük değer ise 237,1 µS/cm olarak sonbahar mevsiminde tespit edilmiştir (Özçelik 2022). Gümüş ve Akköz (2020) Eber Gölü suyunun elektriksel iletkenlik değerinin 697 - 2590 µS/cm arasında değiştiğini ve en düşük değerin kış mevsiminde ölçüldüğünü belirtmişlerdir. Bu durumun da kış aylarında yağışların artması ve su sıcaklığının düşmesinden kaynaklanabileceğini bildirmişlerdir. Bu çalışmada ise en düşük elektriksel iletkenlik değeri yaz mevsiminde tespit edilmiştir. Bu durumun Haziran 2023'te görülen aşırı yağıştan kaynaklandığı düşünülmektedir.

Sularda organik maddelerin bulunması tek başına bir sorun oluşturmayıp, bu organik maddelerin ayrışması sorun teşkil etmektedir. Çünkü organik maddeler parçalanırken oksijen tüketimi gerçekleşir. Tüketilen oksijenin tekrar kazanılması yüzey sularında oldukça güç olup, yeraltı sularında ise hiç olmamaktadır. $BOİ_5$, karbon içeren organik maddelerin parçalanmasını sağlayan aerob bakterilerin parçalanma esnasında ihtiyaç duyduğu oksijen miktarıdır (Göksu 2014). Bu çalışmada Karakuyu Gölü'nde biyolojik oksijen ihtiyacı değerinin 0,3 - 2 mg/L arasında değiştiği belirlenmiştir. Ortalama olarak en yüksek düzeye ilkbahar ve yaz mevsimlerinde, en düşük düzeye ise kış mevsiminde ulaştığı tespit edilmiştir. Gümüş ve Akköz (2020), Eber Gölü'nde ortalama $BOİ_5$ değerini 2,3 mg/L olarak belirlemiştir. Imneisi ve Aydın (2016), Karaçomak Gölü'nde $BOİ_5$ değerlerinin 2,1 - 19,3 mg/L arasında değiştiğini tespit etmiştir. Nehir veya göllerde, oksijenin azalması veya tükenmesi sonucu, balık ölümleri, kötü kokuların meydana gelmesi ve ekosistem için olumsuz şartlar oluşması gibi sorunlara neden olacağından, $BOİ_5$ kirlilik kontrolünde önemli bir parametredir (Göksu 2014).

Klorür, sulara doğal yollardan karışabildiği gibi evsel, tarımsal ve endüstriyel kaynaklardan da karışmaktadır (Göksu 2014). Suyun mineral içeriğinin artışı klorür miktarını da artırır. Kaynak suları düşük miktarda klorür içermesine rağmen nehir ve yeraltı sularında klorür konsantrasyonu daha yüksektir (Sawyer vd. 2003). Karakuyu Gölü'nün suyunda klorür miktarı 1,14 - 11,75 mg/L arasında değişmiştir. En yüksek değer ilkbaharda, en düşük değer ise sonbaharda tespit edilmiştir. Kükrer ve Mutlu (2019) Saraydüzü Baraj Gölü'nde klorür değerinin aralık ayında maksimum (6,28 mg/L), ocak ayında minimum (3,01 mg/L) olduğunu bildirmişlerdir. Kösrelik Göleti'nde klorürün yıllık ortalama değerinin 68,30 mg/L olduğunu, sonbaharda arttığını tespit etmiştir (Ölmez 2022). Jindal vd. (2014), düşük klorür konstantrasyonunun o sucul ortamın evsel atık su ile kirlenmemiş olduğunun bir göstergesi olabileceğini bildirmişlerdir. Bulut vd (2011) Karakuyu Gölü'nde klorür miktarının 4,78 mg/L (Temmuz) ve 11,12 mg/L (Ekim) arasında değiştiğini saptamışlardır. Klorür anyonunun suyun temas ettiği jeolojik formasyonlardan kaynaklandığını ve Karakuyu Gölü'nün klorür değerleri açısından I. sınıf yani yüksek kaliteli su sınıfına girdiğini belirtmişlerdir (Bulut vd. 2011). Mevcut çalışmada da Karakuyu Gölü suyunun klorür miktarı açısından I. kalite sınıfında olduğu ve suda yaşayan canlılar açısından bir sorun teşkil etmediği görülmektedir. Elektriksel iletkenlik değerinin genel olarak düşük olması da klorür değerinin düşük olmasını doğrulamaktadır.

Sülfat, tatlı sularda sülfürün en çok rastlanan formudur. Suya kayaçlardan, sülfat barındıran sedimetten ve yağmurlardan geçer. Bitki gelişimi ve büyümesi için oldukça önemli olan bir maddedir ve biyolojik verimlilik için ortamda yeterince bulunmalıdır. Eksikliğinde fitoplankton gelişimi olumsuz etkilenir (Atıcı vd. 2005; Tanyolaç 2009; Göksu 2014). Sülfat iyonu miktarı 0,09 - 3,45 mg/L arasında değişiklik göstermiştir. Sonbaharda maksimum değere ulaşırken, yaz mevsiminde minimum değerde olduğu saptanmıştır. Eber Gölü'nde 113 mg/L (Gümüş ve Akköz 2020), Uluabat Gölü'nde 54,8 mg/L (Elmacı vd. 2010), Eğirdir Gölü'nde 26,57 mg/L (Bulut ve Kubilay 2019) olarak bulunmuştur. Sülfatın yüksek çıkması genel olarak sucul sistemlerin yakınındaki tarımsal faaliyetler ile ilişkilendirilmiştir (Tepe 2009; Gümüş ve Akköz 2020). Karakuyu Gölü'nün sülfat değerlerinin diğer çalışmaların sonuçlarına göre daha düşük olmasının sebebi göl etrafında yoğun bir tarımsal faaliyetin bulunmaması olabilir.

Doğadaki azot kaynağı atmosfer ve canlılardır. Azot havadan suya doğru bir çevrim izlemektedir. Çözünmüş azot algler ve bakteriler tarafından önce nitrata daha sonra da nitratın bir kısmı nitrit ve amonyak formuna dönüştürülür. Amonyum ise azotlu organik maddelerin ya da proteinlerin bakteriler tarafından parçalanması sonucu oluşur (Göksu 2014). Eğer ortamda oksijen var ise amonyum azotu nitrit ve nitrata dönüşür. Ortamdaki azotun oksidasyonu sırasında oksijen tüketilmektedir. Nitrat su ortamının temel besin maddelerinden biri olsa da suda fazla miktarda bulunduğunda canlı gruplarına zarar vermekte ve ötrofikasyona neden olmaktadır (Sawyer vd. 2003; Göksu 2014). Çalışmamızda nitrat azotu miktarının tüm mevsimlerde en düşük değerleri analiz limitinin altında iken en yüksek değere kış mevsiminde (1,53 mg/L) rastlanmıştır. Amonyum azotu değeri ise kış mevsiminde analiz limitinin altında iken diğer mevsimlerde en düşük değerler analiz limitinin altında çıkmıştır. Yaz ve sonbaharda ortalama amonyum azotu miktarının eşit olduğu (0,08 mg/L) belirlenmiştir. Her iki parametrenin belirlenen değerlerinin EU, EPA, WHO ve TS 266'da belirtilen içme suyu standartlarına göre kabul edilebilir değerler içerisinde yer aldıkları belirlenmiştir (TSE 2005; EPA 2018; EU 2020; WHO 2022). Eber Gölü'nde amonyum azotunun 2,55 mg/L, nitrat azotunun ise 1,45 mg/L olduğu bildirilmiştir (Gümüş ve Akköz 2020). Yenişehir Gölü'nde ortalama nitrat değeri 5,09 mg/L olarak belirlenmiştir (Tepe 2009). Saraydüzü Baraj Gölü'nde nitrat ve amonyum değeri eylülde maksimum (3,62 mg/L; 0,0016 mg/L) düzeye ulaşmıştır. Karakuyu Gölü'nde nitrat miktarı 0,86 - 2,46 mg/L arasında değişiklik göstermiş ve nitrat değerine göre göl suyunun I. sınıf yüksek kaliteli su sınıfına girdiği bildirilmiştir (Bulut vd. 2011). Sucul sistemlerdeki fazla nitratın azotlu gübre kullanımı ve kanalizasyon artıklarından kaynaklandığı bilinmektedir (Demir 2011). Karakuyu Gölü'nün çevresinde yoğun bir tarımsal faaliyet olmaması bu iki parametrenin değerlerinin düşük çıkmasını doğrular niteliktedir.

Doğadaki başlıca fosfor kaynağı kayaçlar ve doğal fosfat yığınlarıdır (Göksu 2014). Gündelik yaşamda ise gübreler, deterjanlar ve yıkama suları fosforun diğer kaynaklarıdır. Ayrıca sedimentte biriken fosfatta uygun koşullarda suya geçer (Ali ve Khairy 2016). Fosfor doğada fosfatlar halinde bulunur ve tüm organik fosfor bileşiklerinin temel yapı taşını ortofosfatlar oluşturmaktadır. Karaçomak Baraj Gölü'nde ortofosfat iyonu 0,021 - 0,08 mg/L (Imneisi ve Aydın 2016), Eğirdir Gölü'nde 0,01 - 0,08 mg/L (Bulut ve Kubilay 2019), Saraydüzü Baraj Gölü'nde 0,0014 - 0,51 mg/L (Kükrek ve Mutlu 2019) arasında değişim göstermiştir. Bu çalışmada tüm mevsimler ve istasyonlarda ortofosfat fosforu iyonu değerlerinin analiz limitinin altında (p <0,05) kaldığı tespit edilmiştir. Ortofosfat, fosfatın bitkiler ve mikroorganizmalar tarafından kullanılan tek formudur (Kutlu vd. 2015). Karakuyu Gölü'nde yoğun bir makrofit gelişiminin olması, etrafında yoğun bir tarım faaliyetinin ve yerleşim yerinin olmaması ortofosfat değerinin çok düşük miktarlarda olmasını doğrular niteliktedir. Analiz limiti altındaki ortofosfat değeri, göle evsel atıklardan deterjan karışımı ve tarımsal faaliyetlerden gübre girişi olmadığı veya az olduğu düşüncesini desteklemektedir.

