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Diatom Indices for Assessment of the Water Quality in the Lower Zab/ Kirkuk Governorate

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ABSTRACT

The current study was conducted to use phytoplankton diatom to assess the quality of the Lower Zab River in Kirkuk province. Water samples were monthly collected from four sites along the Lower Zab River from September 2023 to April 2024. The selected sites were Sadr River Bridge, Ashraya, Al-Shamit, and Al-Shak villages. A total of 74 species of Bacillariophyceae were identified belonging to 18 genera. Five indices were applied to estimate the ecological status in the Lower Zab River. Diatom species were used as ecological bio-indicators. This study utilized several indices, including the Palmer pollution index (PPI), the index of pollution sensitivity (IPS), the trophic diatom index (TDI), the diatomic index (DI), and the Shannon and Weaver index (H). The results indicated that the ecological status of the water suggested the possibility of high organic pollution, ranging from oligo-mesotrophic to eutrophic status, and that the Lower Zab River had a moderate water quality. Thus, a continuous monitoring is mandatory to safeguard the aquatic niche.

INTRODUCTION

One of the most significant issues facing humanity today is the pollution of freshwater supplies. One of the strongest defense strategies is to continuously monitor the state of aquatic ecosystems **(Ali *et al.*, 2017)**. Aquatic organisms are now commonly used as indicators of pollution in many parts of the world. They are included in environmental monitoring programs and helpful for understanding the intricate interactions between an organism's response to environmental signals **(Werner *et al.*, 2003)**.The various biological indicators of fish, macroinvertebrates, aquatic plants, and algae, particularly diatoms, can be utilized to assess the ecological state of the water body **(Torrisi*et al.*, 2010)**. Diatoms are an essential component of microorganisms in freshwater habitats, and their diversity contributes to species richness and increases the significance of these organisms for ecosystem function. Pollution and diversity indices can be used to evaluate the composition of the community and the degree of contamination in the research region **(Ali *et al.*, 2023)**.

The study aimed to evaluate the Lower Zab River quality using bioindicators, such as the quantity and quality of the phytoplankton diatom community, their biodiversity, and the nutritional state of the water.

MATERIALS AND METHODS

Description of the study area

The Lower Zab is one of the tributaries of the Tigris River. Its sources are located in northwestern Iran and extend for a distance of 402km into Iraq. Its origins are in the northwest of Iran, and it flows 402km into Iraq. It crosses through the administrative boundaries of the Erbil Sulaymaniyah and Kirkuk Governorates, and it is situated between two longitudes (43.39 and 46.26°) and two latitudes (35.16 and 36.79°). As the primary source of drinking water, agricultural irrigation, and domestic use, it is the most significant water resource in the Kirkuk Governorate **(Saeedrashed & Guven, 2013)**.Residential waste, whether it be solid waste in the form of discarded dirt by locals or liquid waste in the form of sewage, is visible from this river. The river is contaminated with these wastes as a result of the sewage water meeting at one point and spilling into it.

Study sites

Fig.(1) illustrates the selection of four sites along the Lower Zab River. The distances between the sites varied from 13 to 17km, with the first site at Sadr River Bridge, the second site at ShariatVillage, the third site at ShamitVillage, and the fourth site at Al-Shuk Village. A global position system (GPS) device was used to calculate the locations.

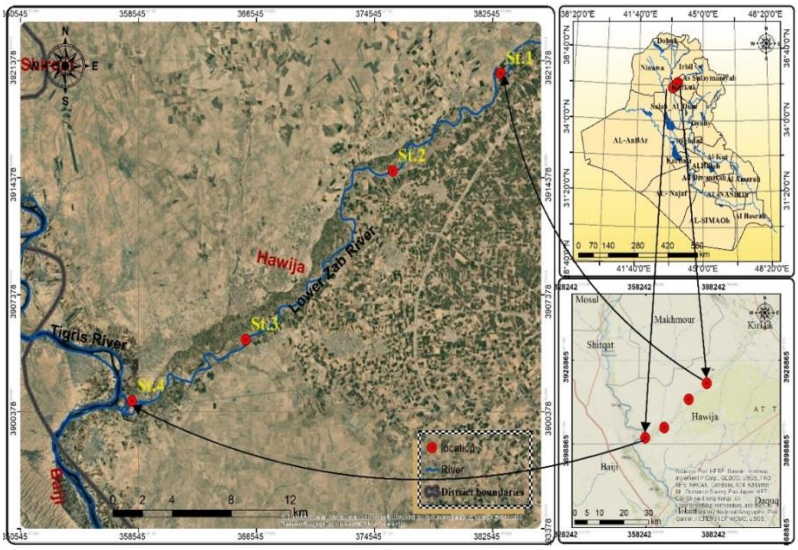

Fig. 1. Map of the present study region (with GPS coordinates)

