Influence of Environmental Variables and Different Hosting Substrates on Diatom Assemblages in the Shatt Al-Arab River, Southern Iraq

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Abstract: The relationship between diatom species, environmental variables and different substrates in Shatt Al-Arab river was studied during the period from December 2012 to November 2013 in seven stations along the course of the Shatt Al-Arab river. A total of 193 taxa belonging to 70 genera were identified. Diatom assemblages in the Shatt Al-Arab river included freshwater forms (28%), brackish water forms (11%) and marine forms (34%). The results of multivariate analysis (PCA) showed four components, the first included most of species which are further divided into two groups, the first group encompassed marine species with strong correlation with turbidity, alkalinity, EC and salinity, whereas the second group included species which have strong correlation with nutrients. Both PCA and CCA analysis showed most of the diatom species having strong correlation with plankton and plant host substrates, but few species preferred the mud and solid substrates.

Keywords: Diatoms, environmental variables, substrates, Shatt Al-Arab river.

INTRODUCTION

Diatoms are one of the most important groups of microalgae in the freshwater environment. They serve as potential bioindicators for water quality (Harding et al., 2005; Leelahakriengkrai & Peerapornpisal, 2010; Bere, 2014). The diatoms have been widely used to infer past limnological and oceanographical conditions. Based on their variable ecological preferences, they were successfully used to monitor different marine and freshwater aquatic systems, including several aspects like hydrologic and climatic changes in saline lakes, acidity of surface water, lake eutrophication, long-term environmental changes, water level change in freshwater lakes, coastal paleoenvironment indicators and relative sea level changes, environmental changes in brackish waters, estuaries and shallow coastal, marine paleoceanography, environmental changes at both Arctic and Antarctic regions, in addition to other applications like forensic science, archeology, exploration of oil and gas in different regions and atmospheric transport markers (Smol & Stoermer, 2010).

Every species of diatoms requires different kinds of physical, chemical and structural features for its habitat. When these features are subject to minor changes due to natural or human activities, correlated diatom communities respond quickly and mostly change in both biomass and taxonomic structure (Lavoie et al., 2008; Bere & Tundisi, 2009). Most pollution monitoring programs in freshwater ecosystems include routine checking of diatoms water

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quality indicators (Taylor et al. 2007c; Lavoie et al. 2008; Bere & Tundisi, 2011).

In Many developing countries, diatom based monitoring programs are applied using diatom indices modeled in European or other western ecosystems which might not be applicable accurately in these countries (Pipp, 2002; Bere et al., 2014). Such situation calls for investigations to find diatom models suitable for each environment, e.g. in tropical and subtropical regions.

Investigations on using diatoms as bioindicators to assess water quality in aquatic ecosystems of Iraq are rather rare. The study of diatoms in relation to their tolerance to organic pollution (saprobity) has been pioneered by Al-Handal & Abdullah (1994). Eassa (2012) may have been the first to use diatoms indices for the assessment of water quality in Shatt al-Arab river, followed by Al-Saboonchi et al. (2012) who applied P-IBI for the assessment of water quality at Chebaish marsh. Recently, Al-Ankush (2013) carried out a study to monitor Shatt Al-Arab river's water quality by models prepared for benthic diatom assemblages.

The present study is aiming at investigating the relation of diatoms distribution to changes in aquatic parameters, both physical and chemical and also to explore the relationship between diatom assemblages and the different natural substrates inhabited by diatoms taxa using direct observations and statistical analysis.

MATERIALS AND METHODS

Study area

Seven stations were selected along the course of Shatt Al-Arab river (Fig. 1). Station 1 (Al-Mohamadiyah, N: 30 36.623, E: 47 45.662) lies about 14 km north of Basrah city center. Samples were collected from the eastern bank of this site which is muddy and supports dense growth of some aquatic plants such as *Phragmites australis* (Cav.) Trib. Ex Steud., *Typha domingensis* Pres. and *Schoenoplectus litoralis* (Schrad) Palla.

Station 2 is located at Al-Maqal area (N: 30 33.755, E: 47 47.563), south of Al-Sendibad island, opposite to Al-Maqal port. Sampling was carried out in the eastern muddy bank which was covered by many species of aquatic plants, the most common of these were *Phragmites australis*, *Typha domingensis*, *Schoenoplectus litoralis*, *Ceratophyllum demersum*, *Myriophyllum spicotum*, *Potamogeton crispus*, *Potamogeton perfolitus* and *Vallisneria spiralis*.

