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Assessment of surface water quality in Asir region (Saudi Arabia) using biological and trophic diatom indices

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Abstract: In the present study, the biological diatom index (BDI) and the trophic diatom index (TDI) were applied for the assessment of ecological status and water quality of surface and dug wells in Asir region, at the first time of Saudi Arabia. A total of 22 diatom species were identified and used to calculate the diatom indices. The species composition and distribution differed between surface and groundwater sites. Based on BDI and TDI values, the water quality of surface waters (dam reservoirs and streams) ranged between bad and moderate qualities and varied from poor to moderate for dug well water. These diatom indices were significantly correlated with most environmental variables, particularly nitrate and silicate concentrations in these water bodies. Thus, the BDI and TDI are useful metrics for trophic status and water quality assessment in this area and could be adequately applied in other tropical regions for water monitoring purpose.

Keywords: Biological index, Dam reservoirs, diatoms, Groundwater, streams.

1 Introduction

In spite of the arid nature of Saudi Arabia, some regions, particularly Asir region, contain permanent and semi-permanent rain-fed water bodies [**1**]. Once, water body is made, it turns into a virgin freshwater ecosystem. Consequently, the surrounding terrain as well as the original biota especially algae play a significant role in the further evolution and succession of the aquatic system [**2**]. Therefore, algae are the first organisms that participate in organic matter production in the aquatic environment, using biogenic compounds of nitrogen and phosphorus, and play an important role in self-purification of water [**3**]. The intensity of the nutrient load in aquatic environment is reflected by the abundance and species composition of algae developing under these conditions [**3**,**4**]. Thus, the features of algal community such as the abundance, biomass, and species composition, are used as bioindicator to determine water quality changes [**5**]. These bioindicators give an integrated measurement of water quality and ecological health and complement the physicochemical information [**6**,**7**,**8**]. The most developed system of bioindicators is based on diatoms being very sensitive to changes of environmental conditions [**9**]. Moreover, the quality and quantity of each diatom species and its combination reflect the status of water quality [**10**]. A variety of diatom indices are used in the assessment of water quality worldwide, including the most convenient ones: Biological Diatom Index (BDI) and trophic diatom index (TDI) [**7**,**11**,**12**]. Most of the widely used indexes come from the Zelinka and Marvan equation [**13**], which is:

$$\text{Index} = \Sigma\,(A_i v_i j_i)/A_i v_i$$

Where A is the relative abundance of species i, v is the indicator value of the species and j its sensitivity. The indexes differ in both diatom species and the values of v and j assigned for each index.

Although several studies have been carried out on the distribution of and ecology of diatom taxa in different regions in Saudi Arabia [**1**, **14**, **15**, **16**], no study concerning using diatoms to assess water quality has been conducted yet in Saudi Arabia. This prompted the first attempt to apply diatom indices (BDI and TDI) for the evaluation of water quality in surface and ground waters in Saudi Arabia.

2 Materials and Methods

2.1. Study area

Water bodies selected for this study are located within Asir region (18"-19‘N and 42"-43‘30E). The six surface water bodies include Dam reservoirs (assigned as S1, S4), and streams (assigned as S2, S3, S5, S6). The six groundwater bodies are dug wells and assigned as G1-G6 (Fig.1). Both surface and dug well waters in this region are used for spray and surface irrigation [**17**].

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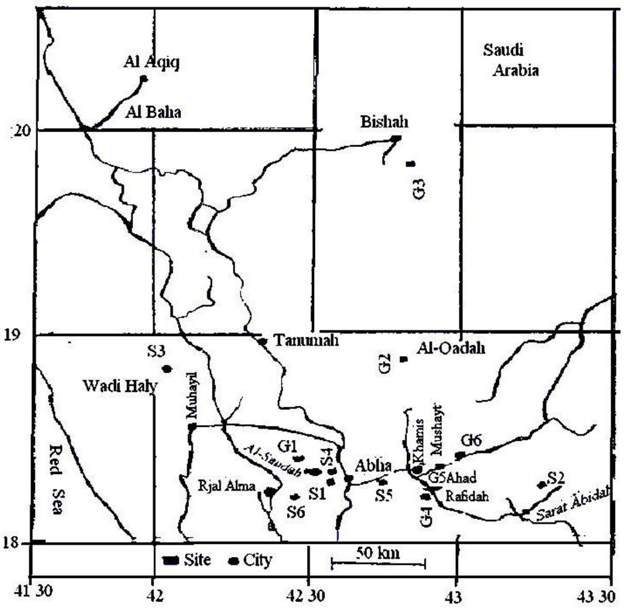

