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BIODIVERSITY OF DIATOMS IN THE KASHKAN RIVER IN THE ZAGROS MOUNTAINS, WESTERN IRAN

S. Safiallah, S. Saadatmand, S. Kheiri & A. Iranbakhsh

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Iran is a country that serves as the spot for diverse landscapes and aquatic ecosystems. Zagros Mountains, as one of its main ranges and the important segment of Alpine-Himalayan orogenic system are known as the biodervisity hotspots for plants and animals worldwide. Despite the numerous rivers flowing in the area, little survey has been conducted about the diatom flora of its rivers. Diatoms are the most diverse microalgae that have great contribution to the primary production in the aquatic ecosystems. Due to importance of diatoms in the aquatic ecosystems and the ecological and geological importance of the Zagros in the world, we aim to study the diatom flora in the Kashkan River flowing in the Zagros Mountains. In this research, 48 epipelic and epilithic samples were collected along the Kashkan River in Spring 2019. A total of 91 taxa was identified from which four species were recorded as new for the diatom flora of Iran. Furthermore, identification of 10 taxa are provisional which are designated as cf., when finalized, these may also be recognized as new records. Meanwhile, twenty unidentified taxa which are marked as sp., are potetilly new species, in need of furthere investigations. These novel taxa are highlights and prominence of this study. Our results serves as a baseline for the diatoms biodiversity in the Zagros Mountain.

Somayyeh Safiallah, Sara Saadatmand (correspondence< sara.saadatmand2@gmail.com>), Department of Biology, Science and Research Branch, Islamic Azad University, Tehran, Iran. -Somayyeh Kheiri, Research Institute of Forests and Rangelands, Agricultural Research, Education and Extension Organization (AREEO),Tehran, Iran.- Alireza Iranbakhsh, Department of Biology, Science and Research Branch, Islamic Azad University, Tehran, Iran.

Key words: Zagros Mountains; Diatom; biodiversity; Kashkan River; Iran

تنوع زیستی دیاتومه‌های رودخانه کشکان در رشته کوه‌های زاگرس، غرب ایران

سمیه صفی‌اله: دانشجوی دکترای سیستماتیک گیاهی، گروه زیست‌شناسی، دانشگاه آزاد اسلامی، واحد علوم و تحقیقات، تهران، ایران

سارا سعادتمند: دانشیار گروه زیست‌شناسی، دانشگاه آزاد اسلامی، واحد علوم و تحقیقات، تهران، ایران

سمیه خیری: استادیارپژوهش مؤسسه تحقیقات جنگل‌ها و مراتع کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی، تهران، ایران

علیرضا ایرانبخش: استاد گروه زیست‌شناسی، دانشگاه آزاد اسلامی، واحد علوم و تحقیقات، تهران، ایران

ایران به‌عنوان کشوری با تنوع بالای اکوسیستم‌های آبی و خشکی به شمار می‌آید و رشته کوه‌های زاگرس به‌عنوان بخش مهمی از سیستم کوه‌زایی آلپ- هیمالایا هستند که برای گیاهان و جانوران به‌عنوان نقاط داغ تنوع زیستی در سطح جهان شناخته شده‌اند. با وجود رودخانه‌های بسیاری در این ناحیه ، مطالعات کمی در مورد فلور دیاتومه‌های رودخانه‌های آن انجام شده است. دیاتومه‌ها متنوع‌ترین ریزجلبک‌ها هستند که سهم زیادی را در تولید اولیه اکوسیستم‌های آبی دارند. باتوجه به‌اهمیت دیاتومه‌ها در اکوسیستم‌های آبی و اهمیت اکولوژیک و زمین‌شناسی رشته کوه‌های زاگرس در جهان، هدف ما مطالعه فلور دیاتومه‌های رودخانه کشکان واقع در رشته کوه‌های زاگرس می‌باشد.در این مطالعه ۴۸ نمونه اپی‌پل و اپی‌لیت در طول رودخانه کشکان در فصل بهار در سال ۱۳۹۸ جمع‌آوری شد. در مجموع ۹۱ تاکسون شناسایی شد که از میان آنها، چهار گونه به‌عنوان رکورد