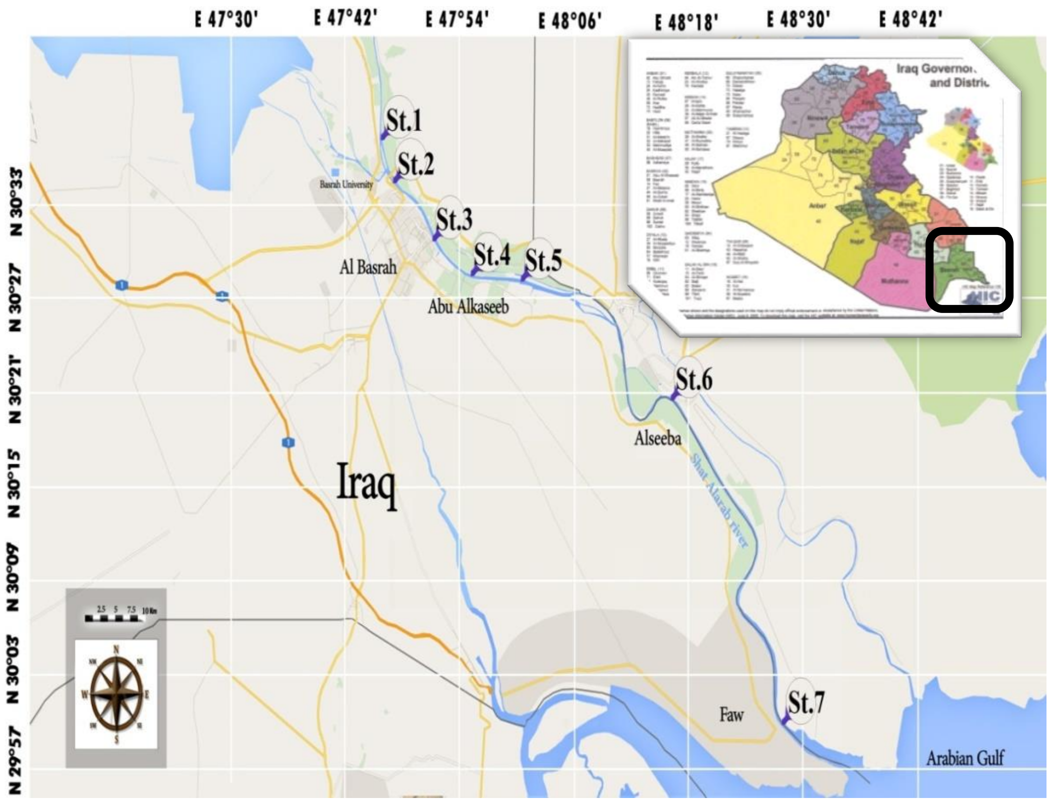

Figure 1: Map showing location of study sites at Shatt Al-Arab river.

Station 3 is located at Al-Bradhiyah village (N: 30 30.376, E: 47 51.328), opposite to a drinking water treatment plant, at the southern part of Basrah city center. Samples were obtained from the western bank which was sandy to muddy with few aquatic plants such as *Phragmites australis*, *Ceratophyllum demersum* and *Vallisneria spiralis*.

Station 4 was at Mehellah village (N: 30 28.476, E: 47 55.343), Abu Al-Khaseeb district, in front of a drinking water treatment plant. Samples were taken from the western bank. Sediments were mostly muddy with some macrophytes prevailing such as *Phragmites australis*, *Ceratophyllum demersum*, *Vallisneria spiralis* and *Schoenoplectus litoralis*.

Station 5 was at Abu Flous village (N: 30 27.251, E: 48 02.810). Both banks of the river were muddy with few macrophytes and less human activities. In some parts of the western narrow tidal flat, sand and cobbles cover the sediment which is remnants of old military constructions. Few macrophytes can be seen such as *Schoenoplectus litoralis*, *Ceratophyllum demersum* and *Vallisneria spiralis*.

Station 6 was at Al-Seebah village (N: 30 20.240, E: 48 16.145). The region suffers sever pollution coming from Abadan oil refinery which lies on the eastern bank. Turbidity increases considerably when Karun river (20 km to the north) discharges. Sea water front reaches this station during high tide. Samples were obtained from the western side which was muddy with only two macrophytes growings, *Cyperus laevigatus* and *Enteromorpha* sp.

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Station 7 was at Al-Faw town (N: 29 59.240, E: 48 27.360), in front of small oil port. Sea water effect was very clear. Karun river discharge reaches the station during low tide. Tidal flat expands to 50 m during low tide and sediments were almost silty. Aquatic macrophytes disappear except for scattered *Enteromorpha* sp. but the salt tolerant plant *Salicornia herbacea* was widely distributed.

Samples collection

Samples for various analyses were collected monthly from December 2012 to November 2013 during lower level of low tide from all stations. Sampling from stations 1, 2, 3, 4 and 5 were collected on the same day starting from station 5 up to station 1, while samples from the rest of stations (6 and 7) were obtained on another day of the same week. Tides period was estimated using a Tidal Prediction Program (Total Tide) version 1,0,11,0 (United Kingdom Hydrographic Office, UK).

Sampling and measurements of environmental parameters

For chemical analysis, water samples were collected approximately from the middle of the river by immersing and filling a 2 L polyethylene bottles from15-30 cm depth. All samples were kept in a cool box. Analyses were done immediately upon return to laboratory. For dissolved oxygen determination, Winkler bottles were filled with water and fixed directly by adding 2 ml of each of manganese sulfate solution, alkaline iodide azid solution and concentrated sulfuric acid and then analysis was completed in the laboratory.

Some physical and chemical parameters were measured in situ. These included air and water temperatures, light transparency, salinity, electrical conductivity, turbidity and hydrogen ion concentration (pH) using different instruments. Reactive Nitrite (NO_2), nitrate (NO_3), reactive phosphate (PO_4) and reactive silicate (SiO_3) were measured according to Strickland & Parson (1972), Lind (1979) and APHA (1999, 2005).

Diatoms sampling, cleaning and slides preparation

Planktonic diatoms at all stations were collected monthly using Wildco Phytoplankton net with 20 µm mesh size, 20 cm mouth diameter and 90 cm long (Wildco Supply Company, USA).The net was hauled behind a motor boat running at its lowest speed for 15 minutes. Samples were kept in plastic bottles, marked and fixed by adding 4% formalin.