Karakuyu Gölü'nün suyunun bazı fizikokimyasal parametrelerinin birbirleri ile olan ilişkilerini belirlemek amacıyla Pearson Korelasyon testi yapılmıştır. Buna göre sıcaklık ile pH, elektriksel iletkenlik, çözünmüş oksijen, klorür ve sülfat arasında, pH ile elektriksel iletkenlik ve nitrat arasında, elektriksel iletkenlik ile biyolojik oksijen ihtiyacı, sülfat ve nitrat arasında, çözünmüş oksijen ile biyolojik oksijen ihtiyacı, sülfat, nitrat ve amonyum arasında, biyolojik oksijen ihtiyacı ile sülfat ve nitrat arasında, klorür ile sülfat ve amonyum arasında, sülfat ile amonyum arasında, nitrat ile amonyum arasındaki ilişkilerin negatif olduğu, diğer tüm ilişkilerin ise pozitif olduğu belirlenmiştir. Kükrek ve Mutlu (2019) Saraydüzü Baraj Gölü'nde çözünmüş oksijen değerinin pH, elektriksel iletkenlik ve biyolojik oksijen ihtiyacı ile arasında negatif bir ilişki olduğunu bildirmişlerdir. Tekin-Özan vd. (2024), Karataş Gölü'nün suyunda sıcaklık ile pH ve çözünmüş oksijen arasında, pH ile elektriksel iletkenlik arasında negatif bir ilişki olduğunu tespit etmişlerdir. Loktak Gölü'nde pH ile nitrat arasında negatif, sıcaklık ile nitrat arasında pozitif ilişki olduğu tespit edilmiştir (Kangabam vd. 2017). Sıcaklık ile birlikte sularda gazların eriyebilirliliği azaldığından (Tanyolaç 2009) sıcaklık artışına paralel olarak oksijen düzeyinin azalması beklenen bir durumdur. Sucul sistemlerdeki elektriksel iletkenlik değeri jeolojik yapı ve yağış miktarı ile yakından ilişkilidir (Temponeras vd. 2000).

Çalışmanın gerçekleştiği dönemde yağış miktarının Haziran 2023'de maksimum düzeye ulaşması nedeniyle elektriksel iletkenlik değerinin yaz mevsiminde düştüğü görülmüştür. Sülfat düzeyinin sıcaklık artışıyla azalması sülfatın bitkiler tarafından yoğun şekilde kullanıldığına işaret etmektedir. Sularda yüksek alkali ortamda amonyum hidroksit yoğunluğu yüksek miktarlara ulaşmaktadır (Tanyolaç 2009). Nitrifikasyon sürecinde amonyak önce nitrite sonra nitrata dönüştüğünden ortama hidrojen iyonu girişi olması nedeniyle, nitrat miktarı artarken pH düzeyi de düşmüştür (Yaramaz 1992). Nitrifikasyon sürecinde oksijen kullanıldığından (Göksu 2014) oksijen düzeyi ile nitrat ve amonyum değerleri arasında ters bir ilişkinin tespit edilmesi olağandır. Oksijen seviyesi ile sülfat değeri arasındaki negatif ilişkinin organik maddelerin bakteriler tarafından ayrıştırılması esnasında oksijen kullanılması ve son kararlı ürün olarak sülfatın açığa çıkması (Göksu 2014) ile açıklanabilir. Bu reaksiyon aynı zamanda sülfat ve nitrat arasındaki pozitif ilişkiyi de açıklamaktadır. Zira organik maddelerin parçalanması sonucunda nitrat da açığa çıkan kararlı son ürünlerden biridir (Göksu 2014).

Su kalite indeksi (WQI) suyun genel kalitesi hakkında fikir veren, bazı fiziksel ve kimyasal parametrelerin kullanılarak hesaplandığı bir ölçme sistemidir (Imneisi ve Aydın 2016; Taş vd. 2021). Karakuyu Gölü suyu WQI değerlerinin ilkbaharda 25,52, yaz mevsiminde 21,94, sonbaharda 22,69 ve kış mevsiminde ise 26,11 olduğu belirlenmiştir. Bu sonuçlara göre Karakuyu Gölü tüm mevsimlerde mükemmel su kalitesi kategorisinde bulunmaktadır. Karaçomak Baraj Gölü'nde WQI değerleri 35,57 (fakir su) ve 32,41 (iyi) olarak (Imneisi ve Aydın 2016), Saraydüzü Baraj Gölü'nde 17,62 - 29,88 arasında (Kükrer ve Mutlu 2019) ve Loktak Gölü'nde 64 - 77 arasında (Kangabam vd. 2017) tespit edilmiştir. WQI değerine göre mükemmel su sınıfında olması ile Karakuyu Gölü suyunda ölçülen bazı fizikokimyasal parametre değerlerinin EU, EPA, WHO VE TS 266'da belirtilen içme suyu standartlarına göre kabul edilebilir değerler içerisinde yer alması ile uyumlu sonuçlar vermiştir (TSE 2005; EPA 2018; EU 2020; WHO 2022).

Karakuyu Gölü'nün su kalitesini belirlemek amacıyla bir yıl boyunca yapılan bu çalışmada göl suyunun kalite sınıfları belirlenmiştir. Buna göre gölün pH, elektriksel iletkenlik, biyolojik oksijen ihtiyacı, ortofosfat fosforu, klorür iyonu, nitrat azotu ve amonyum azotu değerleri açısından I. kalite sınıfında olduğu belirlenmiştir. Sıcaklık ve sülfat iyonu değerlerine göre göl suyu I. ve II. kalite sınıfına ait iken, oksijen miktarına göre kış mevsiminde II. kalite sınıfında, diğer mevsimlerde ise III. kalite sınıfında yer aldığı saptanmıştır (Çevre, Şehircilik ve İklim Değişikliği Bakanlığı 2023; Tarım ve Orman Bakanlığı 2023). Karakuyu Gölü suyunda ölçülen bazı fizikokimyasal parametre değerlerinin EU, EPA, WHO VE TS 266'da belirtilen içme suyu standartlarına göre kabul edilebilir değerler içerisinde yer aldıkları belirlenmiştir (TSE 2005; EPA 2018; EU 2020; WHO 2022). WQI sonuçlarına göre göl suyunun mükemmel su sınıfında olduğu belirlenmiştir. Sonuçlar değerlendirildiğinde gölün sıcaklık, oksijen ve sülfat dışındaki diğer parametreler açısından kirlilik ve kalitesinin bariz bir sorun teşkil etmediği görülmektedir. Ancak kuraklık, iklim değişikliği, bilinçsiz sulama, tarımsal aktiviteler, hayvancılık ve nüfus artışı gibi sebeplerle ülkemizdeki sulak alanlar kirlilik ve yok olma tehlikesi ile karşı karşıyadır. Bu nedenle Karakuyu Gölü'nün mevcut durumunun korunması, kirletici girişinin mümkün olduğu kadar engellenmesi, ekolojik dengesinin korunması oldukça önemlidir. Gölde düzenli bilimsel çalışmalar yapılarak su kalitesi ve ötrofikasyon durumu kontrol edilebilir. Göl yönetimine katkı sağlamak amacıyla bütüncül bir yaklaşımın benimsenmesinin ve gölün sürdürülebilirliği için modelleme çalışmalarının yapılmasının önemli olduğu düşünülmektedir.

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Comparative Analysis of Full-time and Part-time Fishermen's Exchange Rates: A Case Study of Sungai Batang Ilir Village, Indonesia

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ABSTRACT

This study aimed to assess the economic conditions of fishermen residing in Sungai Batang Ilir village, Indonesia, by analyzing their income levels and financial capacities. The research employed a field survey and descriptive methodology. A total of 40 respondents were selected based on specific criteria: 20 full-time and 20 part-time fishermen. Structured interviews were conducted to gather data on their revenues and expenditures related to fishing and non-fishing activities. The findings indicated that full-time fishermen had a significantly higher average exchange rate (120.29±5.24) compared to part-time fishermen (95.27±6.58), with corresponding exchange rate indexes of 1.12±0.08 and 0.93±0.04, respectively. With July as the reference point, the exchange rate indexes for full-time fishermen exceeding one in August and September, suggesting their greater financial ability compared to part-time fishermen, especially in covering household expenses and fishing operational costs. Variations in income were primarily attributed to differences in the number of working days among fishermen. Despite these differences, the average monthly incomes of both groups remain below the Regional Minimum Wage of Banjar District (approximately 193 USD). The study also discusses measures to enhance fishermen's incomes, aiming to improve their financial well-being and sustainability.

Keywords: Household condition, financial capacity, fisheries, non-fisheries, monthly income.

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Introduction

In a fishing village, the fishermen shape their lifestyle and social background, establishing ownership patterns over fishing boats, fishing gears, business capital, and marketing systems based on local traditions, sometimes influenced the local government interventions. Balasubramaniam et al. (2001) and Seputro et al. (2021) suggested that knowledge, technological adoption, and access to information positively correlate with socio-economic status. Convincing fishermen in higher socio-economic categories to participate can have a ripple effect, influencing others positively. Each group of fishermen within the village exhibits unique characteristics and may hold differing views and attitudes (Ahmadi 2023).

Sungai Batang Ilir village in South Kalimantan Province of Indonesia, is recognized as one of the potential areas for fishery production. The village integrates capture fishery, fish farming, and fish processing as complementary activities. Fishing primarily occurs along the river and swamp using traditional gears such as *rengge* (gillnets), *lukah* (fish pots), *temperai* (stage traps), *hancau* (portable lift nets), *lunta* (cash nets), and *banjur* (stake lines). Fishermen are motivated to catch fish either to meet demand or to generate income, but the widespread pursuit of these goals can deplete fish stocks faster than they can replenish.

Additionally, the village also supports commercial fish farming in cages, focusing on species like Nile tilapia, patin, and grass carp, which proves to be a profitable and cost-effective venture.

Meanwhile, fish processing is traditionally carried out by women, involving drying, salting, and fermenting fish such as snakehead, climbing perch, snakeskin gourami, and three-spot-skin gourami. These processed products are sold locally or directly marketed to neighboring villages and districts, enjoying high consumer acceptance and profitability for the processors. Similar patterns of fisheries and aquaculture development observed in Sungai Batang Ilir village are also prevalent in other developing countries, as documented in studies by Freduah et al. (2017), Twumasi et al. (2021), and Tikadar et al. (2022).