جدید برای فلور دیاتومه ایران تشخیص داده شدند. شناسایی مقدماتی ده گونه نشان می‌دهد که آنها احتمالا رکوردهای جدیدی برای فلور ایران هستند و به‌صورت .cf در لیست مشخص شده‌اند. هم چنین بیست گونه ناشناخته که به‌صورت .sp نشان داده شده‌اند، می‌توانند بالقوه گونه‌های جدید باشند. این گزارش‌های جدید اهمیت این مطالعه را دو چندان می‌کند. این پژوهش، اطلاعات پایه در خصوص شناسایی و تنوع دیاتومه‌ها در منطقه زاگرس به شمار می‌آید.

INTRODUCTION

The diatoms (Bacillariophyta) comprise the most diverse group of microalgae with a unique siliceous cell wall morphology which is their most distinguishing characteristic. They are the most important primary producers that live in all kinds of aquatic ecosystems. Diatoms have been used as the environmental indicators of water quality due to their sensitivity to changes in pH, conductivity, salinity and trophic status in water (Cox, 1996). Therefore, the population and diversity of diatoms are influenced by different criteria such as physical, chemical and biological composition and the geographical features of their ecosystem (Vanormelingen & al. 2008).

Studies have shown that geographical factors play an important role in limiting the dispersal of certain species of diatom to specific regions and data support the endemism of diatom species to particular geographical regions. So far, Asia has been introduced as a continent possessing the highest endemic diatom genera (Vanormelingen & al. 2007; Kocioleck 2018; Kiroly & al. 2007).

Iran is an important country in Asia with diverse ecosystems and geological formations. There has already been conducted much research on the endemism of its plants, animals (Linnaei 1758; Ziaie 1996; Noroozi & al. 2019b ; Kiani & al. 2017) and its unique geology (Stoklin & Nabavi 1973; Nogole-Sadat 1993; Aghanabati 2004). However, there have been few studies conducted on diatom diversity throughout the country. Research on the diatom assemblage and its ecology has been pioneered by mostly foreign researchers (Loffler 1956; Hirano 1973; Moghadam 1975; Wasylik 1975; Compe're 1981; Hulburt & al. 1981). The diatom work has received more attention in recent decades (Snyder & al. 2001; Nejadsattari 2005a; Jamalo & al. 2006; Witkowski & al. 2007; Atazadeh & al. 2007; Zarei-Darki 2011a; Zarei-Darki 2011 b; Soltanpour-Gargari & al. 2011; Shams & al. 2012; Cheraghpour & al. 2013; Kheiri & al. 2013; Pourgholam & al. 2014; Mohebbi & al. 2016; Panahy Mirzahasanlou & al. 2018; Ahmadi Musaabad & al., 2019; Kheiri & al. 2018a; Kheiri & al. 2018b; Kheiri 2019). So far, only two endemic species, *Nitzschia iranica* Compe're and *Achnanthes iranensis* Moghadam have been recorded from Iran (Compe're 1981; Moghadam 1975). According to the global biodiversity, Zagros Mountains as a part of Irano-Anatolian plate are one of the 34 biodiversity hotspots in the world (Noroozi & al. 2018). The ranges are extending northwest-southeast Iran. They are a part of Alp-Himalayan belt formed by the closure of the Neo-Tethyan ocean and the collision of a variety of continental plates as African, Arabian, Indian and Eurasian plates (Hatzfeld & al. 2010; Mohajjel & Fergusson 2013; Massaro & al. 2019). The Zagros Mountains are the source for many springs and rivers. The Lorestan basin is one of the largest sub basins of the Zagros.