Benthic diatoms were also collected monthly following the methods described by Kelly et al. (2001) and Taylor et al. (2007a). Epipelic diatoms were collected by randomly scrapping the top 0.5 cm of mud and silt at each station. Sandy sediment was only found at stations 3 and 5. Sediment were kept in plastic containers and left in icebox until return to laboratory. Epilthic diatoms are not merely inhabiting submerged rocks but also on any hard surface such as bricks, stones, cobbles, wood and iron. Samples were obtained from all of these substrates randomly. Diatoms were removed from hard surface by brushing or scarping using stiff tooth brush or sharp tools and rinsed by distilled water in a clean plastic tray, then all samples were preserved in 4% formalin in marked plastic container. At least, five shoots of emergent aquatic macrophytes were collected. The attached diatoms were removed by vigorous shaking of plant shoots inside plastic containers and then rinsed with distilled water. Resulting suspension poured into marked plastic container and preserved with formalin.

Diatoms were cleaned for microscopic examination using the hot H_2O_2 technique as described by Taylor et al. (2007a) and Al-Handal & Wulff (2008). Ten ml of diatoms suspension was boiled in 20 ml of 35% H_2O_2 for 30-60 minutes or until the suspension becomes clear. Diatoms suspension was then left to cool in room temperature then washed with distilled water through filtering with No.1 Whatman filter paper. The clean diatom material was transferred to glass vials, marked and kept until use.

Permanent diatom slides were made by drying 1 ml of the cleaned diatoms suspension on a cover slip at room temperature and then inverted on a microscope slide containing 0.5 ml of Naphrax® (Brunel microscope Ltd, UK). The slide was placed on a hotplate and heated for about 150 ^{o}C for few seconds to remove all air bubbles. Examination and imaging of diatoms were done using Zeiss Axiophot 2 imaging microscope (Carl Zeiss AB), at the Department of Marine Biology, Marine Science Center, University of Basrah.

For identification of diatoms species, several publications were consulted including Patrick & Reimer (1966), Hustedt (1930, 1985), Desikachary (1988-1989), Krammer & Lange-Bertalot (1986, 1988, 1991), Lange-Bertalot (1996, 2013), Witkowski et al. (2000), Taylor et al. (2007b), Al-Handal (2009) and Al-Kandari et al. (2009).

Statistical analysis

XLSTAT pro v.4 software was used for multivariate statistical method to analyze Principal Component Analysis (PCA) and Canonical Correspondence Analysis (CCA) to elucidate the correlation between diatom species and both environmental variables and type of substrate. Statistica v.6 package was applied to elucidate cluster analysis (CA). All environmental parameters were standardized (z-scale) before PCA and CCA were analyzed (Fan et al., 2010). According to Liu et al. (2003) and Ahmed et al. (2005), components loading values are classified as the followings: strong (>0.75), moderate (0.75-0.50) and weak (0.50-0.30).

RESULTS

Changes in all environmental parameters measured in the present study are shown in Table 1. In total, 193 diatoms taxa belonging to 70 genera were identified. Diatom assemblages in the Shatt Al-Arab river included freshwater forms (28%), brackish water forms (11%) and marine forms (34%). 27% of the encountered taxa were of uncertain ecological preferences. Freshwater species dominated at stations 1, 2, 3 and 5, and both freshwater and marine species were in equal percentage at station 4, while other stations towards the lower reaches of the river (stations 6 and 7) were dominated by marine species.

Table 1: Values of environmental parameters measured at all stations during the present study.

Parameters	Values
Air temperature	11.5-44 ^{o}C
Water temperature	13.3-33.4 ^{o}C
Secchi disc	10-51 cm
Turbidity	8.38-536 NTU
pH	7.40-8.54
Salinity	0.8-32 psu
EC	1.57-51.4 ms/cm
Dissolved oxygen	3.1-10.7 mg/l
Total alkalinity	97-190 mg/l
Reactive nitrite	0.492-12.442 µg/l
Nitrate	0.047-3.871 mg/l
Reactive phosphate	0.32-7.968 µg /l
Reactive silicate	35.564-234.207 µg/l

Periphytic species constituted about 80.3% of all encountered diatoms and most of them were epiphytic. In contrast, 19.7% were planktonic species. Most of epiphytic diatom taxa were found on *Potamogeton australis* (79 species) at station 1 while the lowest number was recorded on *Salicornia herbacea* and *Enteromorpha* sp. at station 7. However, other substrates such as rocks, wood, metal and sand have less attached diatom taxa particularly on sandy places (stations 3 and 5).

Centric diatoms constituted ca. 21% of the total taxa (19 genera), the rest (79%) were pennate diatoms belonging to 51 genera. *Nitzschia* was the most common genus with 31 species and was found almost at all stations. Higher numbers of diatom taxa were recorded in December 2012 at all stations particularly at stations 1 and 6. On the other hand, the lower species numbers for all stations were observed in July and August 2013, and the lowest one was recorded at station 1 in August 2013.

The correlation between species composition and environmental parameters was studied using PCA. According to eigenvalue-one criterion, four components were considered and explained 91.78% of the total variance. To make interpretation of PCA results, the data matrix was reduced and only the principal components with eigenvalue greater than one (>1) were selected. The results are shown in Fig. 2.

The PCA ordination in Fig. 2 exhibited 39 species of diatoms (Table 2) having different correlation with the measured environmental parameters. The first two components are 18.05 and 7.63, respectively. Both of them explain 65.88% of total variance, whereas the first and the third components explained 62.39% of the total variance.