Phytoplankton collection and identification

Samples of phytoplankton were collected from September 2023 to April 2024 using a phytoplankton net with a 20µm mesh. The samples were gathered and placed in plastic containers with 2-3 drops of Lugol's iodine solution added. The phytoplankton count was determined using the sedimentation method, as reported by **FuretandBenson- Evans (1982)**. Using the temporary and permanent preparations, phytoplankton was recognized and examined under an Olympus microscope 40X. The references used for algae diagnosis include **Taylor *et al.* (2007)**, **Lavoie and Hamilton (2008)**, **Saini *et al.* (2022)** and **Guiry and Guiry (2023)**.

Indices

Palmer pollution index (PPI)

This index was computed by **Bellinger and Sigee (2015)**. **Palmer (1969)** listed twenty genera of algae, with type numbers ranging from 1 to 5 based on the genera of organic pollution they contain. By adding all the points on the form mentioned above, we calculated the amount of organic pollution, as shown in Table (1).

Table 1. The value of Palmer pollution index

Level of pollution	**Palmer index score**
Organic pollution is high	Less than 15
The possibility of a high organic pollution	15-19
High organic pollution	20 or more

Pollution sensitivity index (IPS)

The IPS was calculated using the equation of **Prygiel and Coste (1993)** as follows:

$$IPS = (\sum AjSjVJ/AjVj \ \times 4.75) - 3.75$$

Aj = Abundance, or the percentage of the species in the specimen.
Sj = Sensitive feeders (1–5) of various kinds taken from private tables
Vj = Value type guide (1-3), taken from the private tables.

Table (2) provides a general guidance value for diatoms, which ranges from 4–20.

Table 2. Pollution sensitivity values index

Water Characteristics	**PSI score**
High	17- 20
Good	13-17
Moderate	9 – 13
Poor	5 -9
Bad	< 5

Trophic diatom index (TDI)

Based on 86 diatom species that were chosen for their indicator value-tolerance to inorganic nutrients, simplicity of identification served as the foundation for this index. According to **Kelly and Whitton (1995)**, the TDI was computed using this equation:

$$TDI = (\sum Aj\ SjVj\ /AjVj \times 25) - 25$$

Aj = Abundance or the percentage of the sample's species
Sj = Sensitivity of various feeder types (1-5)
Vj = Guide to value types (1-3)

The aquatic environment can be classified into five stages based on the diatom nutrient guidance value, which varies from 0 to 100 (Table 3).

Table 3. Pollution states' values index

States of pollution	Value
Oligotrophic	<35
Oligo-mesotrophic	35-50
Mesotrophic	50 – 60
Eutrophic	60 – 75
Hypertrophic	>75

Diatomic index (DI)

The formula below was used to calculate the DI **(Descy, 1979)**:

$$DI = \sum Aj\ SjVj\ /AjVj$$

The value ranges from guide diatoms (1–5), and the outcomes are shown in the Table (4), with a brief explanation.

Table 4. DI index explanatory values

Value	An explanation
> 4.5	Improved biological quality and lack of pollution in the water
4-4.5	The water's natural condition has returned, with minimal pollution and slight alterations in the diatom community
4-3	Shifts in diatom society's clarity, the absence of delicate species, and the average pollution
3-2	Predominant species are resistant, lacking or disappearing sensitive species, elevated levels of pollution.
2-1	Significant pollution, the domination of a remarkable species resilience, and the disappearance of several species.

Shannon and Weaver index (H')

The diversity index was calculated following the method of **Bellinger and Sigree (2015)** as follows:

$$\boldsymbol{H} = -\sum_{i=1}^{s} Pi\ Ln\ Pi$$

S= Total number of species.

Pi= Percentage of species i among a sample of N individual. A value >3 denotes a high diversity.