There has been a pioneer work on diatom diversity in the Lorestan basin (Kheiri & al. 2018b). However, due to the presence of many rivers in the region, our understanding about diatom diversity in the Zagros is very poor. The Kashkan River is one of the longest rivers of Lorestan province which originates from its source in the Zagros Mountains and with four major perennial tributaries as Doab, Khorramabad, Jehlool, and Madianrud, it drains one-third of the province (Mostafaei 2014). We selected the Kashkan River to study its diatom assembelage as it is a very important river in the Lorestan province used as drinking water and in agriculture. No study has been conducted in the area for the diatom flora yet. The unique geology of the region as part of the Zagros makes the study more outstanding. This research aimed to study the composition of epipelic and epilithic diatoms and survey the distribution of the species in the Kashkan River basin.

MATERIALS AND METHODS

Study area

The Kashkan River is one of the longest rivers of Iran and with a length of approximately 900 km, it has a drainage area of 9.236 km^2 in the Lorestan province. The river is flowing along the Zagros Mountains from an altitude of about 3140 m a.s.l. (Mostafaei 2014). It is one of the principal tributaries of the Karkheh River (in the north of Khuzestan province) that terminates to the Persian Gulf .The Horroud and Aleshtar streams are two main streams that join together to form the Kashkan River in the mountains of Aleshtar. The river receives sewage of the villages and the industrial-municipal wastewater of the cities of Aleshtar, Poledokhtar,Jogolvandi, koohdasht, khoramabad in its way (Mostafaei 2014; Negaresh & al. 2011). The basin is one of the most important center for agriculture and a drinking source for the residents of the Lorestan Province.

Geologically, Kashkan rocks are composed of red colored siltstone, sandstone and conglomerate and the Kashkan formation belongs to the Paleocene-middle Eocene (Yusefi-Yeganeh & al. 2011).

Four sampling stations were selected along the Kashkan River (fig. 3, table 1). The sites are located in the centeral-western part of the basin with the elevation range of 983-1030 m. Except site 4 which is located inside the village, the other sites are located along the Khoramabad- Koohdasht road near villages. All sites were close to agricultural lands. Waste plastic bottles and oil containers were present in the second site, “near the Kashkan bridge”. This place is close to tourists camps and there were some pumps around for irrigating the agricultural fields (figs 1-2).

Sampling method

48 samples were collected from the surface of rocks and mud along the Kashkan River in Spring 2019. The temperature in Spring is optimum for the diatom growth and diversity (Zhang & al. 2019) and we sampled the periphytic diatoms from the substrates of the river in May. It is assumed that the high preceptation improves the water quality and we collected the samples after the rainfall for the best possible water quality.

For collecting epipelic samples, a plastic syringe (with a capacity of 60 ml and diameter of 29.1 mm) with the barrel cut off at the needle adapter end was inserted into the substrate. Most epilithic samples were collected from submerged rocks at the depth of 10 to 20cm. A brush was used to collect diatoms at the area of 10cm×10cm on the surface of the rock (Kheiri & al. 2013). Samples were preserved in 4% formaldehyde and transported to the laboratory. The samples were treated with hydrogen peroxide 30 ٪(H_2O_2) and hydrocloric acid 37 ٪(HCl) for the removal of the organic material and carbonates respectively. After repeated washing with the distilled water, the slides were mounted by Naphrax (Taylor & al. 2007).

Observation of the diatom slides were done using an Olympus BX53 equipped with a DP72 camera. Diatoms were identified according to known references (Rabenhorst 1853; Reichardt 1999; Reichardt & Lange-Bertalot 1991;Patrick & Rimer 1966; Krammer 1997a; Krammer 1997b; Krammer 2002; Krammer & Lange-Bertalot 1991a; Krammer & Lange-Bertalot 1991b; Krammer & Lange-Bertalot 1986; Krammer & Lange-Bertalot 1988; Lange-Bertalot 2001; Lange-Bertalot & Krammer 1989; Potapova & Ponder 2004; Morales & Vis 2007; Levkov 2009; Hofmann & al. 2011; Bey and Ector 2013a; Bey and Ector 2013b; Kheiri & al. 2018a; Liu & al. 2019). We used Image J Software for measuring diatoms (Schneider & al., 2012).