The first component (PC1) accounted for 46.3% of the total variance. This component has two groups of diatom species, the first includes *Coscinodiscus asteromphalus*, *Coscinodiscopsis jonesiana*, *Cyclotella straita*, *C. stylorum*, *Gyrosigma scalproides*, *Navicula* sp. 1, *Nitzschia* cf. *prolongata*, *N. sigma*, *Pleurosigma elongatum,* *Thalassiosira eccentrica* and *T. spinosa* which have strong positive correlation with turbidity, alkalinity, salinity and EC, respectively. The second group includes *Cocconeis placentula* var. *euglypta*, *Nitzschia* sp. 3, *Pleurosira indica*, *P. laevis*, *P. inusitata*, *Tabularia tabulata*, *Tabularia* sp. and *Thalassiosira* sp. which have strong positive loading on Secchi disc, nitrate, phosphate and silicate, whereas *Bacillaria paxillifer*, *Caloneis permagna* and *Tabularia fasciculata* have moderate positive loading on the same later parameters. On the other hand, species of the first group have strong to moderate negative correlation with Secchi disc, nitrate, phosphate and silicate, while species of the second group have strong to moderate negative correlation with turbidity, alkalinity, salinity and EC.

The second component (PC2) explained 19.57% of the total variance and includes *Entomoneis alata*, *E. paladosa*, *Gyrosigma sinensis*, *Navicula* sp. 4, *Nitzschia clausii*, *Nitzschia kurzeana*, *Surirella fluminensis*, *S. striatula* and *Ulnaria ulna*. These species did not exhibit obvious correlation with any of the measured environmental parameters.

The third component (PC3) explained 16.08% of the total variance. This component has two groups of diatom species. Group 1 includes only *Luticola nivalis* which has strong positive correlation with nitrite only, while *Sieminskia wohlenbergii* and *Stephanodiscus* sp. 2 possessed moderate positive loading on nitrite. The second group includes *Gyrosigma attenuatum* which has moderate positive correlation with pH and DO. On the other hand, the species of the first group has a strong negative correlation with pH and DO, whereas the second species group has moderate negative loading on nitrite.

Finally, PC4 explained 9.82% of the total variance. This component also includes two groups of species; the first includes *Navicula digitoradiata* and *Achnanthes brevipes* var. *intermedia* which had strong and moderate negative correlation with water temperature. The second group includes *Cyclotella meneghiniana* which has moderate positive correlation with the same parameters.

The correlation between diatom species and substrates were analyzed using CCA and PCA. PCA was performed to elucidate the correlation between all species and their substrates, whereas CCA was used to elucidate the relationship between diatom species in reduced data (>0.05) and substrates among all stations. Several and different substrates were reduced and divided into four types, N: plankton, P: plants (aquatic plants and macroalgae), M: mud and S: hard substrates (rocks, wood, metal).

The PCA first component (D1) explained 48.04% of the total variance, the second component (D2) explained 29.77% of the total variance and after varimax rotation and both of them explained 77.81% of the total variance. The correlation between all species and the substrates is shown in Fig. 3. The diatom species were distributed among the substrates but mostly concentrated around the plankton and plant hosts, the rest are distributed in few numbers around the mud and solid submerged substrates.

Table 2: Abbreviated codes of diatom species used in the statistical analysis

Species	Abbreviated code	Species	Abbreviated code
Achnanthes brevipes var. *intermedia*	ACHBREINT	*Navicula digitoradiata*	NAVDIG
Bacillaria paxillifer	BALPAX	*Navicula* sp. 1	NAVSP. 1
Caloneis permagna	CALPER	*Navicula* sp. 4	NAVSP. 4
Cocconeis placentula var. *euglypta*	COCEUG	*Nitzschia clausii*	NITCLA
Coscinodiscus asteromphalus	COSAST	*Nitzschia sigma*	NITSIG
Coscinodiscopsis jonesiana	COSJON	*Nitzschia* sp. 3	NITSP. 3
Nitzschia cf. *prolongata*	NITPRO	*Pleurosigma elongatum*	PLEELO
Nitzschia kurzeana	NITKUR	*Pleurosira laevis*	PLULAE
Pleurosira indica	PLUIND	*Sieminskia wohlenbergii*	SIEWOH
Pleurosira inusitata	PLUINU	*Sieminskia zeta*	SIEZET
Surirella fluminensis	SURFLU	*Stephanodiscus* sp. 2	STEPSP. 2
Cyclotella meneghiniana	CYCMEN	*Surirella striatula*	SURSTR
Cyclotella straita	CYCSTR	*Tabularia fasciculata*	TABFAS
Cyclotella stylorum	CYCSTY	*Tabularia* sp.	TABSP
Entomoneis alata	ENTALA	*Tabularia tabulata*	TABTAB
Entomoneis paladosa	ENTPAL	*Thalassiosira spinosa*	THALSP. 1
Gyrosigma attenuatum	GYRATT	*Thalassiosira eccentrica*	THALECC
Gyrosigma scalproides	GYRSCA	*Thalassiosira* sp.	THALSP.
Gyrosigma sinensis	GYRSIN	*Ulnaria ulna*	ULNULN
Luticola nivalis	LUTNIV		