RESULTS AND DISCUSSION

In the Lower Zab River at the four sites of the current study, 74 species of Bacillariophyceae belonging to 18 genera were identified. The total central diatoms were 6 species belonging to 3 genera (8.11% of the total species), while pennate diatoms were 68 species belonging to 15 genera (91.89% of the total species). The number of species at sites 1,2,3, and 4 was 50,48,62 and 59 species. respectively.

The highest species number at site3 reached 62 species belonging to 15 genera, with 6 central diatoms belonging to 3 genera (9.67%), and 56 pinnate species belonging to 12 genera (90.33%) of the total of species. Whereas, the lowest diatom species at site2 recorded 48 species belonging to 12 genera, with 5 central diatoms belonging to 3 genera (10.42%) and 43 pinnate diatoms belonging to 9 genera (89.58%) (Table 5).

Table 5. The genera and species of diatom phytoplankton and their percentages at the studied sites

Sites	St.1		St.2		St.3		St.4		Total number	
Types of Diatoms	Central diatoms	Pinnate diatoms	Central diatoms	Pinnate diatoms	Central diatoms	Pinnate diatoms	Central diatoms	Pinnate diatoms	Central diatoms	Pinnate diatoms
Species	5	45	5	43	6	56	6	53	22	197
Genus	3	11	3	9	3	12	3	12	12	44
Percentage of Species %	10	90	10.42	89.58	9.67	90.33	10.16	89.84	40.25	359.75
Total number of Species	50		48		62		59		**219**	
Total number of Genus	14		12		15		15		**56**	

The results of the distribution of the number of phytoplankton diatom cells along the Lower Zab River at the study sites showed that the highest average total number recorded was 4863cells×10^3/l at site4, and the lowest average total number was 3669cells×10^3 /l at site2 (Table 6).

The highest value of Bacillariophyceae was recorded (5456 cells × 10^3/L) at site3 in September 2023, while the lowest value was (1986 cells × 10^3/l) at site2 in January 2024.The total number of central diatoms ranged between 300 cells × 10^3/l - 907 cells × 10^3/l in November and October at sites 1 and 4, respectively, whereas pennate diatoms ranged between 1986 cells × 10^3/l-4648 cells × 10^3/l in January and September at sites 1 and 3, respectively.

Table 6. Number and distribution of diatoms species at the study sites

Diatoms taxa	St.1	St.2	St.3	St.4
Division: Bacillariophycophyta **Class: Bacillariophycophyceae**				
Order: Centrales **Family: Aulacoseiraceae**				
Genus: Aulacoseiragranulata (Ehrenberg) Simonsen	52	57	150	148
Genus: A. granulata var. *angustissima* (O.Müller) Simonsen	20	-	30	77
Genus: A. ambigua (Grunow) Simonsen	65	97	126	171
***Family:* Stephanodiscaceae**				
Genus: Cyclotella meneghiniana Kützing (*Stephanocyclus meneghinianus* (Kützing) Kulikovskiy)*	175	183	186	178
Genus: C. ocellata Pantocsek (*Pantocsekiella ocellata* (Pantocsek) K.T.Kiss&Ács.)*	99	36	113	125
Family: Coscinodiscaceae				
Genus: Coscinodiscus sp.	-	4	15	19
Total number centrales (cell*10⁴/l)	411	377	620	718
Order: Pennales **Family: Fragilariaceae**				
Genus: Fragilaria biceps Ehrenberg	-	34	58	-
Genus: F. ulna (Nitzsch) Lange-Bertalot *(Ulnaria ulna* (Nitzsch) Compère)*	147	164	151	130
Genus: F. capucina Desmazières	-	-	28	37
Genus: F. crotonensis Kitton	36	49	80	76
Genus: F. brevistriata Grunow *(Pseudostaurosira brevistriata* (Grunow) D.M.Williams & Round*)**	90	2	18	-
Genus: Synedra acus Kützing *Genus: (Ulnaria acus* (Kützing) Aboal.)*	147	116	172	192
Family: Tabellariaceae				
Genus: Asterionella formosa Hassall	35	-	14	53
Genus: Diatoma vulgaris Bory	75	98	64	60
Family: Cymbellaceae				
Genus: Cymbella aspera (Ehrenberg) Cleve	108	121	60	101
Genus: C. cistula (Ehrenberg) O.Kirchner	71	104	133	158