Physicochemical Analysis

Water samples were collected from the sampling sites in May 2019. The samples for chemical analysis were collected into the bottles with the volume of 1500cc and transported chilled to the laboratory of AZMA Company (Tehran, Iran). Temperature was measured *in situ*.Water chemistry analyses included pH, specific conductivity, total dissolved solids, total suspended Solids, turbidity, ammonium, nitrate, nitrite, total nitrogen, organic nitrogen and total phosphate following APHA (2017).

RESULTS

A total of 91 taxa belonging to 26 genera, 15 families and three classes were identified from 48 epipelic and epilithic samples at four stations along the Kashkan River. Among these taxa, *Navicula caterva* Hohn & Hellermann, *Ulnaria contracta* (Østrup) E. A. Morales & M.L.Vis, *Nitzschia paleaeformis* Hustedt and *Hantzschia abundans* Lange-Bertalot were identified as new records for the diatom flora of Iran. Furthermore, three other taxa seemed new to the diatom flora of Iran, but their identification was not final. Here, we represent the preliminary identification as follows: *Ulnaria* cf. *rhombus* D.M.Williams, *Cymbopleura* cf. *anglica* (Lagersted) Krammer, *Gomphonema* cf. *cymbelliclinum* E.Reichardt & Lange-Bertalot.

Meanwhile, *Achnanthidium* sp.$_1$, *Achnanthidium* sp.$_2$, *Nitzschia* sp., *Tryblionella* sp., *Gomphonella* sp.$_1$, *Gomphonella* sp.$_2$, *Gomphonella* sp.$_3$, *Gomphonella* sp.$_4$, *Eunotia* sp., *Encyonopsis* sp., *Gomphonema* sp.$_1$, *Gomphonema* sp.$_2$, *Gomphonema* sp.$_3$, *Gyrosigma* sp., *Navicula* sp.$_1$, *Navicula* sp.$_2$, *Navicula* sp.$_3$, *Craticula* sp., *Surirella* sp., and *Diatoma* sp. were the taxa that remained unidentified which are designated as sp. here. Furthere investiagation may reveal them as new taxa.


1


2

Figs. 1-2. Images of different stations of the Kashkan River in Lorestan province.