Fig. 1: Map showing locations of surface (S1-S6) and groundwater sites (G1-G6) in Asir region (■ Site , ● City).

2.2. Sampling and analysis

Water samples were collected in 500-ml polyethylene bottles in triplicate from each site during spring season. The samples of each site were mixed together and divided into two parts; one of them was preserved in Lugol's solution (1% final concentration) for diatoms identification and enumeration, while another part was filtered through GF/C filter paper and used for chemical analysis. In the laboratory, the diatom valves were cleaned with H_2SO_4 (98%) and HNO_3 (35%) and then washed several times with distilled water according to the method described by Gray and Vis [18]. An aliquot of 1 mL sample was settled and counted on the Sedgewick rafter counting chamber. Diatoms were identified according to Hustedt [19], John [20], Foged [21, 22], Hardley [23], and the floristic papers of Shahin [24] and Akbulut and Yildiz [25]. Physical parameters (temperature, pH, conductivity) were measured using mercury thermometer, pH-meter, and conductivity meter, respectively. Chemical analyses were carried out according to Standard methods APHA [26].

2.3. Estimation of diatom indices

Diatom composition and abundance in water samples were used to calculate the BDI and TDI indices. The BDI index was calculated by using the Calculate BDI-2006 with Excel spreadsheet adapted from [27]. The ecological status and the water quality were classified based on the BDI values according to the BDI values followed Szulc and Szulc [28], as shown in Table 1. The TDI was calculated using the following formula following the method adapted from Kelly et al. [29].

$$TDI = (WMS \times 25) - 25$$

Where, the Weighted mean sensitivity (WMS) value is calculated as:

$$TDI = (WMS \times 25) - 25$$

Where, the Weighted mean sensitivity (WMS) value is calculated as:

$$WMS = \frac{\sum_{j=1}^{n} aj\ vj\ sj}{\sum_{j=1}^{n} aj\ vj}$$

where: aj is abundance or density of valves of species j, vj and ij are indicator value and pollution sensitivity, respectively, obtaining from specific Tables in Kelly et al. [29]. The classification scheme of Kelly et al. [29] was also used to evaluate the ecological status (Table 1).

Table 1: Water quality ranking with the use of BDI and TDI (adapted from [29, 30]).

BDI score	TDI score	Water quality rank	Trophic status
>17	<20	High quality	Oligotrophy
15–17	21-40	Good quality	Oligo-mesotrophy
12–15	41-60	Moderate quality	Mesotrophy
9–12	61-80	Poor quality	Mesoeutrophy
<9	>80	Bad quality	Eutrophy

2.4. Statistical analysis

The relationships between physical and chemical parameters, and diatom indices, were established by calculating Pearson's correlation coefficients.

3 Results

3.1. Environmental variables

The physico-chemical variables determined for surface and dug well waters are presented in Table 2. These waters are slightly alkaline with pH values ranging from 7.7-8.3. Electrical conductivity did differ significantly between surface and ground waters. Concentrations of nutrient pollutants varied remarkably between surface and groundwater ($P < 0.05$). Nitrate concentrations were higher in groundwater (18.4 mg/L) than surface water (15.4 mg/L), while soluble phosphate and silicate concentrations were higher in most surface water sites (2.1 & 25.7 mg/L, respectively) than in ground waters (0.04 & 23.4 mg/L, respectively). Furthermore, the concentrations of these nutrients showed significant variation between different sites ($P < 0.05$).