According to Seputro et al. (2021), individuals engaged in fishery business activities have significant opportunities to optimize and sustain their businesses, despite some perceptions that fisheries yield lower incomes compared to agriculture and other sectors. This belief often stems from a lack of information regarding fishermen's exchange rates in the studied area. Poverty within traditional fishing communities is commonly attributed to unequal resource ownership, where impoverished individuals possess limited and low-quality resources, alongside challenges in accessing skilled human resources and capital (Njagi et al. 2013; George et al. 2014; Mozahid et al. 2018). The exchange rate of fishermen serves as a crucial indicator for assessing their welfare levels, derived from comparing total revenues with expenditures on household needs and fishing operations. To address these issues, a field survey was conducted in Sungai Batang Ilir village to determine the exchange rates of full-time and part-time fishermen, identify influencing factors, and propose solutions if the reality falls short of expectations. Ultimately, the exchange rate can inform local government policies aimed at enhancing the welfare of fishing communities.

Materials and Methods

Study site

This study was conducted in Sungai Batang Ilir village, located in South Kalimantan Province at coordinates 03°22'36 S and 114°49'29 E (Figure 1). The village is situated within the West Martapura sub-district and spans an area of 23.47 km^2. It shares administrative borders with Limamar village to the north, Sungai Batang and Minggu Raya villages to the east, Sungai Rangas Ulu village to the west, and Penggalaman village to the south. This village is predominantly characterized by wetland areas where water levels fluctuate between 0.5-2 m. These wetlands are primarily regulated by rainfall, resulting in two distinct environmental conditions. During the rain season, the entire wetland area is flooded, making fishing challenging. In contrast, during the dry season, the wetland is covered with aquatic plants, concentrating fish in sludge holes or shallow waters, facilitating easier catching. This regular alternation between aquatic and high plant biomass environments plays a crucial role in regulating the high production of freshwater fish in the wetland.

Data collection

A total of 40 respondents were included in this study, comprising 20 full-time fishermen and 20 part-time fishermen. Structured questionnaires were used to collect primary data, focusing on both revenues and expenditures related to fisheries and non-fisheries activities to establish the fishermen's exchange rates (see Annex). Secondary data were gathered from institutional reports and relevant literature. Respondents were selected based on specific criteria: they must reside in the village, be married to family members, possess their fishing gear such as *rengge* (gillnet), *lukah* (fish trap), *banjur* (hook and line), or *lunta* (cash net), and engage in an unincorporated fishing business. The research employed a field survey combined with a descriptive method. Data collection for determining fishermen's exchange rates took place individually following the procedure.

In this study, the income derived from capture fisheries focused specifically on four key fish species: snakehead (*Channa striata*), climbing perch (*Anabas testudineus*), three-spot-skin gourami (*Trichogaster trichopterus*), and snakeskin gourami (*Trichogaster pectoralis*). The selling price of these fish species served as a fundamental factor in calculating the fishermen's exchange rates. The following describes types of fishing gears commonly used by local fishermen (see Figure 2):

Rengge is a type of gillnet made from monofilament nylon with stretched mesh sizes ranging from 31.75 to 63.50 mm. It is constructed as a straight wall of netting, approximately 10 m in length and 0.5 m in height. The net is equipped with weights at the bottom and floats at the top, and it is anchored at both ends by poles planted approximately 2 m deep into the riverbed. The mesh sizes of gillnet used are smaller than those used in Danau Bangkau village (Irhamsyah et al. 2017), which are designed specifically for catching climbing perch and snakeskin gourami.

Lukah is an elongated, tube-shaped fish trap made from bamboo, typically 150 cm in length with a diameter of 20 cm. It features an entry funnel on one end and an exclusion funnel on the opposite end. It is designed to allow fish to enter easily but makes it difficult for them to escape. Inside, there is a one-way valve called *hinjap*, made from elastic rattan, positioned to prevent fish from exiting once they enter. The traps are deployed in swampy areas with dense vegetation and slow or no current, usually in the morning and retrieved in the afternoon. They are submerged at an oblique angle of about 15º to allow fish to access oxygen at the water's surface. *Lukah* is effective for catching climbing perch, snakehead, and snakeskin gourami.

Banjur is a type of line fishing using bamboo poles about 50 cm long, hooks of size #15, and nylon monofilament rope of about 50 cm in length. The bait commonly used is frogs, specifically *Rana cancarivora*. *Banjur* is set around swampy areas to target snakeheads. The size of the banjur used in Sungai Batang Ilir village is typically smaller than that used in Danau Bangkau village (Irhamsyah et al. 2017).

Lunta is a circular net equipped with small weights distributed around its edge. It is cast or thrown by hand so that it spreads out on the water's surface and sinks. This technique, known as net casting or throwing, allows fish to be caught as the net is pulled back in. *Lunta* is made from monofilament nylon with mesh sizes ranging from 31.75 to 63.50 mm and has a total length of about 4 m with a radius of 10 m.Iron rings, weighing approximately 4.5 kg, are attached to the net's edge. A handline, about 3 m in length, is used to cast and retrieve the net. Fish commonly caught using *lunta* include snakehead, climbing perch, and snakeskin gourami.

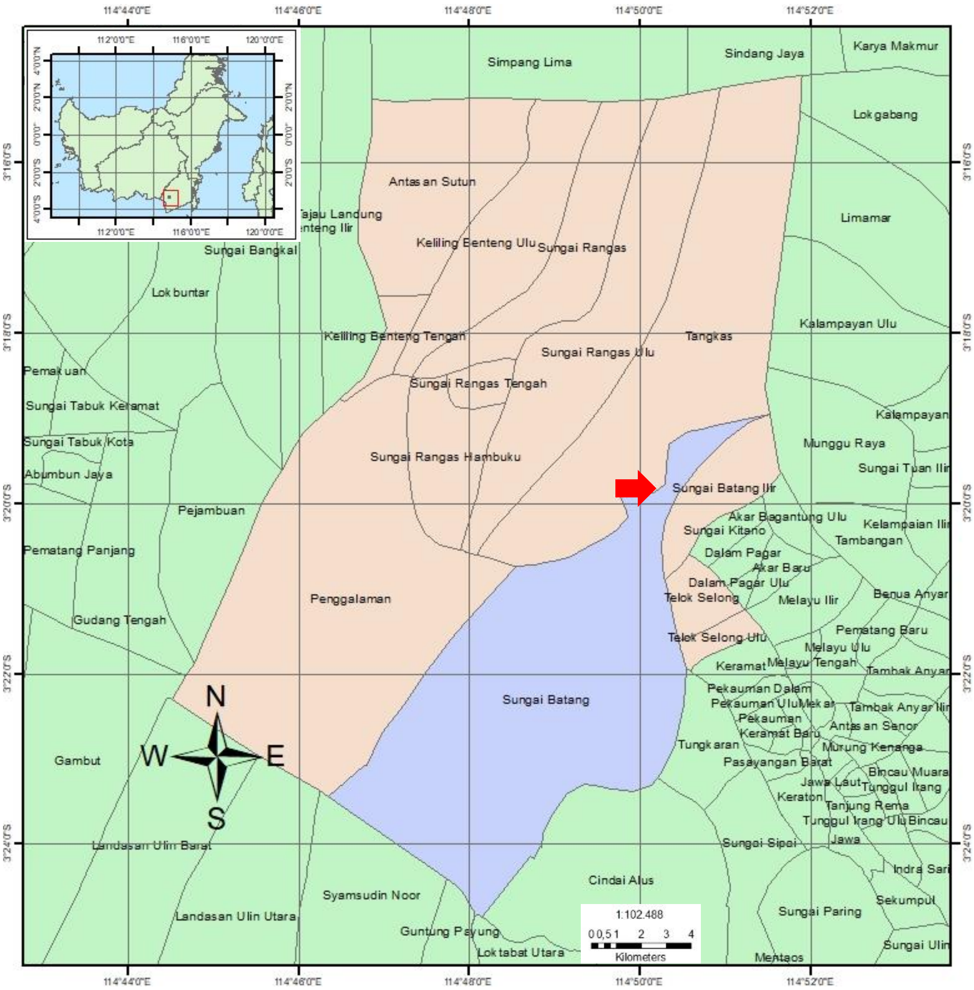

Figure 1. Geographyc location of Sungai Batang Ilir Village, South Kalimantan

Figure 2. Fishing gears used by local fishermen in Sungai Batang Ilir Village (A) *Rengge*, (B) *Lukah*, (C) *Banjur*, and (D) *Lunta*

Data analysis

The fishermen's exchange rate was calculated using the following formula (Basuki et al., 2001):

$NTN = (Yt / Et) \times 100$

$Yt = YFt + YNFt$ and $Et = EFt + EKt$

Where NTN is fishermen's exchange rate, Yt is the total revenue at t period, YFt is the total revenue from fisheries business, YNFt is the total revenue from non-fisheries, Et is the total expenditure at t period, EFt is the total expenditure for fisheries business, EKt is the total expenditure for household consumption, and *t* is period (month). In this case, the month of July was determined as the base month for calculation. If NTN > 100, it means that the welfare of fishermen in the present month is better than the base month. If NTN = 100, the welfare of fishermen is unchanged compared to the base month, and if NTN < 100, the welfare of fishermen in the present month is worse than the base month.

The fishermen's exchange rate index is expressed as the ratio between the total revenue index to the total expenditure index of fishermen's households for a certain time. It is calculated using the following formula:

$INTN = (IYt / IEt)$

$IYt = Yt / Ytd$ and $IEt = Et / Etd$

Where INTN is fishermen's exchange rate index at t period, IYt is an index of total revenue at t period, Yt is the total revenue at t period (current price), Ytd is the total revenue at the basic period (base price of the month), IEt is an index of total expenditure at t period, Et is the total expenditure at t period (current price), and Etd is the total expenditure at basic period (base price).

The value of INTN can be less than, equal to, or greater than one. If INTN < 1, it indicates that fishermen's families have low purchasing power, making it difficult for them to meet their life needs and potentially leading to a household budget deficit. If INTN = 1, they can only meet their subsistence needs. Conversely, if INTN > 1, it signifies a good level of welfare, allowing them to meet their subsistence needs and potentially consume secondary/tertiary goods or save through investments. An increase in income will alter the consumption patterns of family members, depending on their needs and ability to manage income. INTN serves as an indicator to measure the effectiveness of various price policies implemented by the government for fishermen's groups.

Statistical analysis

Data were analyzed using Microsoft Office Excel and SPSS version 18, and were statistically presented as average ± standard error (SE) or percentage, displayed in graphs or tables. Data normality and homogeneity were assessed with the Kolmogorov-Smirnov test. To compare the monthly revenue and expenditure differences between full-time and part-time fishermen, we conducted either one-way ANOVA or the Kruskal-Wallis test, depending on the data distribution. A t-test was used to examine the average differences in these variables. Statistical significance was determined at a p-value of less than 0.05.