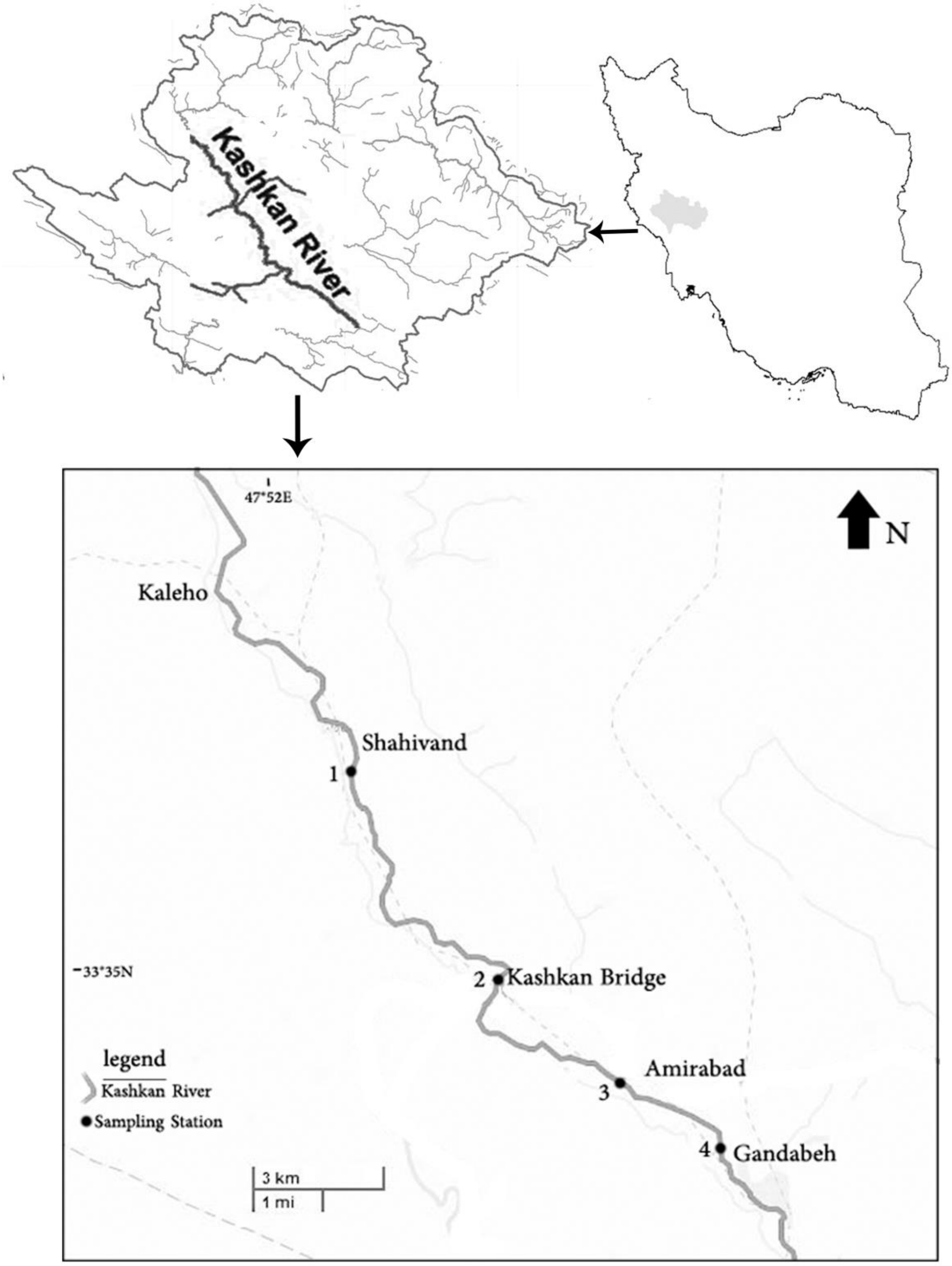


Fig. 3. Map of the Kashkan River (Lorestan province), sampling sites are marked with numbered black dots.

Table 1. Sampling sites along the Kashkan River.

Site	Elevation (m)	Latitude and Longitude	Location and site description
1	1030	33° 32′ 44″ N 47° 56′ 26″ E	Khoramabad(Sarabdore), near the village of Kaleho, Shahivand, 35 Km from Koohdasht.
2	1015	33° 35′ 22″ N 47° 52′ 50″ E	Khoramabad(Sarabdore), near the Kashkan Bridge, 45 km from Koohdasht.
3	980	33° 33′ 40″ N 47° 55′ 31″ E	Khoramabad(Sarabdore), near the village of Amirabad, 55 km from Koohdasht.
4	983	33° 35′ 16″ N 47° 52′ 55″ E	Khoramabad(Sarabdore), in the Gandabe village, 65 km from Koohdasht.

Ten species showed somewhat different characteristics from the known species. Therefore, the most similar taxa were chosen for naming the species as cf. taxa. Twenty species did not match with the references and were identified at the genus level as sp. species in the Kashkan River. The taxonomic references used for the identification and morphometric characterisctics for the specimens are given for each species (table 2).