3.2. Diatom assemblages

A total of 22 diatom species belonging to 14 genera, were identified in surface and ground water bodies during this study. All investigated species belonged only to Order Pennales (Table 3). The diatom composition and distribution were different between surface and ground water sites. Some species such as, *Diploneis ovalis*, *Epithemia sorex*, *Fragillaria crotonensis*, *Navicula minima*, *Navicula radiosa*, *Nitszchia hungarica*, *Meridion circulare*, *Pinnularia obscura*, and *Synedra ulna*, have frequently occurred in surface water sites, but they were rare in ground water sites. On the other hand, some species such as *Amphora ovalis*, *Navicula cryptocephala* and *Surirella angusta*, were frequently found in groundwater sites with rare occurrence in surface water sites.

Some species such as Epithemia adnata, Meridion circulare, Navicula minima, Navicula schoenfeldii, Pinnularia obscura, Rhopalodia gibba and Surirella angusta were frequently found in both fresh and groundwater sites (Fig. 2).

Table 2: Some physico-chemical parameters of surface and dug well waters of the studied sites in Asir region during the present study.

Sites	Temp. (^oC)	pH	Cond. (µs cm^{-1})	NO_3^- (mg/L)	NH_4^+ (mg/L)	PO_4^{-3} (mg/L)	SiO_2 (mg/L)
S1	26	8.1±0.1	698±35	13±1	5.7±0.7	2.1±0.2	18.3±2.1
S2	24	8.3±0.2	689±43	10±1	4.1±0.6	1.3±0.1	13.6±2
S3	25	7.9±0.1	668±45	10.1±2	1.5±0.4	1.5±0.3	14.3±1.7
S4	26	8.2±0.2	704±44	9.1±1.5	1.8±0.6	1.7±0.3	11.1±2
S5	24	8.3±0.2	681±23	15.4±2	2.6±0.3	1.2±0.2	25.7±3.5
S6	25	7.9±0.1	675±43	2.4±0.7	2.9±0.5	1.2±0.1	1.3±0.1
G1	20	7.7±0.2	687±33	12.3± 2.1	2.6±0.4	0.04±0.01	12.1±2.3
G2	18	7.9±0.2	671±43	18.8±2	2.3±0.2	0.03±0.01	19.2±3.1
G3	18	7.8±0.1	569±61	15.7±2	2.1±0.3	0.02±0.01	14.2±1.4
G4	20	8.1±0.1	587±34	8.7±1.5	1.8±0.4	0.03±0.01	9.6±1.5
G5	19	8±0.1	597±52	12.4±2.3	1.9±0.3	0.04±0.01	13.4±2.1
G6	18	8.1±0.2	636±34	9.1±2	1.2±0.2	0.04±0.01	10.6±2.2

Each value is the mean of three readings ±SD. S = surface water site, G = groundwater site.

Table 3: List of diatom species identified in surface and groundwater sites in Asir region