Results

The selling prices of four commercial fish species at the fishermen level are listed in Table 1, varying according to the type and size of the fish. All species have good consumer acceptance due to their delicious and high-quality meat. Snakehead has the highest price at 3 USD/kg, followed by Climbing perch at 2 USD/kg, Snakeskin gourami at 1 USD/kg, and three spot-skin gourami at 0.5 USD/kg. Snakehead and Climbing perch are popular dishes in restaurants, while Snakeskin gourami and three spot-skin gourami are typically sold as salted fish products.

There were no significant variation in the monthly revenue and expenditure among either full-time fishermen or part-time fishermen (p>0.05). Monthly income for each group remained relatively stable. Despite comparable monthly costs, full-time fishermen outperformed part-time fishermen in terms of sales volume and price, leading to higher average incomes (Table 2). Full-time fishermen generated a monthly income of about 155 USD, with the highest income received in July (194 USD) and the lowest in September (126 USD). Most of their expenditure budget was allocated for household consumption needs (65.80%) and fishing operational costs (17.55%), with the remaining income, retained as savings (16.65%). Part-time fishermen earned a monthly income of about 110 USD, with the highest income in July (125 USD) and the lowest in September (99 USD). Their average income was primarily spent on household consumption needs (62.34%), agriculture expenses (30.90%), and fishing expenses (12.70%). This group faced financial deficits and economic hardship due to expenditures exceeding their revenue. No significant difference was observed in the percentage distribution of monthly revenue and expenditure among either full-time or part-time fishermen (p>0.05). The detailed percentages of monthly revenue and expenditure for each group are presented in Table 3

Table 1. Type of fish, volume and selling price of full-time and part-time fishermen in Sungai Batang Ilir village

Full-time fishermen	**July**		**August**		**September**		**Average**	
Type of fish sold	kg	USD/kg	kg	USD/kg	kg	USD/kg	kg	USD/kg
- Three spot-skin gourami	47.50	0.45	55.60	0.30	81.20	0.22	61.4	0.30
- Snakeskin gourami	24.30	1.12	29.30	0.97	41.20	0.75	31.6	0.91
- Climbing perch	21.80	1.87	28.10	1.49	33.70	1.12	27.9	1.44
- Snakehead	35.00	2.99	19.30	2.99	17.50	2.24	23.9	2.81
Part-time fishermen								
- Three spot-skin gourami	19.50	0.45	23.20	0.30	31.8	0.22	24.8	0.31
- Snakeskin gourami	9.70	1.12	10.10	0.97	12.7	0.75	10.8	0.93
- Climbing perch	9.30	1.87	8.20	1.49	9.30	1.12	8.9	1.49
- Snakehead	9.30	2.99	5.60	2.99	5.60	2.24	6.83	2.79

Table 2. Revenue and expenditure of full-time and part-time fishermen during the three-month survey period (in USD)

Group	Financial Aspect	July	Aug	Sep	Average	SE
Full-time fishermen	**Revenue**	**194**	**145**	**126**	**155**	**20.25**
	- Fisheries	194	145	126	155	20.25
	- Non-fisheries (Agriculture)	-	-	-	-	-
	Expenditure	**155**	**115**	**115**	**128**	**13.31**
	- Household consumption	127	90	91	102	12.38
	- Fishing expenses	28	26	24	26	1.01
	- Agriculture expenses	-	-	-	-	-
	Surplus or Minus	**39**	**30**	**11**	**27**	**8.16**
Part-time fishermen	**Revenue**	**125**	**106**	**99.4**	**110**	**7.60**
	- Fisheries	64.9	45.8	39.6	50.1	7.60
	- Non-fisheries (Agriculture)	59.8	59.8	59.8	59.8	0
	Expenditure	**116**	**115**	**116**	**115**	**0.33**
	- Household consumption	68.0	67.2	68.3	67.9	0.33
	- Fishing expenses	13.8	13.8	13.8	13.8	0
	- Agriculture expenses	33.6	33.6	33.6	33.6	0
	Surplus or Minus	**9.18**	**-9.14**	**-16.4**	**-5.45**	**7.60**

Table 3. The percentage of revenue and expenditure of full-time and part-time fishermen

Variable observed	Full-time fishermen					Part-time fishermen				
	July	Aug	Sept	Average	SE	July	Aug	Sept	Average	SE
Revenue										
Fisheries (selling price)	**100**	**100**	**100**	**100**	**0**	**52.03**	**43.35**	**39.85**	**45.07**	**3.62**
- Three spot-skin gourami	10.98	11.48	14.45	12.30	1.08	7.02	6.57	7.17	6.92	0.18
- Snakeskin gourami	14.05	19.66	24.44	19.38	3.00	8.77	9.30	9.55	9.21	0.23
- Climbing perch	21.01	29.01	29.98	26.67	2.84	13.94	11.61	10.49	12.01	1.02
- Snakehead	53.96	39.85	31.14	41.65	6.65	22.31	15.86	12.63	16.93	2.84
Agriculture	-	-	-	-		**47.97**	**56.65**	**60.15**	**54.93**	**3.62**
Total Revenue	**100**	**100**	**100**	**100**	**0**	**100**	**100**	**100**	**100**	**0**
Expenditure										
Household consumption	**63.67**	**61.87**	**71.86**	**65.80**	**3.07**	**54.56**	**63.69**	**86.76**	**62.34**	**4.15**
- Foods	27.22	26.12	30.60	27.98	1.35	10.79	12.82	14.16	12.59	0.98
- Health	23.03	20.39	23.58	22.33	0.98	23.76	28.24	30.08	27.36	1.88
- Education	0.41	0.55	0.64	0.54	0.07	0.97	1.50	1.13	1.20	0.16
- Electricity	2.97	3.97	4.55	3.83	0.46	4.51	4.88	5.88	5.09	0.41
- Cigarettes	10.04	10.84	12.48	11.12	0.72	14.53	16.25	17.52	16.10	0.87
Fishing expenses	**14.26**	**19.20**	**19.20**	**17.55**	**1.65**	**11.09**	**13.10**	**13.91**	**12.70**	**0.84**
- Oil	4.65	7.75	6.93	6.45	0.93	2.34	2.76	2,93	2.68	0.18
- Bait	3.56	3.36	2.97	3.30	0.18	0.30	0.35	0.38	0.34	0.02
- Boat care	0.19	0.26	0.30	0.25	0.03	6.03	7.12	7.56	6.90	0.46
- Fishing gear maintenance	5.85	7.83	9.00	7.56	0.92	2.43	2.87	3.05	2.78	0.18
Agriculture expenses	**-**	**-**	**-**	-	**-**	**26.98**	**31.87**	**33.84**	**30.90**	**2.04**
- Wage	**-**	**-**	**-**	-	-	11.98	14.16	15.04	13.73	0.91
- Labour consumption	**-**	**-**	**-**	-	-	6.00	7.08	7.52	6.87	0.45
- Fertilizer	**-**	**-**	**-**	-	-	8.99	10.62	11.28	10.30	0.68
Total Expenditure	**77.93**	**81.07**	**91.05**	**83.35**	**3.96**	**92.64**	**108.66**	**116.51**	**105.94**	**7.02**
Surplus or Minus	**22.07**	**18.93**	**8.95**	**16.65**	**3.96**	**7.36**	**-8.66**	**-16.51**	**-5.94**	**7.02**

Our findings indicate that full-time fishermen had a significantly higher average exchange rate (120.29±5.24) compared to part-time fishermen (95.27±6.58), with corresponding exchange rate indexes of 1.12±0.08 and 0.93±0.04, respectively (Table 4). With July as the reference point, ;the exchange rate indexes for full-time fishermen exceeding one in August and September, suggesting their greater financial ability compared to part-time fishermen, especially in covering household expenses and fishing operational costs.

Table 4. Comparative value of fishermen's exchange rate (in USD) and exchange rate index between full-time and part-time fishermen in Sungai Batang Ilir village

Group	Fishermen's exchange rate					Exchange rate index				
	July	Aug	Sep	Av Average	SE	July	Aug	Sep	Average	SE
Full-time fishermen	125.23	125.81	109.82	120.29	5.24	1	1.26	1.10	1.12	0.08
Part-time fishermen	107.94	92.03	85.85	95.27	6.58	1	0.92	0.86	0.93	0.04

Discussion

Investigating the factors contributing to the popularity of specific species, such as taste, cultural significance, or preparation methods, could provide further insights into consumer preferences impacting these prices. Understanding these price variations can be valuable for fishermen in optimizing their catch strategies and potentially maximizing their earnings by targeting in-demand species. The price disparity between Snakehead (3 USD/kg) and Three-spot gourami (0.5 USD/kg) suggests a potential influence of consumer preference on market value. Snakehead's popularity as a fresh fish delicacy might command a premium compared to gourami, often consumed as a preserved product. This price range also offers opportunities for different market segments. Restaurants seeking high-quality fresh fish may prioritize Snakehead and Climbing Perch, while those specializing in preserved goods might focus on the more affordable gourami varieties. These preferred freshwater fish commodities were also highlighted in previous studies (Aminah and Ahmadi 2018; Ahmadi 2021; Ahmadi and Ansyari 2022). To gain a complete understanding of the economic role of salted fish products like Snakeskin gourami and Three-spot gourami within the fishery, further research should explore the processing costs and profit margins involved. This aligns with the ongoing development of diverse processing methods and technologies in the traditional fish processing industry reported by Paul et al. (2018), Siddhnath et al. (2022), and Ravishankar et al. (2023).

The research reveals a significant disparity in income between full-time and part-time fishermen. Full-time fishermen earn a considerably higher average monthly income compared to part-time fishermen (Table 2). This difference likely reflects the volume of fish sold – full-time fishermen likely catch and sell larger quantities, commanding higher prices. Despite seasonal variations in income for both groups, full-time fishermen can still allocate a portion of their income (16.65%) towards savings, indicating a more stable financial situation (Table 3). In contrast, part-time fishermen face financial challenges due to their lower income. A larger share of their earnings (62.34%) goes solely towards household necessities, leaving limited resources for other expenses. Additional agricultural expenses (30.90%) can exceed their fishery earnings, suggesting a crucial need for alternative income sources. This research highlights the importance of full-time fishing for achieving financial security in this community. The average monthly incomes of both groups were still below the Regional Minimum Wage of Banjar District (193 USD) in 2023.