Morphological types of the diatoms included as follows: 1. Centric diatoms, represented by the families of Melosiraceae and stephanodiscaceae with one genus (*Melosira*) and one species for the former and two genera and two species for the latter (genera: *Cyclotella* & *Pantocsekiella*), 2. Symmetrical biraphid diatoms comprising the three families, Amphipleuraceae with one genus (*Amphipleura*), Stauroneidaceae with one genus (*Craticula*), Naviculaceae with three genera (*Navicula*, *Gyrosigma, Caloneis*), 3. Asymmetrical biraphid group including the families of Catenulaceae (genus: *Amphora*), Cymbellaceae (genera: *Cymbella, Cymbopleura*), Cymbellales inceratae sedis (genus: *Gomphonella*), and Gomphonemataceae (genera: *Encyonema, Encyonopsis, Gomphonema, Reimeria*), 4. Monoraphid taxa consisisting the two families of Achnanthidiaceae (genus: *Achnanthidium*) and Cocconeidaceae (genus: *Cocconeis*), 5. Araphid group comprising the two Families of Tabellariaceae (genus: *Diatoma*) and Ulnariaceae (genus: *Ulnaria*), 5. Nitzschioid group consisting of the family Bacillariaceae with four genera (*Denticula, Hantzschia, Nitzschia, Tryblionella*), 6. Surirelloid group represented by the family Surirellaceae with one genus (*Surirella*) and 7. Eunotioid taxa belonging to the family Eunotiaceae with the genus *Eunotia*.

The most diverse group was asymmetrical biraphid with 8 genera and 20 species. Symmetrical biraphid with 17 species had the second rank in diversity. Eunotioid with one genus and one species was the least diverse group in the samples.

Among the new record taxa, *Ulnaria contracta* and *Navicula caterva* appeared in all sampling sites. *Nitzschia paleaeformis* occurred in sites 2 to 4. *Hantzschia abundans* was only found in site 1.

The most dominant genera in the sites were *Navicula* (15 species) and *Nitzschia* (11 species) with the richest species diversity in the Kashkan River. Other genera which were commonly found in both epipelic and epilithic assembelage included *Gomphonema* (9 species), *Cymbella* (8 species), *Achnanthidium* (5 species), *Surirella* (4 species), *Ulnaria* (4 species), *Diatoma* (3 species) and *Cocconeis* (3 species).

The species that were present in two stations along the river included ¼ of the flora and comprised the taxa of *Craticula* cf. *accomoda* (Hustedt) D.G.Mann, *Cyclotella meneghiniana* Kützing, *Cymbella tumida* (Brébisson) Van Heurck, *Diatoma* sp., *Encyonopsis microcephala* (Grunow) Krammer, *Encyonopsis subminuta* Krammer & E.Reichardt, *Gomphonema* cf. *dichotomum* Kützing, *Gomphonema* cf. *cymbelliclinum*, *Gomphonema* sp.$_1$, *Melosira varians* C. Agardh, *Navicula* cf. *antonii* Lange-Bertalot, *Navicula cryptotenella* Lange-Bertalot, *Navicula erifuga* sensu Bey and Ector 2013, *Navicula gregaria* Donkin, *Navicula trivialis* Lange-Bertalot, *Navicula* sp.$_3$, *Nitzschia* cf. *desertorum* Hustedt, *Surirella angusta* Kützing and *Ulnaria acus* (Kützing) Aboal (table 2).

The species which were observed in only one station also included ¼ of the flora. They comprised the species of *Achnanthidium* sp.$_2$, *Amphipleura pellucida* (Kützing) Kützing, *Caloneis bacillum* (Grunow) Cleve, *Cyclotella atomus* Hustedt, *Denticula kuetzingii* Grunow, *Encyonema lange-bertalotii* Krammer morphotype1, *Encyonopsis* sp., *Eunotia* sp., *Gomphonema micropus* Kützing, *Gomphonema productum* (Grunow) Lange-Bertalot & E.Reichardt, *Gyrosigma* sp., *Hantzschia abundans*, *Navicula radiosa* Kützing, *Nitzschia* cf. *acicularis* (Kützing) W.Smith, *Nitzschia flexa* Schumann, *Nitzschia recta* Hantzsch ex Rabenhorst, *Nitzschia* sp., *Pantocsekiella iranica* Nejadsattari, Kheiri, Spaulding & Edlund, *Reimeria sinuata* (W.Gregory) Kociolek & Stoermer, *Surirella librile* (Ehrenberg) Ehrenberg, *Surirella* sp. and *Ulnaria* cf. *rhombus* (table 3).