Species	Surface water sites						Dug well water sites					
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**
Amphora ovalis (Kutz) Kutz	3.1	7.8	0	5.7	0	0	0	18.9	10.5	0	12.4	0
Cymbella lanceolata Agardh	0	0	2.6	0	3	1.5	0	0	4.6	14.8	11	0
Cymbella ventricosa Agardh	21	0	31.2	0	15.2	0	13.5	0	0	0	11.7	0
Diploneis ovalis (Hilse) Cleve	2	2.3	0	0	0	0	0	0	0	19.8	0	26.8
Epithemia adnata (Kutz) Breb	1.2	1.9	5.5	12	2.1	1.9	0	13.6	15.5	21.2	9.7	11.2
Epithemia sorex Kutz	3	1.5	0	1	0	0	0	0	10	11.6	0	0
Fragilaria crotonensis Kitton	1.3	0	0	1.5	0	0.7	0	12.4	0	0	0	11.1
Fragilaria pinnata Eher	0	13	11	2	0	1.7	0	0	9.3	0	0	6.7
Gomphonema angustatum Rab	0	1.6	1.3	1	2.3	0	21	0	3	0	0	8.9
Gomphonema parvulum Kutz	30	28.5	19	31.2	35.6	0	2.6	0	2.7	0	0	2.1
Meridion circulare (Grev) Agardh	1.4	12	2.6	11.2	14.5	0	4.8	17.8	0	6.8	2.8	0
Navicula cryptocephala Kutz	0	5.8	0	9.8	0	42.2	0	12.5	4.6	0	0	3.7
Navicula minima Grunow	17.3	3.2	3.5	3	6.4	26.7	11	8	7.9	3.4	5.9	2.6
Navicula radiosa Kuz	3	0	1.9	1.3	0	0	22.5	0	0	2.1	0	1.6
Navicula schoenfeldii Hustedt	6.5	5	4.2	1.5	3.1	0	6.9	9.6	6	1.8	8.3	2.9
Nitzschia amphibia Grun	0	0	12.8	13.8	15.2	0	0	0	0	1.4	0	1.8
Nitzschia hungarica Grun	2	10	0	0	0	6	0	0	1.5	0	5.2	0
Nitzschia palea (Kutz) W. Smith	0	4.3	0	2.1	0	13.6	0	4.5	0	3.7	3.4	0
Pinnularia obscura Krasske	1	1.5	1.7	1	1	1.6	0	1.2	2.2	2.5	1.2	2.8
Rhopalodia gibba Eher	4	1.6	0.7	0	0.6	0.6	17.7	0	19.2	8.8	21.2	8.7
Surirella angusta Kutz	3.2	0	0.9	0.5	1	1.8	0	1.5	1.3	2.1	5.7	2.8
Synedra ulna (Nitzsch.) Eher	0	0	1.1	1.4	0	1.7	0	0	1.7	0	1.5	6.3
Total No. of species	15	15	15	17	12	12	8	10	15	13	13	15

*Each value is the mean of three readings ±SD. S = surface water site, G = groundwater site