The higher income for full-time fishermen can be attributed to the difference in working days, with full-time fishermen working about 25 days a month, roughly twice as many as part-time fishermen (10-15 days a month). Despite part-time fishermen combining income from fisheries and agriculture, it still does not compare to the income of full-time fishermen. During the dry season, fish are easier to catch with fishing gear, leading to a decline in fish selling prices, while rice production becomes less profitable.

If the fishermen's exchange rates remain unfavorable, several efforts should be undertaken to increase their business income, such as: (a) establishing joint business groups to access business capital, (b) providing grant aids for environmentally friendly fishing gear, (c) empowering fishermen's wives to diversify fishery products (d) improving irrigation systems to enhance rice production, and (e) creating alternative businesses such as growing vegetables and fruits or poultry farming. In the short term, a decline in fishermen's exchange rates may not lead fishermen to reduce or cease their fishing activities because they lack the skills for other non-fishery professions. However, a sustained low index value will diminish their incentives to maximize fisheries productivity in the long term.

Empirical measurements of fishermen's exchange rates in certain study areas have been conducted by both individuals (Rupaidah 2013; Lestari et al. 2014; Yampu and Mardjudo 2015; Mumu et al. 2019; Sitorus et al. 2020; Rahman et al. 2021) and research institution (Zulham et al. 2011). The index value of fishermen's exchange rates varied between 1.08 and 1.89 (Table 5), indicating that fishing households experience a surplus, allowing them to save the remaining income for other purposes. While a good catch translates directly to a fisherman's income, high fuel costs and inflation (e.g., the rising cost of food, bait, or fishing gear) pose significant challenges that can squeeze their profit margins (Yunianto and Sumertajaya 2015). According to Zulham et al. (2011), the prices of consumable goods, input prices, and output prices play a crucial role in the fishermen's exchange rate index. In essence, strengthening fishers' purchasing power relies on a multi-pronged approach. Increased fish prices are critical, but long-term sustainability is equally important. Encouraging sustainable fishing practices can result in healthier fish stocks, potentially resulting in higher prices due to scarcity and better quality catches. In addition, reducing operational costs and ensuring affordable basic necessities will amplify these profits.

Table 5. Comparative value of revenue, expenditure, fishermen's exchange rate and exchange rate index from different geographical areas

Locations	Revenue (USD)	Expenditure (USD)	fishermen's exchange rate	Exchange rate index	References
Sungai Batang Ilir, Banjar District	155	128	120	1.20	Present study
Bangkau, Hulu Sungai Selatan District	320	208	153	1.54	Rupaidah (2013)
PPP Tasik Agung Rembang District	4,036	2,018	167	1.67	Kadhita et al. (2014)
Betahwalang village, Demak District	849	599	140	1.40	Lestari et al. (2014)
Bitung City, Padang City, Malang Districts	1,328	1,002	120	1.20	Ramadhan et al. (2014)
Bonoege, Donggala District	850	475	189	1.89	Yampu and Mardjudo (2015)
Bulutui, North Minahasa	656	394	166	1.67	Mumu et al. (2019)
Maen,North Minahasa	1,798	1,251	143	1.44	Sitorus et al. (2020)
Talisaysan, Berau District	72,909	67,574	107	1.08	Rahman et al. (2021)

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Annex

QUESTIONNAIRE
THE FISHERMEN EXCHANGE RATE
SUNGAI BATANG ILIR VILLAGE, SOUTH KALIMANTAN PROVINCE

Date of Survey: Time**:** ☐ 6 – 12 am.
☐ 1 – 6 pm.

A. IDENTITY OF RESPONDENT

Name: ……………………………………………………………..........…………………......

Home Address : ……………………………………………………………………………........

Telephone: …………………………………… Whatsapp: ……………………………………

Sex: ☐ M ☐ F

Age: …………. year old

Dependent Family Member: ☐ 1-2 persons ☐ 3-4 persons ☐ >5 persons

Education level: ☐ Elementary School ☐ Junior High School ☐ Senior High School
☐ Bachelor Degree ☐ Master Degree ☐ Doctor Degree

Profession: ☐ Full-time fishermen ☐ Part-time Fishermen ☐ Other:…………….

B. FISHING ASPECT

No	Type of Fishing Gears	Specification	Fish targeted
1			
2			
3			
4			
5			
6			

Fishing boat dimension: Length = …… m. Breadth = …… m. Depth = …… m.

Fishing ground: ☐ Rivers ☐ Swamp ☐ Irrigation canals

Fishing operation: ………… am/pm

Fishing coordinates: ……………………….....…….…………………………………………….

Problem being faced: ………………………………………………………………………...

C. FINANCIAL ASPECT

Income and Expenses	July	August	September
Revenue			
- Fisheries (type of fish sold) 1. 2. 3. 4. 5.			
- Agriculture 1. 2.			
Expenditure			
-Household consumption 1. Foods 2. Health 3. Education 4. Electricity 5. Cigarettes 6. Other			
-Fishing expenses 1.Oil 2.Bait 3.Boat care 4.Fishing gear maintenance 5.Other			
-Agriculture expenses 1.Wage 2.Labour consumption 3.Fertilizer 4.Other			

Problem being faced: ………………………………………………………………………..

D. MARKETING ASPECT

Marketing channel: ☐ direct ☐ indirect (through the intermediateris)

Distribution of fish production: ☐ Local ☐ Outside: ....

Number of wholesaler(s): .... person(s) come from: ....….

Number of Retailer(s): .... person(s) come from: ....

Payment methods: ☐ cash ☐ credit ☐ other

Problem being faced: ………………………………………………………………………........

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Taxonomic Structure of the Benthic Macroinvertebrate Fauna from a Tropical Rainforest River in Southern Nigeria.

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ABSTRACT

This study investigates the impact of anthropogenic activities on the benthic macroinvertebrate community structure of Owan River, Edo State Nigeria. A total of 513 individuals, comprising of 11 species distributed in 9 families, 7 orders and two 2 phyla were recorded during the study. Benthic macro-invertebrate distribution was in the order Station 1 > Station 2 > Station 3 > Station 5 > Station 6 > Station 4, with species abundance highest in Station 1 (159) and lowest at Station 4 (28), while diversity was highest in stations 3 and 6. The observed phyla were Arthropoda (8 species) and Mollusca (3 species) from the orders Basommatophora, Caenogastropoda, Decapoda, Diptera, Neotaenioglosa, Odonata and Trichoptera. The species *Tympanotonus fuscatus* (62.18%) of the phylum Mollusca was the most dominant, while the species *Caridina africana* (1.56%), *Clinotanypus* sp (1.36%) and *Corynoneura* sp (1.56%) of the phylum Arthropoda were rare. Diversity indices of Dominance Index (0.27 to 0.48), Evenness index (0.47 to 0.73) and Margalef index (0.79 to 1.50) indicated low species diversity. The dominance of *T. fuscatus* and *M. tuberculatus* is an indication of deteriorating water quality from pollution. The need to forestall further decline in water quality is recommended.

Keywords: Community structure, Specie distribution, Macroinvertebrates, Water pollution, Owan River

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Introduction

Rivers plays a vital role in the environment as they provide diverse aquatic ecosystem services to man and also home to a diverse group of aquatic organisms (Egun and Oboh 2023; Biose et al. 2024). Benthic macro-invertebrates "Benthos", are organisms that live on, in or near the bottom and consist of crustaceans, molluscs, aquatic worms and larval forms of aquatic insects (Nkwoji et al. 2010; Ochieng et al. 2019; Bate and Sam-Uket 2019; Nkwoji et al. 2020). Benthic macro-invertebrates communities play an important role in the structure and functioning of aquatics ecosystems, as they serve as a critical intermediate pathway for the transportation and utilisation of energy and matter. These roles include mineralization, mixing of sediment and flux of oxygen into sediment, cycling organic matters and for assessing the quality of waters (Adi et al. 2009). With individual taxa responding differently to various kinds of pollutants,

benthic macro-invertebrates are able to serve as indicators of water quality over time (Odume and Muller 2011; Appiah et al. 2017; Keke et al. 2017). They also have the potential utility for assessing other environmental pressures such as sedimentation (Extence et al. 2011). The composition of benthic macroinvertebrates in an aquatic ecosystem is indicative of the prevailing site specific ecological conditions of the water body as their communities are structured by a wide range of biotic and abiotic factors, which are a template for the evolution of species traits, creating selection pressures that adapt these species to successfully occupy a variety of biotopes within the freshwater system (Li et al. 2010; Ogidiaka et al. 2012; Keke et al. 2017).

According to Sengupta and Dalwani (2007), the ubiquitous nature of benthic macro-invertebrates in aquatic ecosystems rivers makes them susceptible to influences from environmental disturbances in many different types of aquatic systems. Kalyoncu and Zeybek (2011) reports that these organisms are also easy to sample and identify, thereby acting as a continuous monitor of the aquatic habitat, enabling long-term analysis of both regular and intermittent discharges, variable concentrations of single and multiple pollutants, and synergistic or antagonistic effects. Also, their sedentary mode of life, sensitive life stages and relative long lifespan enables them to absorb changes in their environment (Nkwoji et al. 2020). As some of these organisms are relatively pollution tolerant, thereby providing vital information for interpreting the cumulative effects of xenobiotic in the ecosystem (Tampo et al. 2021). Therefore, data on their community structure and distribution are considered as useful tools in environmental monitoring programs, and it’s also an essential ecological tool to describe spatial and temporal changes in aquatic ecosystems (Arimoro et al. 2007; Badea et al. 2010; Kubosova et al. 2010; Ayoade and Olusegun 2012; Simmou et al. 2015; Aiwerioghene and Ayoade 2016).