The remainder of the species which contributed to approximately half of the whole flora, were the species with high percentage of occurunce found in three to four stations along the river (table 3).

A few species were only observed in one substrate. They included *Amphipleura pellucida* (Kützing) Kützing (observed in site 1), *Denticula kuetzingii* Grunow (observed in site 4), *Tryblionella* sp. (observed in sites 2,3,4), *Eunotia* sp.(observed in site 2), and *Encyonema lange-bertalotii* Krammer morphotype1 (observed in site 2). *Pantocsekillea iranica* only occurred as Epilithic species (table 2).

Physicochemical data

Physicochemical parameters observed in the water of the Kashkan River during the sampling time are shown in table 3. Based on the analysis, temperature had an average value of 25°C in the sampling sites and did not show much variation along the river. It only tended to be a little low in site 3 (21°C) .pH was basic in the sampling sites with slight increase toward downstream of the river. The concentrations of TDS, TSS and EC did not vary much along the sites. Nutrients such as nitrite was almost constant in sampling sites. The concentration of organic nitrogen had an ascending trend toward downstream stations and its highest value was detected in station 3. Other nutrients such as total nitrate and total phosphate increased from upstream sites to downstream sites. As the altitude decreased along the stations from station 1 to station 4, the value for turbidity increased.

Turbidity was the only parameter among the physicochemical factors that exceeded the standard permissible limits of WHO in the River. (table 3).

DISCUSSION

Despite Iran's large area and its numerous and diverse aquatic ecosystems, the knowledge about diatom diversity is poor throughout the country (Kheiri & al. 2018a). Survey on diatom assemblage in the Zagros basin, as the second important mountainous range in Iran, draws a significant attention. The present study is performed to increase our understanding about the regional patterns of diatom diversity in the central-western part of the Kashkan River basin, located in the Lorestan province and is a part of the Zagros basin. Comparison of diversity of Kashkan River with the diatom flora of Marbareh River, one of the main tributaries of the Sezar River in the Lorestan Province (Kheiri & al. 2018b) presents some similar taxa. Species such as *Cymbella excisa* Kützing, *Cymbella lange-bertalotii* Krammer, *Diatoma moniliformis* (Kützing) D.M.Williams, *Diatoma vulgaris* Bory, *Ecyonema minutum* (Hilse) D.G.Mann, *Gomphonema micropus*, *Navicula capitatoradiata* H.Germain ex Gasse, *Nitzschia dissipata* (Kützing) Rabenhorst, *Nitzschia linearis* W.Smith, *Reimeria sinuata*, *Surirella angusta* and *Ulnaria ulna* (Nitzsch) Compère were found in both rivers. Comparing the diatom flora of Kashkan River with the diatom diversity of the other aquatic ecosystems in Iran shows some species common and widespread throughout Iran. These species include *Cyclotella meneghiniana* Kützing, *Melosira varians*, *Achnanthidium minutissimum* (Kützing) Czarnecki, *Surirella angusta*, *Caloneis bacillum*, *Diatoma moniliformis*, *Cocconeis lineata* Ehrenberg, *Cocconeis placentula* var. *euglypta* (Ehrenberg) Grunow, *Cocconeis placentula* Ehrenberg, *Ulnaria ulna*, *Navicula radiosa*, *Navicula capitatoradiata*, *Navicula gregaria* Donkin, *Denticula kuetzingii*, *Cymbella tumida*, *Nitzschia linearis*, *Nitzschia recta*, *Nitzschia palea* (Kützing) W.Smith, *Nitzschia dissipata*, *Amphora pediculus* (Kützing) Grunow and *Gomphonema parvulum* (Kützing) Kützing (Hirano 1973; Moghadam 1975; Wasylik 1975; Afsharzadeh 2003; Nejadsattari 2005a, Nejadsattari & al. 2005b; Witkowski & al. 2007; Zarei-Darki 2009a; Zarei-Darki 2009b; Zarei-Darki 2011a; Panahy-Mirzahasanlou & al. 2018; Kheiri & al. 2018a). The unique species in the Kashkan River with a wide distribution in the sites included *Cymbopleura* cf. *anglica*, *Gomphonema* cf. *cymbelliclinum*, *Navicula caterva*, *Nitzschia paleaeformis*, *Ulnaria contracta*. *Hantzschia abundans* and *Ulnaria* cf. *rhombus* had a limited distribution in the river and were observed in only one site.