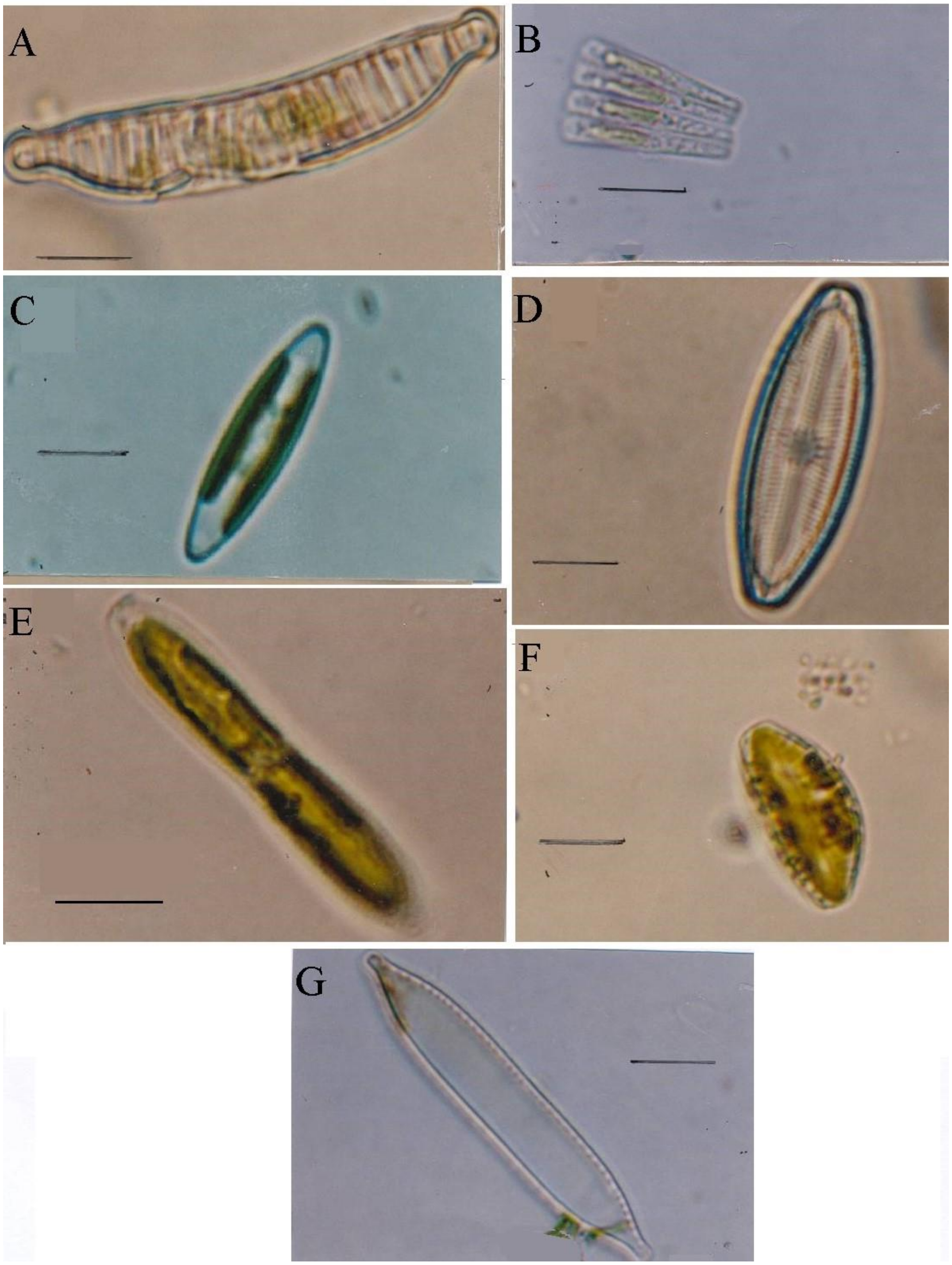

Fig. 2: Light microscope photographs of Diatom species that were frequently found in both surface and groundwater sites: A. *Epithemia adnata,* B. *Meridion circulare,* C. *Navicula minima,*D. *Navicula schoenfeldii,*E. *Pinnularia obscura,* F. *Rhopalodia gibba* and G. *Surirella angusta.* (each scale bar = 10 µm).

3.3. Diatom indices and water quality

The values of the BDI and TDI indices calculated for each site, with correspondent judgement and class of water quality are presented in Tables 4 and 5. The BDI and TDI indices were clearly different between surface water sites and groundwater sites ($p<0.05$). Surface water exhibited lower BDI values (1.9-10.4) and higher TDI values (42.5 -77.8), indicating poor water quality with mesotrophic to eutrophic status. Groundwater had moderate BDIs (10.1-13.1) and low TDIs (22-44.8), indicating moderate water quality with oligotrophic to mesotrophic status.

Table 4. Biological diatom index (BDI) values for surface and Dug well waters in Asir region, with correspondent trophic status and water quality

Sites	BDI	Trophic status	Water quality
S1	7.7	Eutrophy	Bad quality
S2	2.6	Eutrophy	Bad quality
S2	6	Eutrophy	Bad quality
S4	2.4	Eutrophy	Bad quality
S5	1.9	Eutrophy	Bad quality
S6	10.4	Mesoeutrophy	Poor quality
G1	12.6	Mesotrophy	Moderate quality
G2	10.1	Mesoeutrophy	Poor quality
G3	10.3	Mesoeutrophy	Poor quality
G4	12	Mesoeutrophy	Poor quality
G5	13.1	Mesotrophy	Poor quality
G6	12.5	Mesotrophy	Poor quality