The quality of the environmental conditions is also a determining factor in benthic macro-invertebrate assemblages in rivers (Mokgoebo 2019). The knowledge of community composition, distribution and diversity of macroinvertebrate fauna is essential in understanding the impact of anthropogenic activities on freshwater ecosystems. As the predictable response of the community structure and assemblages of benthic macroinvertebrates to environmental changes, has emerged as a basis for evaluating anthropogenic influences on aquatic ecosystems (Boyle and Fraleigh 2003). Several studies on benthic macroinvertebrate communities of different aquatic ecosystems in Nigeria have been documented (Udebuana et al. 2015; Adebayo et al. 2016; Asibor and Adeniyi 2017; Iyagbaye et al. 2017; Onyenwe et al. 2017; Aduwo and Adeniyi 2019; Olaniyan et al. 2019; Onyena 2019). The paucity of information on the benthic macroinvertebrate community structure of the stretch of Owan River that transverses through several rural communities, where it serves as their major source of freshwater and exposed to the impact of commercial agricultural activities is a concern for public health. An assessment of the benthic macroinvertebrate fauna of Owan River at these communities will provide data on the benthic macroinvertebrate fauna and information on the impact of anthropogenic activities on their composition along the river stretch. Also, it will provide an insight on the pollution status of the water, and the plausible community health risks from the consumption of the water and aquatic animals that are higher in the aquatic food chain of the river. The aim of this study is to determine the macrobenthic invertebrate diversity of Owan River at Sabongidda-Ora and Uhonmora-Ora Communities in Edo State Nigeria.

Materials and Methods

Description of the study area

Owan River is an oligotrophic lotic freshwater body that transverses the rain forest belt ecological zone of Edo State (Egun and Oboh 2023). Vegetative canopy comprising of secondary rain forest occurring laterally for most parts of the river bank, and commercial cocoa and plantain farms are found within the Owan river basin. This study was carried out along the stretch of Owan river traversing the communities of Saboginda-Ora (Lat. 6°54'36.5"N and Long. 5°56'13.3"E) (Figure 1) and Uhonmora-Ora (Lat. 6°52'50.6"N and Long. 5°56'26.5"E) (Figure 2) in Edo State, Nigeria. Common plants noticed along the banks at these localities are the bamboo plant (*Bambusa vulgaris*), trees (*Elaeis guineensis*, *Mangifera indica* and *Theobroma cacao*) and grasses (*Megathyrsus maximus* and *Pennisetum purpureum*). Ongoing anthropogenic activities within the watershed of the river stretch include intensive commercial farming activities, domestic and commercial washing activities, use of the river for traditional religion activities, the discharge of surface run offs and effluents processing of agricultural produce.

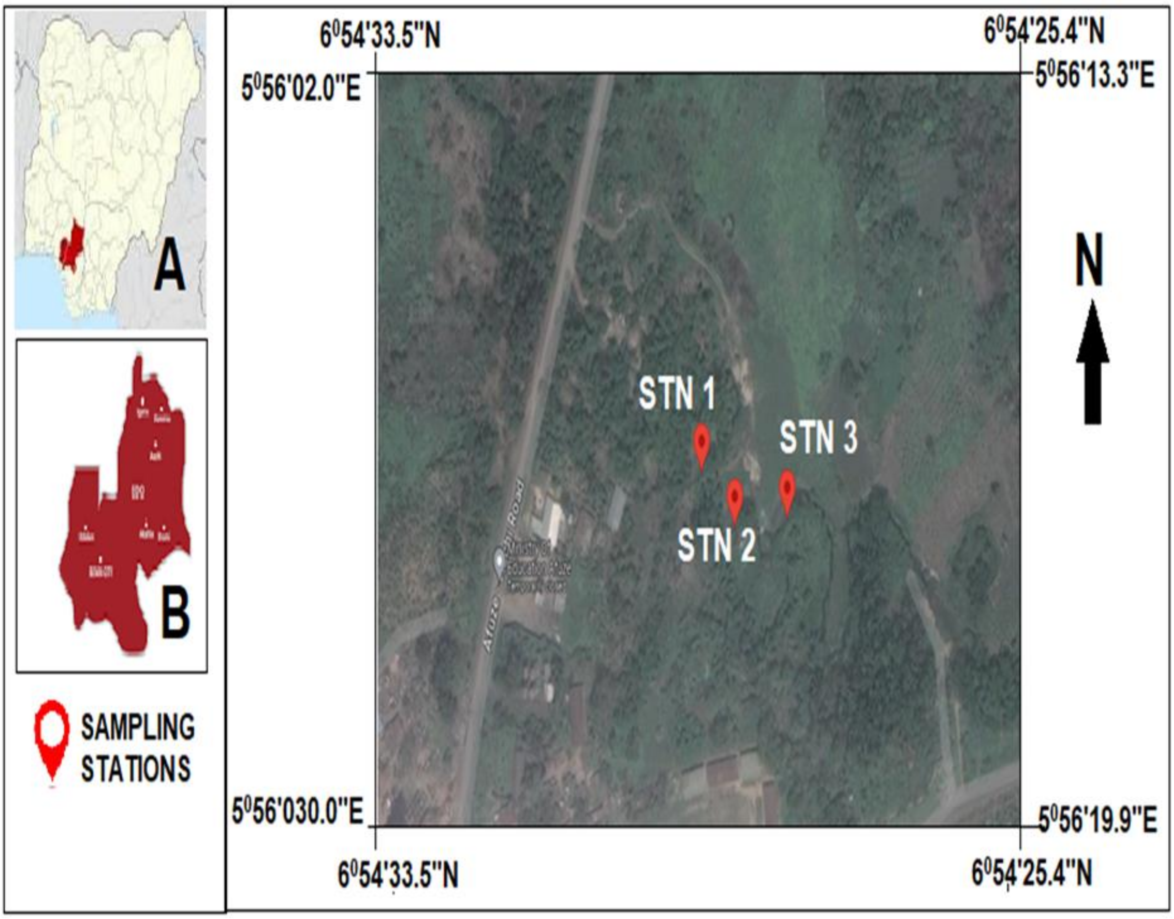

Figure 1: Owan River at Sabongidda-Ora Owan West Local Government Area of Edo State

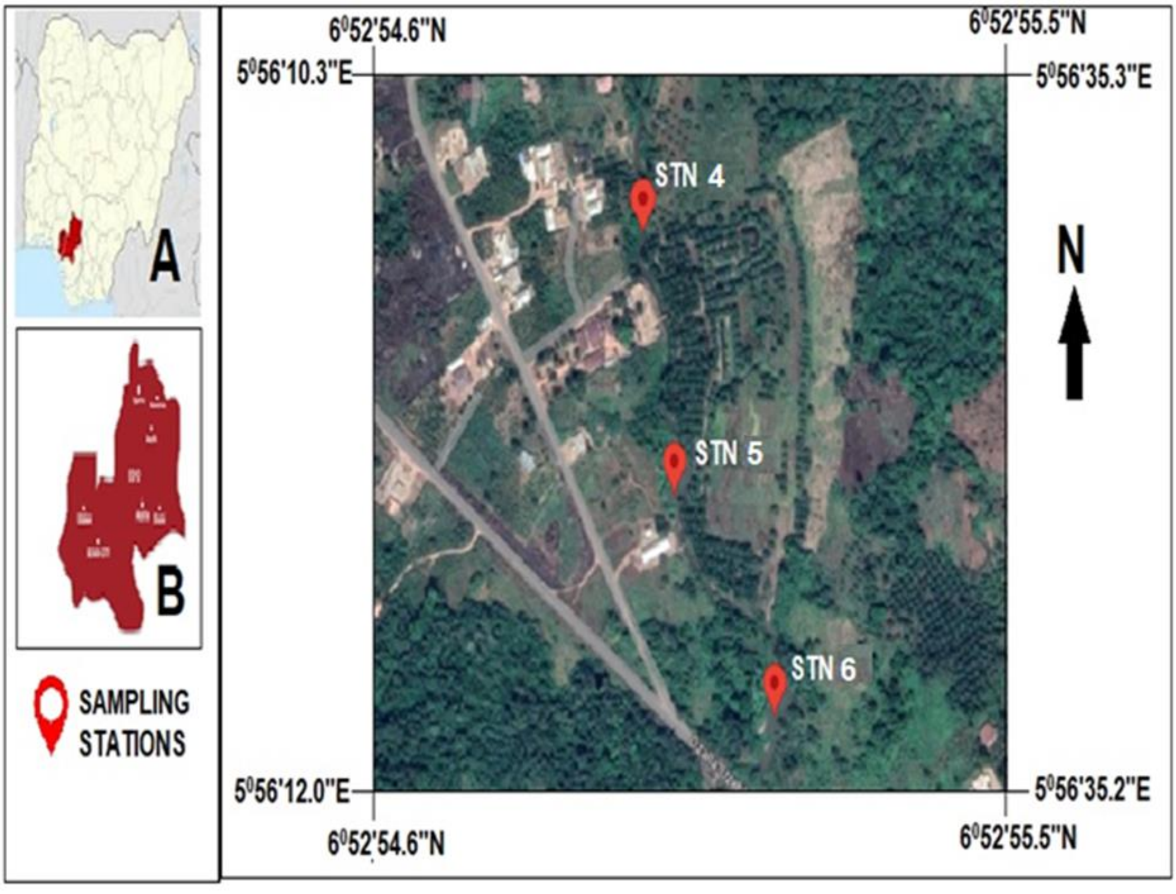

Figure 2: Stretch of Owan River at Uhonmora-Ora in Owan West Local Government Area of Edo State

Sampling stations

For the study, three (3) sampling stations were selected at Sabongidda-Ora and Uhonmora-Ora community respectively along the Owan River, with different level of human disturbances, vegetation types/cover and proximity to domestic dwellings and poultry/agricultural farms. The Sabongidda-Ora and Uhonmora-Ora Communities are located a distance of 4,484 km from the Atlantic Ocean.

Station 1

This station is located upstream of the river at at Sabongidda-Ora community (Lat. 6°54'36.5"N and Long. 5°56'08.4"E). Its bank is flanked by a thick covering of bamboo plants (*Bambusa vulgaris*), with grasses and shrubs, amidst guinea grass (*Megathyrsus maximus*) and elephant grass (*Pennisetum purpureum*).The substratum is sandy with little decaying organic matter. Activities at this point include washing of clothes, bathing and traditional religious activities.

Station 2

This station is located downstream of station 1 ("Lat. 6°54'30.0"N and Long. 5°56'07.5"E" midstream). The vegetation is made up of trees, shrubs and grasses, which include palm trees (*Elaeis guineensis*), rubber tress (*Haveabra siliensis*), elephant grass (*Pennisetum purpureum*) and guinea grass (*Megathyrsus maximus*). The substratum is sandy and contains little organic materials. Human activities along this stretch of the river are washing of clothes and bathing.

Station 3

Station 3 is the downstream point (Lat. 6°54'27.4"N and Long. 5°56'13.3"E), it is surrounded by thick vegetation over of bamboo plants (*Bambusa vulgaris*) and grasses such as elephant grass (*Pennisetum purpureum*) and guinea grass (*Megathyrsus maximus*) Swimming, washing of clothes and kitchen utensils were collective activities observed. The substratum is composed of mainly of mud and decaying organic materials.