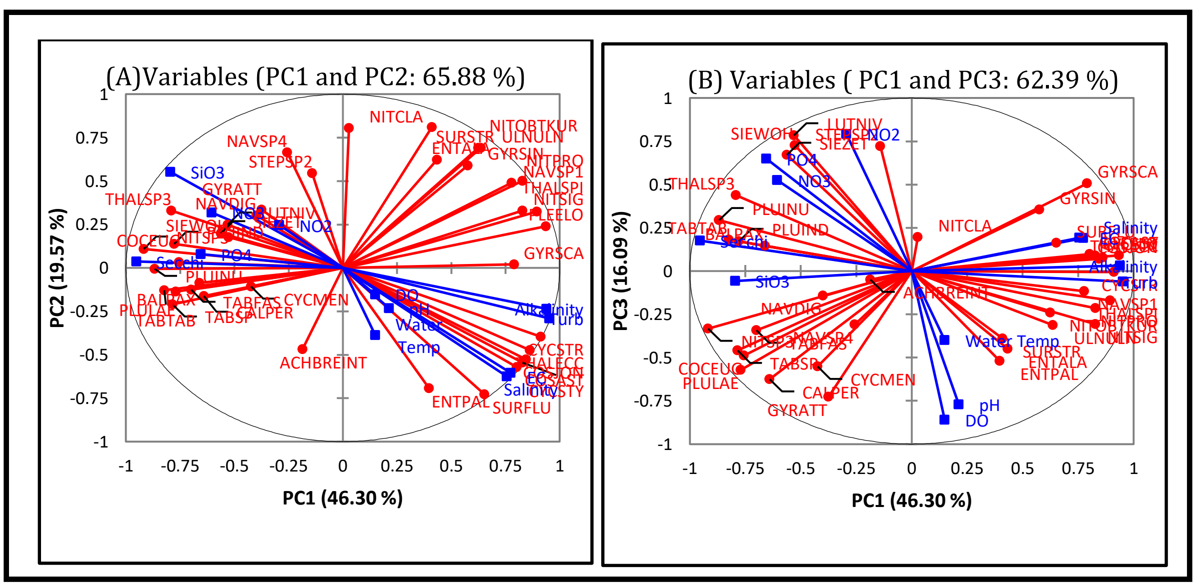

Figure 2: PCA ordination diagram of correlation between diatom species with environmental parameters, (A) - PC1 and PC2, (B) - PC1 and PC3.

Most of the species which have significant positive correlation with the plankton were centric and planktonic forms such as *Coscinodiscopsis jonesiana*, *Coscinodiscus asteromphalus*, *Cyclotella stylorum*, *Chaetoceros affinis*, *C. curvisetus*, *Hemiaulus* cf. *sinensis*, *Odontella* cf. *sinensis*, *Eucampia zodiacus*, *Rhizosolenia setigera*, *Thalassiosira spinosa* and *T. eccentrica*, but there are also many benthic species found here such as *Tryblionella apiculata*, *Trachyneis debyi*, *Entomoneis paladosa*, *Epithemia adnata*, *Surirella robusta*, *Gyrosigma attenuatum* and many other species belonging to some genera such as *Nitzchia* and *Gyrosigma*. These species are not truly planktonic and not tychopelagic taxa but most likely brought to water surface by certain turbulence.

Most of the species which have significant positive correlation with plant hosts were epiphytic as well as periphytic forms. However, few species have significant positive correlation with both mud and hard substrates, most of these belong to *Navicula* and *Nitzschia* whose most species are epipelic and periphytic forms. Figure 3 also shows several species which are epipelic and epilithic forms such as *Gyrosigma scalproides*, *G. sinensis*, *Luticola nivalis*, *Diploneis smithii* and *Cymbella cymbiformis*, in addition to an episammic diatom; *Pleurosigma delicatulum*.

The first component of the CCA analysis (PC1) explained 43.48% of the total variance, while the second component (PC2) explained 28.3% of the total variance and both of them explains 62.85% of total variance.

As is evident in Fig. 4, there is a correlation between 28 diatom species (reduced data) and substrates at all stations. Most of the species have significant positive correlation with stations 1, 2 and 4, and these are epiphytic and epipelic forms such as *Caloneis permagna*, *Cocconeis pediculus*, *C. placentula*, *C. placentula* var. *euglypta, Tabularia tabulata*, *Tabularia* sp., *Entomoneis alata*, *Nitzschia capitellata*, *Thalassiosira* sp. The epilithic and episammic species are found at stations 3 and 5 and have positive correlation with its substrate such as *C. placentula*, *C. placentula* var. *euglypta*, *Luticola nivalis* and *L. ventricosa*, as well as the epipelic species *G. sinensis*.

Station 6 exhibited few species which have significant positive correlation with different habitats such as *Entomoneis alata*, *Surirella striatula*, *Campylodiscus* cf. *bicostatus*, *Navicula schroeterii* and *Navicula* sp. 4. Finally, only planktonic and epipelic species have been found at station 7, the most common of which were *Coscinodiscopsis jonesiana*, *Coscinodiscus asteromphalus*, *Gyrosigma scalproides*, *Entomoneis paladosa*, *E. alata*, *Navicula* sp. 1 and *Nitzschia* cf. *prolongata*.

Three species of the genus *Cocconeis* appeared in Fig. 4, *C. placentula* var. *euglypta* has positive correlation with the plankton, mud and plants substrates but exhibited negative correlation with hard substrates, whereas *C. placentula* has also positive correlation with the plankton and mud but had negative correlation with plants and hard substrates, the same results were observed for *C. pediculus*.