S = surface water site, G = groundwater site

Moreover, Both BDI and TDI indices showed significant correlations with some physico-chemical parameters of surface and groundwater (Tables 6, 7). In surface water sites, BDI negatively correlated with pH (r= -0.8, P <0.05), nitrate (r= -0.6, P <0.05), and silicate (r= -0.6., P <0.05), while TDI had positive correlations with these parameters (r= 0.4, 0.9, 0.9, P <0.05, respectively). In groundwater sites, BDI had negative correlations with nitrate (r =-0.8, P<0.05) and silicate (r=-0.7, P<0.05), but TDI showed positive correlations with nitrate (r=0.6, P<0.05) and silicate (r=-0.7, P<0.05). BDI was negatively correlated with TDI (r= -0.6, P<0.05) in both surface and dug well waters.

Table 5: Trophic diatom index (TDI) values for surface and Dug well waters in Asir region, with correspondent trophic status and water quality

Sites	TDI	Trophic status	Water quality
S1	75.1	Mesoeutrophy	Poor quality
S2	67.3	Mesoeutrophy	Poor quality
S2	75.1	Mesoeutrophy	Poor quality
S4	66.3	Mesoeutrophy	Poor quality
S5	77.8	Mesoeutrophy	Poor quality
S6	42.5	Mesotrophy	Moderate quality
G1	24.5	Oligo-mesotrophy	Good quality
G2	37	Oligo-mesotrophy	Good quality
G3	30.8	Oligo-mesotrophy	Good quality
G4	14.8	Oligotrophy	high quality
G5	44.8	Mesotrophy	Moderate quality
G6	22	Oligo-mesotrophy	Good quality

S = surface water site, G = groundwater site

Table 6: Spearman correlations between diatom indices (BDI and TDI) and some physical–chemical properties of surface waters in Asir region.

	Temp.	pH	Cond.	NO3-	NH4+	PO4-3	SiO2	TDI	BDI
Temp.	1								
pH	-0.3656	1							
Cond.	0.519976	0.57163	1						
NO3-	-0.16776	0.617037	0.24649	1					
NH4+	0.114053	0.229338	0.410501	0.221192	1				
PO4-3	0.825501	-0.06191	0.619097	0.294399	0.474376	1			
SiO2	-0.27444	0.600668	0.133425	0.987821	0.170101	0.167583	1		
TDI	-0.06182	0.449652	0.173373	0.943432	0.087938	0.384485	0.907088	1	
BDI	0.363259	-0.84006	-0.35135	-0.62311	0.254134	0.14664	-0.60773	-0.5993	1

Table 7: Spearman correlations between diatom indices (BDI and TDI) and some physical–chemical properties of dug well waters in Asir region.

	Temp.	pH	Cond.	NO3-	NH4+	PO4-3	SiO2	TDI	BDI
Temp.	1								
pH	-0.08305	1							
Cond.	0.095671	-0.38145	1						
NO3-	-0.5119	-0.56697	0.225129	1					
NH4+	0.332498	-0.86039	0.409564	0.603602	1				
PO4-3	0.332182	0.2	0.522254	-0.47756	-0.18741	1			
SiO2	-0.54465	-0.39447	0.312289	0.964876	0.492512	-0.32133	1		
TDI	-0.40428	-0.2194	0.005544	0.634026	0.259732	0.05838	0.690101	1	
BDI	0.557731	0.297053	0.062822	-0.76922	-0.30146	0.845954	-0.69049	-0.10374	1