Genus: C. tumida (Brébisson) Van Heurck	93	56	106	38
Genus: C. minuta Hilse	9	46	53	18
Genus: C. turgidula Grunow	4	-	63	-
Genus: C. amphicephala Näegeli ex Kützing	108	9	20	-
Family: Gomphonemataceae				
Genus: Gomphonema abbreviatum C.Agardh *(Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot)*	10	-	-	-
Genus: G. minutum (C.Agardh) C.Agardh	156	133	186	198
Genus: G. insigne W.Gregory	68	29	48	23
Genus: G. affine Kützing	132	75	156	128
Genus: G. truncatum Ehrenberg	54	-	26	15
Genus: G. olivaceum (Hornemann) Ehrenberg	62	118	121	64
Genus: G. parvulum Kützing	32	-	34	78
Genus: G. rhombicum Fricke *(Gomphoneis rhombica* (Fricke) Merino) *	67	107	57	85
Family: Achnanthaceae				
Genus: Achnanthes minutissima Kützing	14	-	-	-
Genus: A. coarctata (Brébisson ex W.Smith) Grunow	-	-	-	28
Genus: Achnanthes sp.	2	30	44	28
Family: Cocconeidaceae				
Genus: Cocconeis placentula Ehrenberg	114	122	154	-
Genus: C. pediculus Ehrenberg	15	18	69	96
Family: Eunotiaceae				
Genus: Eunotia sp.	-	-	-	22
Family: Rhopalodiaceae				
Genus: Epithemia adnata (Kützing) Brébisson	4	-	31	28
Family:Mastogloiaceae				
Mastogloia sp.	-	4	12	-
Family: Catenulaceae				
Genus: Amphora veneta Kützing (*Halamphora veneta* (Kützing) Levkov.)*	-	-	75	113
Genus: A. ovalis (Kützing) Kützing	-	-	-	99
Genus: A. copulata (Kützing) Schoeman & Archibald	-	-	25	49
Family: Pinnulariaceae				
Genus: Pinnularia gibba (Ehrenberg) Ehrenberg *(Epithemia gibba* (Ehrenberg) Kützing)*	7	-	19	-
Family: Naviculaceae				
Genus: Navicula capitatoradiata H.Germain ex Gasse	89	143	113	142
Genus: N. cryptocephala Kützing	-	61	35	116
Genus: N. cryptotenella Lange-Bertalot	132	-	185	164
Genus: N. radiosa Kützing (*N. tripunctata* (O.F.Müller) Bory.)*	159	167	91	179
Genus: N. gregaria Donkin	79	-	102	61
Genus: N. veneta Kützing	56	19	19	86
Genus: N. rostellata Kützing	6	83	113	175
Genus:N.capitata Ehrenberg *(Hippodonta capitata* (Ehrenberg) Lange-Bertalot)*	-	7	9	46
Genus: N. elginensis (W.Gregory) Ralfs *(Placoneis elginensis* (W.Gregory) E.J.Cox*)**	16	-		4
Genus: Navicula sp.	89	14	15	-
Genus: Gyrosigma acuminatum (Kützing) Rabenhorst	-	143	57	100
Genus: G. attenuatum (Kützing) Rabenhorst	132	128	52	75
Family: Bacillariaceae				
Genus: Nitzschia reversa W.Smith	158	155	91	135
Genus: Nitz. filiformis (W.Smith) Van Heurck	61	101	-	-
Genus: Nitz.intermedia Hantzsch ex Cleve & Grunow	13	60	26	24
Genus: Nitz. palea (Kützing) W.Smith	163	204	192	155
Genus: Nitz. sigma (Kützing) W.Smith	52	99	130	133
Genus: Nitz. sigmoidea (Nitzsch) W.Smith	73	-	58	59
Genus: Nitz. kurzeana Rabenhorst	20	30	-	-
Genus: Nitz. acicularis (Kützing) W.Smith	14	103	89	-
Genus: Nitz. linearis W.Smith	1	-	14	-
Genus: Nitz. gracilis Hantzsch	1	45	104	27
Genus: Nitz. dissipata (Kützing) Rabenhorst	9	91	40	154