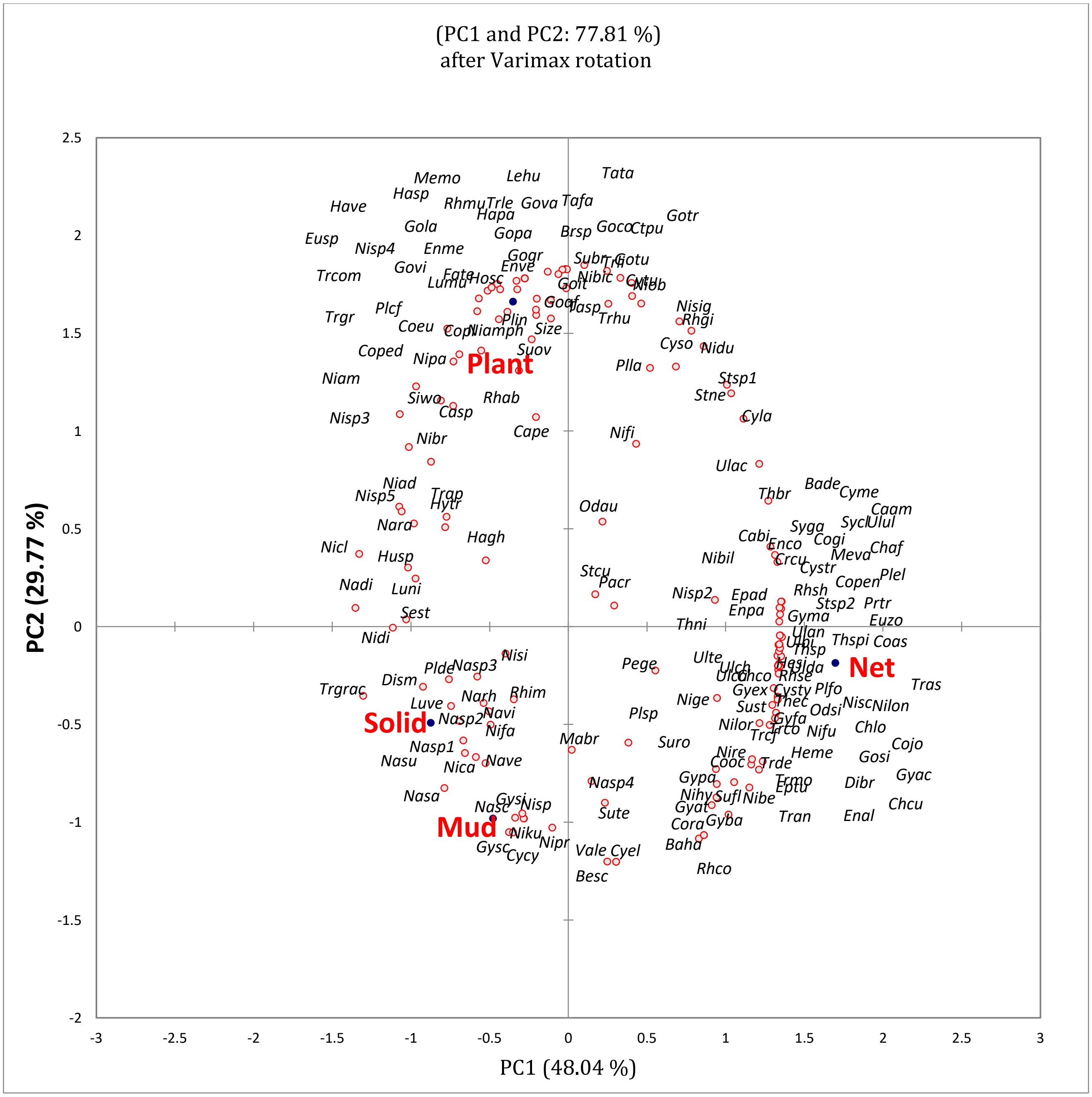

Figure 3: PCA ordination diagram showing the correlation between all diatom species and substrates.

However, *Caloneis permagna* and *Entomoneis alata* have positive relationship with all substrate except for hard ones. *Cymatopleura solea* has positive correlation with the plankton and plants. On the other hand, *Gyrosigma scalproides*, *G. sinensis*, *Navicula digitoradiata*, *N. schroeterii*, *Navicula* sp. 1, *Navicula* sp. 4, *Nitzschia capitellata*, *N. kurzeana* and *N.* cf. *prolongata* have positive correlation with mud substrates, while *Coscinodiscopsis jonesiana*, *Coscinodiscus asteromphalus*, *Cyclotella menghiniana*, *Thalassiosira* sp. and *Stephanodiscus* sp. 2 have positive relationship with the plankton. Positive correlation was also recorded for *Tabularia tabulata* and *Tabularia* sp. with plant host. Finally, positive relationship was noticed for *Luticola nivalis* and *L. ventricosa* with hard substrates.