Station 4

This station is located upstream of the river at Uhonmora-Ora community (Lat. 6°52'50.6"N and Long. 5°56'21.3"E). Its bank is flanked by vegetation consisting of shrubs, trees, grasses and other plant, amongst which are guinea grass (*Megathyrsus maximus*) and cocoyam species (*Colocasia esculenta* "Red cocoyam" and *Xanthosoma sagittifolium* "White cocoyam"). The substratum is sandy with little decaying organic matter. Human activities along this stretch of are mainly swimming and washing of clothes.

Station 5

This station is located downstream of station 4 ("Lat. 6°52'40.9"N and Long. 5°56'24.1"E" midstream). The vegetation is made up of trees and grasses, which include mango trees (*Mangifera indica*), bush mango (*Irvingia gabonensis*), palm trees (*Elaeis guineensis*) and guinea grass (*Megathyrsus maximus*). Here the substratum is sandy and organic materials at varying stages of decomposition are present. Human activities along this stretch of the river are washing and swimming.

Station 6

Station 6 is the downstream point (Lat. 6°52'39.0"N and Long. 5°56'26.5"E), it is surrounded by thick vegetation comprised primarily of trees (*Elaeis guineensis*, *Mangifera indica* and *Irvingia gabonensis*), elephant grass (Pennisetum *purpureum*) and guinea grass (*Megathyrsus maximus*) and shrubs. Spiritual cleansing African Traditional Worship, bathing and washing are common on this stretch of the river. The substratum is composed of sand, mud and decaying organic materials.

Study duration

The collection of macroinvertebrates was carried out monthly at each sampling station for a duration of six (6) months - January to March 2023 (dry season) and April to June 2023 (rainy season).

Table 1: GPS Coordinates of Sample Stations selected for the study

Sabongidda-Ora Community		Uhonmora-Ora Community	
Station 1	Lat. 6°54'36.5"N, Long. 5°56'08.4"E	**Station 4**	Lat. 6°52'50.6"N, Long. 5°56'21.3"E
Station 2	Lat. 6°54'30.0"N, Long. 5°56'07.5"E	**Station 5**	Lat. 6°52'40.9"N, Long. 5°56'24.1"E
Station 3	Lat. 6°54'27.4"N, Long. 5°56'13.3"E	**Station 6**	Lat. 6°52'39.0"N, Long. 5°56'26.5"E

Collection of Benthic macroinvertebrates

Benthic macroinvertebrates were collected by kick sampling methods. The kick net used was1 x 1 meter square mesh net of 500 microns with a pole handle on each side. A composite sample comprising four samples were collected at each station to represent a lone sample (Arimoro and Muller 2010). The substrate was agitated, with the sampling moved gradually upstream. Collected samples were preserved in 10% formalin. Samples collected between 7 am and 11 am on each sampling day starting from station 1 and ending at station 6.

At the laboratory the samples were washed through a sieve of 1mm x 1mm mesh size to remove debris/sand and collect the benthos (Idowu and Ugwumba 2005). The organisms were sorted using the American Optical Dissecting Microscope (LB-570, Bausch and Lomb Optical Co.). The sorting was made effective by adding moderate volume of water into the container to improve visibility. Large benthos was hand-picked using forceps while the smaller ones were pipetted out. The organisms were sorted into their different groups and preserved in 4% formalin in labelled specimen bottles for identification and counting. Identification was done using relevant keys and the counted.

Data analysis

Benthic macroinvertebrates diversity was assessed with Margalef's index (species richness), Shannon-Wiener and Simpson's indices (species diversity) and Equitability index (evenness). These indices were estimated using PAST 3.18. The Duncan Multiple Range (DMR) test was utilized in testing for significant difference among the benthic macroinvertebrate population across the sample stations at $p < 0.05$.

Results

Benthic macroinvertebrate Fauna

The study showed that the taxonomic structure for the studied locations consisted of eleven (11) species distributed in nine (9) Families, seven (7) order and two (2) phyla with a total of 518 individuals (Tables 2 and 3). Observed benthic macroinvertebrates belonged to the Phyla Arthropoda (18.13%) and Mollusca (81.87%). The total number of taxa present in Stations 1, 2, 3, 4, 5 and 6 respectively, were 159, 111, 82, 28, 73 and 60 individuals (Table 3). It was observed that the order Diptera had the highest species diversity, with the benthic macro-invertebrate species *Pentaneura* sp, *Clinotanypus* sp and *Corynoneura* sp recorded.

Table 2: Checklist of Benthic macroinvertebrates from Owan River at Sabongidda-Ora and Uhonmora-Ora Communities (January to June, 2023)

KINGDOM:	**ANIMALIA**
Phylum	**Arthropoda**
Subphylum:	Crustacea
Class:	Malacostraca
Order:	Decapoda
Family:	Gecarcinidae
Genus:	Cardiosoma
Species	***Cardiosoma* sp**
Family:	Atyidae
Genus:	*Caridina*
Species:	***Caridina africana* (Kingsley 1883)**
Class:	Insecta
Order:	Trichoptera
Family:	Polycentropodidae
Genus:	*Polycentropus* (Curtis 1835)
Species	***Polycentropus* sp**
Family:	Hydropsyche
Genus:	*Hydropsychidae*
Species	***Hydropsychidae* sp**
Order:	Diptera
Family:	Chironomidae
Subfamily:	Tanypodinae
Species	***Pentaneura* sp**
Family:	Chironomidae
Species:	***Clinotanypus* sp**
Species:	***Corynoneura* sp**
Order:	Odonata
Suborder:	Anisoptera
Family:	Libellulidae
Species:	***Sympetrum* sp**
Phylum	**Mollusca**
Class	Gastropoda
Order	Caenogastropoda
Family	Potamididae
Genus	Tympanotamus
Species	***Tympanotamus fuscatus* (Linnaues 1758)**
Sub- class:	Heterobranchia
Order	Basommatophora
Family	Planoribidae
Genus	*Ferrisia* (Walker, 1903)
Species	***Ferrisia* sp**
Order	Neotaenioglossa
Family	Thiaridae
Genus	*Melanoides*
Species	***Melanoides tuberculatus***

Table 3: Composition, Distribution, and Relative Abundance of Benthic macroinvertebrates in Owan River.

	Taxa	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Number	Relative Abundance (%)
Arthropoda	*Cardiosoma* sp	8	-	9	-	-	-	17	3.31
	Polycentropus sp	-	11	5	-	-	-	16	3.12
	Hydropsychidae sp	7	-	5	-	-	-	12	2.34
	Pentaneura sp	-	10	3	-	-	-	13	2.53
	Caridina africana	-	-	-	1	1	6	8	1.56
	Clinotonypus sp.	-	-	-	3	-	4	7	1.37
	Corynoneura sp.	-	-	-	1	-	7	8	1.56
	Sympetrum sp.	-	-	-	5	2	5	12	2.34
Mollusca	*Tympanotamus fuscatus*	106	68	55	17	45	28	319	62.18
	Ferrisia sp	21	11	3	-	8	5	48	9.36
	Melanoides	17	11	2	1	17	5	53	10.33
Number of Species		**5**	**5**	**7**	**6**	**5**	**7**	**11**	**11**
Number of Individuals		**159**	**111**	**82**	**28**	**73**	**60**	**513**	**100**

Relative Abundance of Benthic Macro-invertebrates

The relative abundance of benthic macro-invertebrate was in the order Station 1 > Station 2 > Station 3, Station 5 > Station 6 > Station 4, with species abundance highest in Station 1 (159 individuals) and lowest at Station 4 (28 individuals) (Table 3). Spatial distribution of benthic macro-invertebrate composition indicated no significant difference between the two phyla across the sampled stations (Table 4). Figures 3 and 4 shows the spatial and temporal variations in the total faunal density for the benthic macro-invertebrates while the percentage abundance is shown in Figure 5.

Table 4: Spatial Distribution of Benthic macro-invertebrates Composition from Owan River

Taxa	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	P-Value
Arthropoda	15	21	22	10	3	22	$P > 0.05$
Mollusca	144	90	60	18	70	38	$p > 0.05$
Total	**159**	**111**	**82**	**28**	**73**	**60**	

Note: P > 0.05 = No Significant difference.

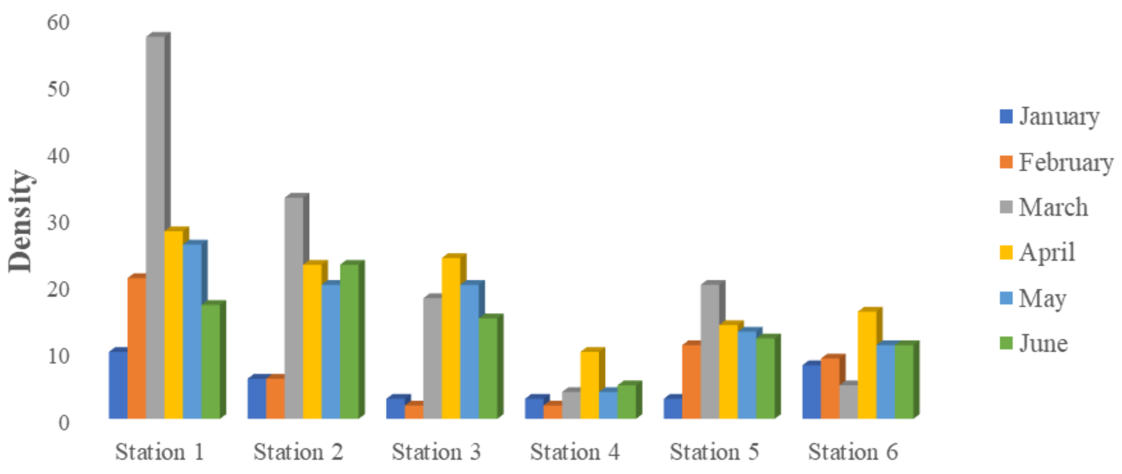

Figure 3: Spatial variations in the total faunal density of Benthic macroinvertebrates from Owan River