Genus: Nitz. amphibia Grunow	26	12	37	24
Genus: Nitz. agnita Hustedt	158	5	9	5
Genus:Nitz. draveillensis Coste & Ricard	61	35	8	1
Genus:Nitz. umbonata (Ehrenberg) Lange-Bertalot	13	18	-	-
Genus: Nitz. obtusa W.Smith	163	134	-	-
Genus: Hantzschia amphioxys (Ehrenberg) Grunow	52	-	24	25
Family: Surirellaceae				
Genus: Surirella robusta Ehrenberg	117	-	99	81
Genus: S. ovalis Brébisson	-	-	97	98
Genus: S. capronii Brébisson & Kitton (*Iconella capronii* (Brébisson & Kitton) Ruck & Nakov)*	92	-	67	26
Genus:Cymatopleura solea (Brébisson) W.Smith (*Surirella librile* (Ehrenberg) Ehrenberg.)*	-	-	28	52
Genus: C. elliptica (Brébisson) W.Smith	5	-	11	81
Total number pennales (cell*10^3/l)	**3670**	**3292**	**3992**	**4145**
Total number (cell*10^3/l)	**4081**	**3669**	**4612**	**4863**

*** Current name, - absent**

The results revealed that some diatom species predominated in terms of both quantity and presence throughout the four sites in the Lower Zab River's waters such as *Aulacoseira granulata, Aula. ambigua, Cyclotella meneghiniana, Cyc. ocellata, Fragilaria ulna, F. crotonensis,Cocconeisplacentula,Synedra acus, Cymbella aspera, Cym. Tumida,Gomphonema minutum, Gom. affine , Navicula capitatoradiata, Nav. radiosa, Nitzschia palea , Nitz. sigma,* and *Surirella robuata.*

Numerous environmental studies of phytoplankton are compatible with the prevalence of diatoms in Iraqi waters **(Darweesh, 2017; Ali *et al*., 2019; Al Hassany, *et al.,* 2021, Ali *et al.,* 2023)**.This is because these species can withstand a variety of environmental conditions, including low nutrition levels and high temperatures. These species likewise favor living in alkaline waters with low salt concentrations, which led to the appearance of these species in the Lower Zab waters **(Al-Ganimy & Al-Rekabe, 2019)**. A variety of environmental factors also influence the temporal and spatial variation of phytoplankton, as the composition of the diatom community responds quickly to physical, chemical, and biological changes **(Ali *et al*., 2020; Alwan & Saeed, 2024)**. Due to their proximity and shared water source, the four study sites have a higher species frequency. This could be ascribed to the ability of diatoms to thrive and reproduce across a wide variety of environmental changes **(Merhoon *et al.*, 2020; Mahmood *et al.*, 2021)**.

The results showed the Palmer pollution values in the Lower Zab ranged between 13-19 at sites 2 and 3 in November 2023 and February 2024, respectively (Table 7& Fig. 2). According to Palmer's classification guide in Table (1), the study indicates that the water has a high possibility of organic pollution.

Table 7. The index's values used for diatoms at the study sites

	2023				2024				
Month / Indices	**September**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**Sites**
Palmer Pollution Index (PPI)	17	15	14	14	14	17	15	18	**St.1**
Index of Pollution Sensitivity (IPS)	4	4	4	5	3	4	4	3	
Trophic diatom index (TDI)	39	40	42	44	37	40	39	35	
Diatomic Index (DI)	1.56	1.63	1.68	1.74	1.48	1.59	1.56	1.39	
Shannon and Weaver Index (H)	3.42	**3.43**	3.23	3.03	3.18	3.16	3.34	3.37	
Palmer Pollution Index (PPI)	17	14	13	17	17	14	13	16	**St.2**
Index of Pollution Sensitivity (IPS)	5	5	3	14	16	16	17	5	
Trophic diatom index (TDI)	44	45	37	71	81	77	83	43	
Diatomic Index (DI)	1.77	1.83	1.50	3.8	4.2	4.1	4.3	1.73	
Shannon and Weaver Index (H)	3.40	3.38	3.12	3.34	3.23	**3.45**	3.29	3.38	
Palmer Pollution Index (PPI)	17	18	16	14	18	19	16	15	**St.3**
Index of Pollution Sensitivity (IPS)	6	15	4	4	4	13	4	4	
Trophic diatom index (TDI)	39	75	40	40	41	65	40	38	
Diatomic Index (DI)	1.7	3.9	1.6	1.6	1.6	3.6	1.6	1.5	
Shannon and Weaver Index (H)	3.66	3.45	3.56	3.38	3.59	3.61	**3.68**	3.52	
Palmer Pollution Index (PPI)	15	15	16	15	15	15	15	15	**St.4**
Index of Pollution Sensitivity (IPS)	4	5	4	4	4	4	4	4	
Trophic diatom index (TDI)	39	43	41	39	39	42	40	40	
Diatomic Index (DI)	1.6	1.7	1.6	1.56	1.56	1.6	1.6	1.6	
Shannon and Weaver Index (H)	3.53	3.53	3.58	3.65	3.56	3.72	3.55	3.47	