4 Discussion

Diatom species react distinctly to varying physical and chemical parameters. They are sensitive to change in nutrient concentrations, and each taxon has a specific optimum and tolerance for a certain nutrient [7]. In our study, although nutrient concentrations, particularly, nitrate, phosphate and silicate are relatively high compared to those obtained elsewhere in freshwater streams and reservoirs in Saudi Arabia [1,15,31], low number of diatom species were recognized in the twelve sites studied. This is in agreement with previous studies reporting low number of diatom species in freshwater bodies in Saudi Arabia. Khoja [31] identified 11 species of diatoms in irrigation and drainage network of Al-Hassa Oases. Al-Homaidan [15] recorded 14 diatom species in reservoirs in southwestern Saudi Arabia. Al-Homaidan and Arif [16] recorded only two diatom species in semi-permanent rain-fed pool at Al-Kharj. However, other studies recorded 41 species of diatoms in streams in Asir mountains [1]. Interestingly, no species of centric diatoms was observed during the present study. These results are thus in agreement with previous studies, which did not record any species of centric diatoms in Saudi Arabia [1,15,16]. The scarcity of centric diatoms is not only restricted to Saudi Arabia environment, but also it was observed in other countries such as Turkey. Shahin [24] identified only one centric species of a total of 53 diatoms surveyed in Dagbasi lake, Rize. Shahin [32] also recorded only one centric species of a total of 29 diatom species investigated in lakes Aygir and Balikli, Trabzon. What is noteworthy here in the present study is the presence of the same diatom species in both surface and ground waters. This may be due to the transfer of these species by the wind from the same source" soil" or by water-wind flows from surface water to groundwater wells. In this respect, Dubovik [33] reported that there are no barriers for algae to migrate by wind and water-wind flows, which move them over long distances and as a result, they can settle on various substrates, reservoirs and groundwater wells.

Although physico-chemical data give basic and very important information on the quality of water bodies, they do not provide all the information required in pollution assessment of any water body [34]. Therefore, water quality classification combined with diatom species can give a more accurate assessment of water quality than measurement of physico-chemical parameters alone [35]. The use of biological indicators, such as diatom indices could achieve a more realistic approach for water quality assessment.

Standardized diatom indices such as BDI and TDI were developed and applied for monitoring water quality in many countries including France [36], Euro [37], China [38], and Africa [39]. In this study, the BDI and TDI were applied for the first time on water quality assessment in Saudi Arabia. In our study, the trophic diatom index (TDI) showed that surface water bodies (streams and Dam reservoirs) were in mesotrophic to eutrophic state (i.e., moderate to bad water quality) (Table, 2, Table 5). However, the biological diatom index (IBD) showed that these water bodies were mesoeutrophic to eutrophic (i.e., poor to bad water quality). On the other hand, the trophic status of groundwater sites varied from oligo-mesotrophy to mesotrophy based on TDI values, indicating good to moderate water quality (Tables 4,5). Based on BDI metric, these groundwater wells exhibited mesotophic to mesoeutrophic status (i.e., moderate to poor water quality). Our results also showed that BDI and TDI values in both surface water and groundwater sites correlated with nitrate and silicate concentrations. These results corroborate previous studies reporting that silica plays an important role in the ecology of aquatic systems as it is an essential element for diatom existence comprising 26–69% of its cellular dry weight [86, 87]. Other studies also revealed association between nitrate concentrations and Diatom indices, being one of the nutrients that favor the growth of diatoms [11]. The presence of significant correlations between BDI and TDI, and selected physico-chemical variables, particularly nutrients suggests that these indices could be suitable for assessment of water quality [40]. Therefore, our results agree with earlier studies that diatom assemblages could be used to assess human impacts on streams and other water bodies in rural and urban areas [30, 41].

What is noteworthy that biological diatom index sensitivity to environmental stressors is a result of the weight of each species, obtained through the previous evaluation of the occurrence and frequency of these species in specific environments equally classified previously [7,11,36]. Species with high relative abundance and significance for the estimation of BDI and TDI in our study, were recorded with relatively high trophic values in other water bodies worldwide [42, 43, 44, 45,46]

5 Conclusions

In this study, the diatom metrics of BDI and TDI were applied to assess the water quality and the ecological status of surface and groundwaters in Asir region, Saudi Arabia. Results indicated that the quality of surface waters (dam reservoirs and streams) ranged between bad and moderate qualities, and it varied from poor to moderate for groundwaters. These diatom indices were highly correlated with nitrate and silicate concentrations in these water bodies. Thus, the BDI and TDI are useful metrics for assessing the trophic status and water quality of water bodies and could be adequately applied in other regions for water monitoring purpose.

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