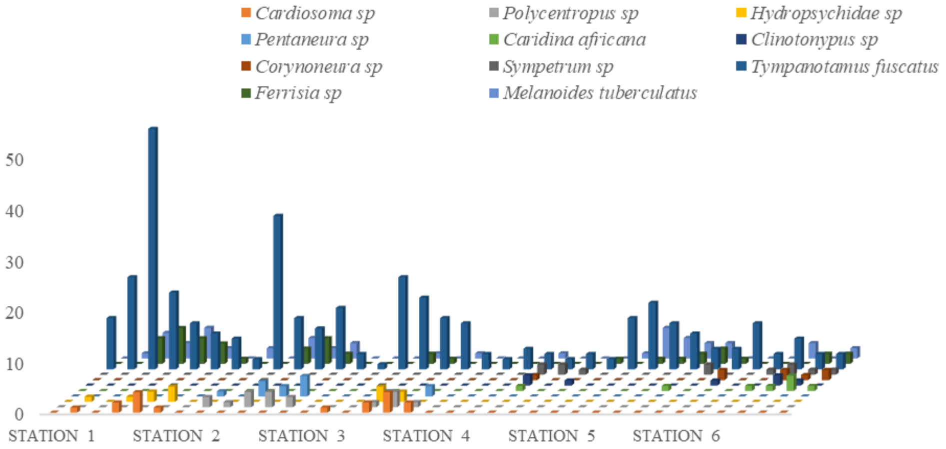

Figure 4: Temporal variations in total faunal density of Benthic macroinvertebrates from Owan River

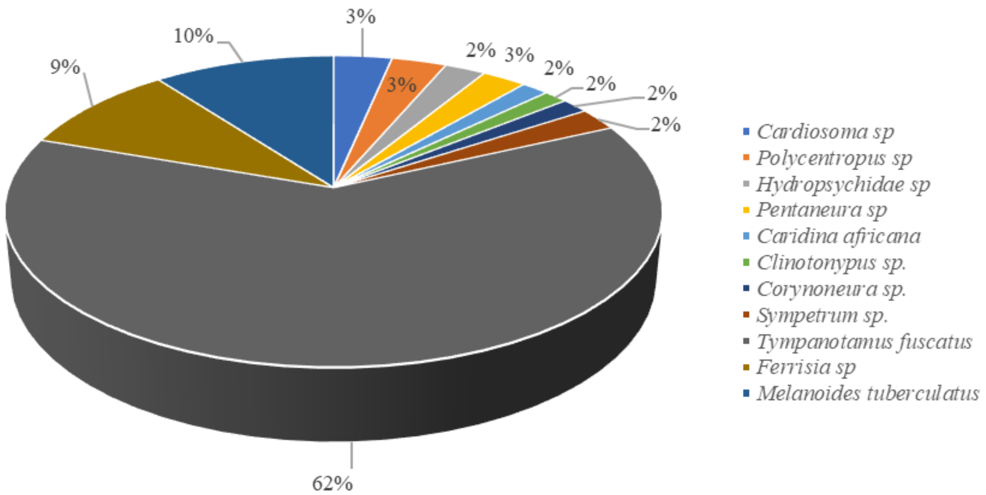

Figure 5: Percentage Abundance of Benthic macroinvertebrates from Owan River

Dominant and Sub-dominant Order of Benthic macroinvertebrates

The distribution of microbenthic invertebrate assemblages from the various stations showed that Caenogastropoda (62.18%), and Neotaenioglosa (10.33%) were dominant order, while Basommatophora (9.36%), Decapoda (4.87%), Diptera (5.46%), Odonata (2.34%) and Trichoptera (5.46%) were sub-dominant (Table 5

Table 5: Relative Percentage Composition of Taxonomic Groups Including the Dominant and Sub-Dominant Groups

Taxa	Number of individuals	Percentage Occurrence (%)
Caenogastropoda	319	62.18
Basommatophora	48	9.36
Decapoda	25	4.87
Diptera	28	5.46
Odonata	12	2.34
Neotaenioglosa	53	10.33
Trichoptera	28	5.46
Total	**513**	**100**

Diversity Indices

The abundance, number of taxa, Dominance, Shannon-Wiener, Simpson, Evenness and Margalef were estimated (Table 6). Station 1 had the highest abundance of individuals, while station 4 recorded the least values. Stations 2 and 6 had the highest Taxa with the least values observed for the other stations. The values for Dominance varied from 0.27 to 0.48, and were recorded in Stations 6 and 1 respectively. Shannon-Wiener diversity peaked at station 6 and recorded the least values at station 1, while Simpson was highest at station 2 and lowest at station 1. Evenness was highest at station 6 and lowest at station 3, with a range of 0.47 to 0.73, while Margalef values varied from 0.79 to 1.50, and peaked at station 4 with the least value recorded at station 1. Equitability was highest at station of 3 and lowest at station 6.

Table 6: Summary of the Diversity Indices of Benthic macroinvertebrates from Owan River

DIVERSITY INDICES	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6
Taxa_S	5	5	7	6	5	7
Individuals	159	112	82	28	77	60
Dominance_D	0.48	0.41	0.47	0.42	0.42	0.27
Shannon_H	1.07	1.21	1.18	1.21	1.09	1.64
Simpson_1-D	0.52	0.59	0.53	0.58	0.58	0.73
Evenness_e^H/S	0.58	0.67	0.47	0.56	0.59	0.73
Margalef	0.79	0.85	1.36	1.50	0.92	1.47

Discussion

The benthic macroinvertebrate fauna of the stretch of Owan River investigated was generally low (11 taxa), with common species often found in freshwater habitats of Western Africa. According to Neumann and Dudgeon (2002) decrease in benthic macroinvertebrate taxa especially group of sensitive benthic fauna in a water body, is reflective of poor water quality caused by anthropogenic activities within the watershed. In a similar study, lower benthic macroinvertebrate composition (7 taxa) was recorded at the stretch of Ikpoba River impacted by brewery effluents (Ibezute et al. 2016). Conversely, higher benthic macroinvertebrate taxa of 26 taxa (Udebuana et al. 2015), 132 taxa (Kaboré et al. 2016), 50 taxa (Ibemenuga et al. 2017), 18 taxa (Odigie and Olomukoro 2016), 39 taxa (Olomukoro et al. 2016), 23 taxa (Asibor and Adeniyi 2017), 26 taxa (Enwemiwe and Arimoro 2017), 45 taxa (Iyagbaye et al. 2017), 24 taxa (Usman and Adakole 2017), 17 taxa (Olaniyan et al. 2019), 17 taxa (Zahraddeen et al. 2019), 52 taxa (Motchié et al. 2020) and 13 taxa (Shreya et al. 2022) has been reported for various water bodies in their respective studies.

Hydrological parameters such as nutrients contents, pH, electric conductivity and substrate organic matter, which are mostly related to anthropogenic activities within a watershed are known to influence benthic community structure of aquatic ecosystem (Milesi et al. 2019). In this study, the distribution of benthic macroinvertebrates fauna decreased in the order Station 1 > Station 2 > Station 3, Station 5 > Station 6 > Station 4. The high abundance of macrobenthic invertebrates in station 1 can be attributed to the location's exposure to air, sunlight and abundance of organic debris which support the photosynthetic activity of aquatic plants and availability of food resources for macrobenthic invertebrates. According to Magbanua et al. (2015), air exposure and light availability to aquatic ecosystems determines photosynthetic rates and food availability for macrobenthic invertebrates which influences their community structure.

The presence and dominance of the phyla Arthropods and Mollusca recorded in this study, has been reported in similar studies to be present in lotic freshwater bodies in Nigeria (Olomukoro and Dirisu 2014; Adebayo et al. 2016; Asibor and Adeniyi 2017; Enwemiwe and Arimoro 2017; Iyagbaye et al. 2017; Keke et al. 2017; Usman and Adakole 2017; Aduwo and Adeniyi 2019; Olaniyan et al. 2019; Abbati et al. 2020; Mohammed et al. 2021), Côte d'Ivoire (Motchié et al. 2020), Kenya (Abongo et al. 2015), and India (Shreya et al. 2022). The dominance of Caenogastropoda (*Tympanotamus fuscatus*) can be attributed to the presence of grasses and the shallow nature of the littoral zone of the river, which the viviparidae can easily take shelter. Also, the dominance of relatively pollution sensitive and tolerant species such as *Tympanotamus fuscatus* is an indicator of a decline in water quality (Nkwoji et al. 2020). Also, the presence of Chironomids (*Pentaneura* sp. *Clinotanypus* sp. and *Corynoneura* sp.) are indicative of organic pollution of the river from surrounding anthropogenic activities (Adu and Oyeniyi 2019; Prat and Castro-López 2023). The presence of species such as *Caridina africana*, *Clinotanypus* sp, *Corynoneura* sp and *Sympetrum* sp recorded in this study have also been reported by Enwemiwe and Arimoro (2017) and Iyagbaye et al. (2017).

The enrichment of aquatic systems with discharges from anthropogenic activities influences the presence and abundance of macroinvertebrate species in them (Nelson et al. 2019; Duque et al. 2022). In this study, the estimates for Dominance (0.27 to 0.48), Shannon-Wiener (1.07 to 1.64), Evenness (0.47 to 0.73) and Margalef (0.79 to 1.50) indices were indicative of low species diversity and the dominance of a few species. The observed declines in the numerical composition of species, are often induced by environmental degradation due to anthropogenic pressures and various biotic factors (Bassey et al. 2020). According to Shanthala et al. (2009), the Shannon-Wiener diversity index is also indicative of the level of pollution of a water body. As the low species diversity index (1.07 – 1.64) in this study indicates that the stretch of Owan River is moderately polluted. The generally low abundance and diversity of benthic macroinvertebrates is study locations indicate an overall decline in the surface water quality and ecosystem health of Owan River.

The taxa composition and abundance of the benthic macroinvertebrates from this stretch of the Owan River could be referred to as poor, when compared to rivers of similar sizes in Southern Nigeria. This is indicative of the influence of anthropogenic activities within the watershed on the water quality and the benthic macroinvertebrate fauna, as shown by the low diversity recorded at sampled points. Also, the dominance of pollution tolerant species - *T. fuscatus* and *M. tuberculatus* and Shannon-Wiener diversity index values indicates that the river is moderately polluted. It is recommended that microbenthic studies be carried out on other stretches of Owan River to establish a better spatial species diversity and distribution of macroinvertebrates and identify non- pollution tolerant species for water quality monitoring. Also, there is need for an integrated management framework for the protection of the water body through the enforcement of riparian buffer zones to help to reduce some of the observed negative effects of agricultural activities on the river system especially in the wet seasons.

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