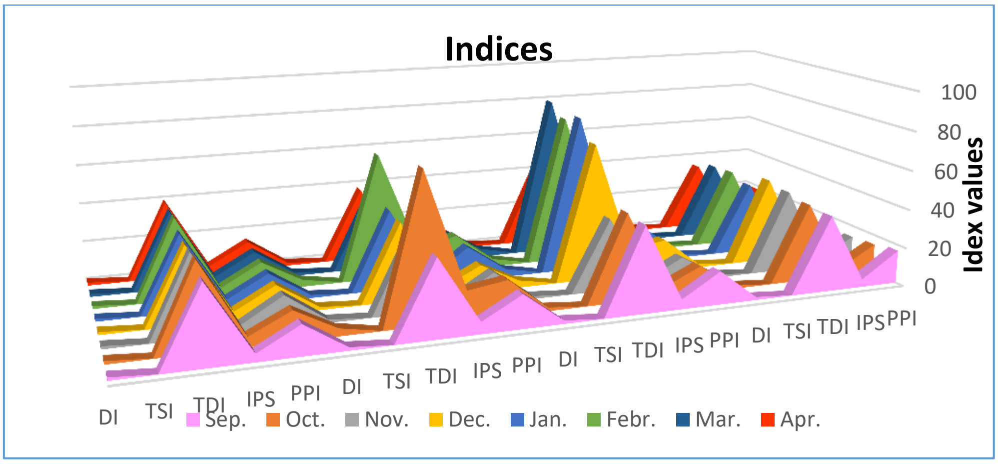

Fig. 2. Index values variations at the study sites

IPS index values ranged from 3 at site 1 in January 2023 and April 2024 and at site 2 in November, to 17 at site 2 in March 2024. During these values, the water quality of the lower Zab River ranged from bad to good.Certain diatom species exhibit sensitivity to changes in physical and chemical parameters that affect the water's surface so that they can be used to assess and determine the quality of the aquatic environment in which they live as bio-indictors **(Ali *et al.*, 2018; Najeeb & Saeed, 2022)**.

The results of TDI index values ranged from 35 at site 1 in April 2024 to 83 at site2 in March 2024. Based on the diatom index results and the comparison with the values in Table (3), the Lower Zab River of the study sites can be classified into Oligo- mesotrophic- Hypertrophic status. The diatomic index (DI) showed that the lowest value was 1.39 at site1 in April 2024, and the highest was 4.3 at site2 in March 2024. According to the classification of DI values in Table (4), the water in this study ranged from extremely polluted to good (low contamination). Resistance species predominate, and sensitive species are either extremely rare or have disappeared in large numbers.

Shannon index values in the lower Zab River were near one another, they ranged from3.03- 3.72at sites 1 and 4 in December 2023 and February 2024, respectively (Table 7& Fig.2).The highbiodiversity values maybe due to the presence of conditions, viz. temperature, water velocity, and nutrient availability that promote the growth of diatoms and increase vital compounds **(Merican *et al*., 2006)**. According to the Shannon diversity results, the lower Zab water exhibits a high biodiversity and slightly polluted water (Table 8).

Table 8. Shannon and Weaver Index scores and level of water contamination

Index scores	Level	Pollution level
0-1	Very less	Heavy
1-2	Less	Moderate
2-3	Moderate	Light
3-4.5	High	Slight

CONCLUSION

The results of the study demonstrated that the pinnate diatom species and abundance have surpassed those of central diatom species and abundance. This serves as an excellent quality indicator for the water. Pollution, trophic, and diversity indices classify the lower Zab River as moderately to highly polluted (Oligeo-mesotrophic) and the sensitivity of diatoms to pollution ranges from poor to good tolerance. As a result, the study's waters are categorized as having poor to moderate water quality.

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