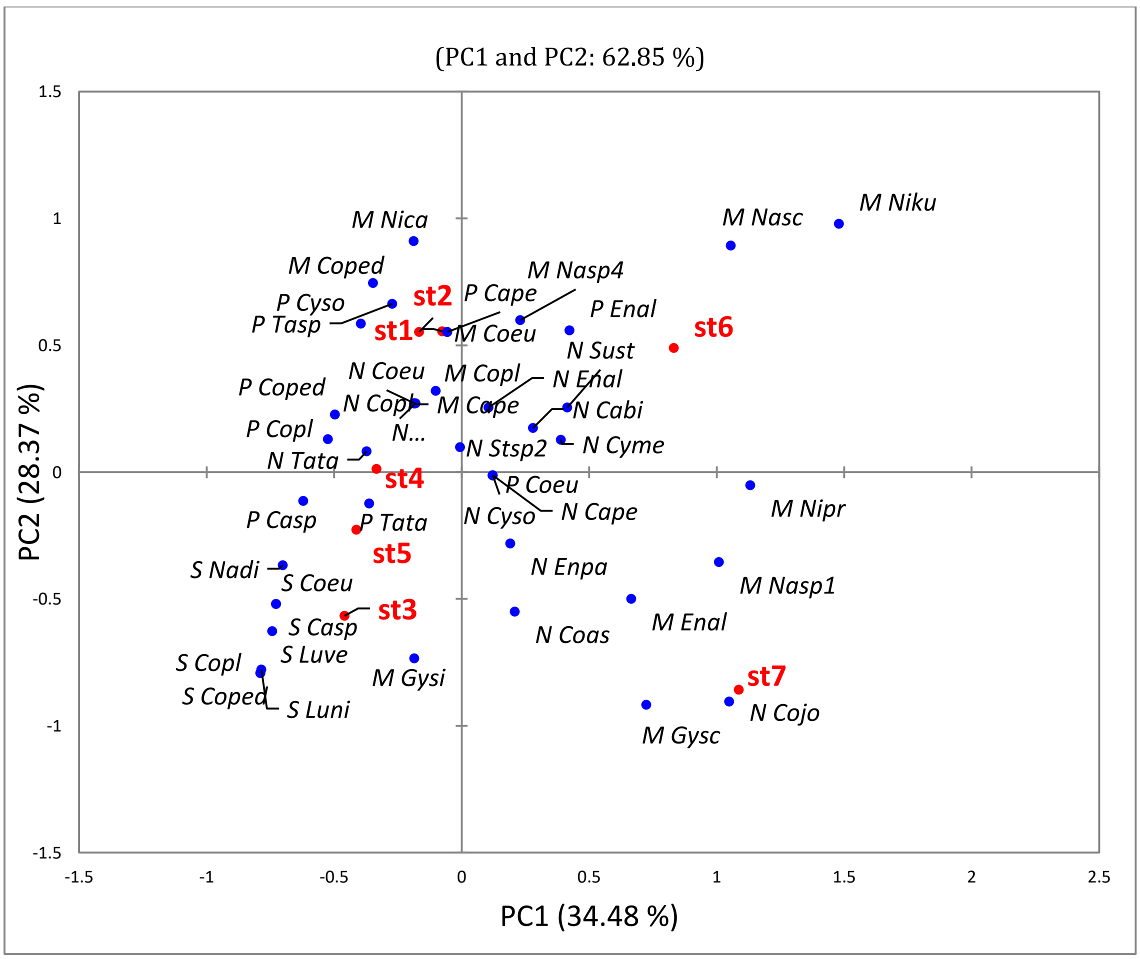

Figure 4: CCA ordination diagram showing the correlation between diatom species (reduced) and substrates among study stations.

DISCUSSION

It is rather difficult to observe a clear relationship between several environmental variables and diatom species directly by using raw data listed in tables only. However, different multivariate statistical approaches were used to extract useful information; one of them is the principal component analysis (PCA) which is a useful technique for reducing large number of variables and recognizing a set of dimensions which cannot be simply detected within a large set of variables (Legndre & Legendre, 1979). This technique makes it easier to elucidate the structure of the observed data with obvious feature by extracting the hidden information. This is done by transmuting the original variables (in the present study it is represented by environmental parameters and relative abundance of diatom species) into new variables (axes). These are termed the principal components (PCs) which represent the linear combinations of the original variables (Fan et al., 2010).

With the exception of *Navicula* sp. 1, all other diatom species of the first group in PC1 were truly marine to brackish forms (Fig. 2). This may explain their strong correlation with salinity and EC parameters, *Cyclotella straita*, *Nitzschia sigma* and *Pleurosigma elongatum* are mesohalobous, and *Cyclotella stylorum* is polyhalobous (Klobe, 1927). In addition, all species in this group (with few exceptions) were common or frequent at stations 6 and 7 which are close to the north eastern parts of the Gulf. Although the environmental preference of *Navicula* sp. 1 is unknown, it was common at stations 6 and 7 and also frequent at the other stations. This may indicate it's brackish to marine preference, a reason behind its positive correlation with salinity and EC.

However, the positive relationship of some species such as *Cyclotella straita* and *Nitzschia sigma* with alkalinity may belong to their preference of alkaline water, a finding coinciding with Hustedt (1937-1938) who classified *Nitzschia sigma* as alkalibiontic (occurring only in alkaline water, pH above 7) and *Cyclotella straita* as alkaliphilous (occurring at pH around 7 with broad distribution over 7). About half of the species in this group were epipelic and periphytic. T his may elucidate their correlation with turbidity especially at stations 5, 6 and 7 where they were frequent to common and also the highest level of turbidity was recorded at these stations.

The diatom species of the second group in PC1 were having significant positive relationship with nutrients (NO_3, PO_4 and SiO_3). This relationship may be referred to their tolerance to organic pollution. According to Harding et al. (2004), species such as *Bacillaria paxillifer* may indicate poor water quality. However, saprobian spectrum which is proposed by Kolkwitz & Mason (1908) classified *Bacillaria paxillifer* and *Cocconeis placentula* var. *euglypta* as oligosaprobic, occurring in waters with complete oxidation of organic compounds and high concentrations of inorganic nutrients, a situation observed in the present study and some other works in the region where dissolved oxygen and inorganic nutrients were high (Moyel, 2010; Al-Bidhani, 2014; Al-Hejuje, 2014). Also, most species of this group were epiphytic or periphytic thriving in an environment with high levels of dissolved oxygen and inorganic nutrients.

However, species like *Tabularia fasciculata* and *T. tabulata* which prefer water with high salt content showed surprising results when exhibiting negative correlation with salinity and EC and positive correlation with nutrients. This situation may have occurred because of a change in their environmental preference where they were adapted to Shatt Al-Arab river conditions which explain their wide distribution at all station. This may also indicate a change in the water quality of the river.

The negative correlation between the diatom species of the first group with parameters of the second group and contrarily, the negative correlation between the diatom species of second group with parameters of the first group was normal due to the negative relationship between some parameters such as transparency (measured as Secchi disk readings) and turbidity and, for some extent, between salinity and nutrients. Al-Zubaidi et al. (2006) recorded inverse relationship between salinity and nitrite in this region.

The second component (PC2) included brackish to marine species but without significant correlation with any of the environmental parameters measured in the present study. This situation may indicate that any of the measured parameters did not pose a significant effect on these species. All of these, however, were epipelic or periphytic and the effect of substrate type may be stronger than the influence of the environmental variables.

The first group of the third component (PC3) included fresh to brackish water species, with epipelic, epiphytic and periphytic habitats. They exhibited strong positive correlation with nitrite. The presence of nitrite is an indicator of pollution by wastewater (Varol et al., 2011). Species of *Stephanodiscus* which appeared in this group may indicate eutrophication according to their environmental preference (Palmer, 1980).

The second group of the third component includes one species *Gyrosigma attenuatum* which showed positive correlation with pH and DO. This may indicate their preference of alkaline water, which is a common feature in Shatt Al-Arab river (Hussain et al., 1991), also it is one of the clean water diatoms (Palmer, 1980). This species prefers alkaline water (alkalibiontic). It was also found in moderately polluted water (beta-mesosaprobic) (Kolkwitz & Mason, 1908; Hustedt, 1937-1938).

Finally, component four (PC4) included *Achnanthes brevipes* var. *intermedia* and *Navicula digitoradiata* which have negative correlation with water temperature, but *Cyclotella meneghiniana* at the same component has positive correlation with water temperature. Mitrovic et al. (2010) found that the maximum growth of *C. meneghiniana* occurs at 25^{o}C in laboratory conditions. The relatively high water temperature of Shatt Al-Arab river (22.78-23.93 ^{o}C) may explain the common occurrence of this species during the study period.

Many of the species which exhibited positive correlation with the plankton are centric forms but several benthic taxa have also showed similar trend. The later taxa are not truly planktonic but most likely drifted from their natural habitats by currents and other disturbances. This finding agrees with some previous studies in the region and considered as natural situation in freshwater ecosystems (Hadi &

Al-Saboonchi, 1989; Al-Mousawi et al., 1990; Al-Essa, 2004; Al-Farhan, 2010; Jaffer, 2010). However, Figure 4 shows only the planktonic and epipelic species thriving at station 7 such as *Coscinodiscopsis jonesiana*, *Coscinodiscus asteromphalus*, *Gyrosigma scalproides*, *Entomoneis paladosa* and *Navicula* sp. 1. The disappearance of taxa inhabiting other substrates is due to the absence of aquatic plants and other substrates at this station.

Most of the species which have significant positive correlation with plant hosts were epiphytic as well as periphytic forms. However, epiphytic diatoms were the most common among other groups of diatoms at most stations especially at stations 1, 2 and 4. This result is considered normal due to the widespread of the aquatic macrophytes in Shatt Al-Arab river (Al-Saadi et al., 1996; Al-Essa, 2004). *Cocconeis placentula* var. *euglypta*, *Caloneis permagna*, *Tabularia tabulate*, *Entomoneis alata*, *Nitzschia capitellata*, *Tabularia tabulata*, *Tabularia* sp. and *Thalassiosira* sp. were common at these stations.

Few species have significant positive correlation with both mud and hard substrates, most of them belong to *Navicula* and *Nitzschia* where many of their species are epipelic and periphytic forms. According to Al-Zubaidi (2000), wide distribution of *Navicula* spp. and *Nitzschia* spp. in Shatt Al-Arab river is due to high organic content in the sediments. Several species belonging to *Navicula* and *Nitzschia* are also epipelic forms and were previously known in the region (Salman et al., 2013; Hassan & Shaawait, 2015).

Gyrosigma scalproides and *G. sinensis* have positive relationship with mud substrate where they were found in high relative abundance. Also, *Luticola nivalis*, *L. ventricosa* have high relative abundance among epilithic diatoms, a reason behind their positive correlation with hard substrates. However, *Pleurosigma delicatulum* was common on sand at stations 3 and 5, thus showing positive correlation with hard substrates.

Cocconeis placentula var. *euglypta* is very common in Iraqi inland waters with wide habitat range and environmental distribution. The wide distribution of this species on the mud, aquatic plants and in the plankton was previously recorded (Al-Farhan, 2010; Al-Handal & Abdullah, 2010; Al-Handal et al., 2014). *Caloneis permagna* has positive relationship with all substrates except for solid ones. This species was common at station 2 on the plants, but Al-Shaban (1996) found it on the mud as well.

As a conclusion, many of the diatoms found in Shatt Al-Arab river are occurring outside their known environmental preferences (either marine or brackish water forms) which is an indication of a remarkable change in water quality of the river so that to support growth of such taxa. The occurrence of truly marine forms in the upper reaches of the river shows how far is the intrusion of sea water front. It has also been found that there is a strong correlation between diatom assemblages and the substrates on which they attach. Different substrates support to some extent different taxa, a situation indicates a host preference.

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