More than 50% of the species had a wide distribution along the river and were present in three or four sampling sites. The species, occurred in only one station accounted for the ¼ of the flora. Very few species present in the Kashkan River preferred only one substrate and appeared as epipelic or epilithic taxa.

Table 2. List of the identified taxa, their description and their presence in the sampling sites and the substrate. L stands for valve length,W for valve width, S for stria number in 10 µm, F for fibulae in 10 µm, D for diameter and C for costa number in 10 µm. +: present. -:not noted. New records are marked by asterisk.

Taxon	Figures	ID reference	Dimension	Stations	Epipelic	Epilithic
Bacillariophyceae						
Achnanthidiaceae						
Achnanthidium gracillimum (F.Meister) Lange-Bertalot	Fig. 14	Hofmann & al. (2011)	L:18.82 µm W: 2.45 µm S:20	1,2,3,4	+	+
Achnanthidium minutissimum (Kützing) Czarnecki	Figs 12-13	Lange-Bertalot & Krammer (1989) Krammer & Lange-Bertalot (1991b); Hofmann & al. (2011)	L:9.91-13.73 µm W: 2-2.27 µm	2,3,4	+	+
Achnanthidium cf. *pyrenaicum* (Hustedt) H.Kobayasi	Fig.15	Hofmann & al. (2011);	L:13.39 µm W: 3.30 µm	1,3,4	+	+
Achnanthidium sp.$_1$	Figs 10-11	Krammer & Lange-Bertalot (1991b); Hofmann & al. (2011)	L:14.13-16.79 µm W: 3-3.18 µm	2,3,4	+	+
Achnanthidium sp.$_2$	Fig.16	Krammer & Lange-Bertalot (1991b); ;Potapova & Ponader (2004)	L: 11.45 µm W: 2.91 µm	3	+	+
Amphipleuraceae						
Amphipleura pellucida (Kützing) Kützing	Fig.18	Hofmann & al. (2011)	L:84.18 µm W: 8.18 µm	1	+	-
Bacillariaceae						
Denticula kuetzingii Grunow	Fig. 66	Krammer & Lange-Bertalot (1988)	L: 22.32 µm W: 4.39 µm F: 9	4	+	-
**Hantzschia abundans* Lange-Bertalot	Fig. 68	Hofmann & al. (2011)	L: 37.63 µm W: 5.97 µm F: 5	1	+	+
Nitzschia cf. *acicularis* (Kützing) W.Smith	Fig. 78	Krammer & Lange-Bertalot (1991a); Hofmann & al. (2011)	L: 46.79 µm W: 4 µm	2	+	+
Nitzschia cf. *desertorum* Hustedt	Fig. 82	Krammer & Lange-Bertalot (1991a)	L: 20.85 µm W: 3.29 µm F: 18	3, 4	+	+
Nitzschia dissipata (Kützing) Rabenhorst	Figs 83-84	Krammer & Lange-Bertalot (1988)	L: 20.12-35 µm W: 3.05-3.90 µm F: 11	1, 2, 3, 4	+	+
Nitzschia dissipata var. *media* (Hantzsch) Grunow	Fig 85-86	Krammer & Lange-Bertalot (1988)	L: 25-49.39 µm W: 3.78-4.51 µm F: 8-9	2, 3, 4	+	+
Nitzschia flexa Schumann	Figs 72-73	Krammer & Lange-Bertalot (1991a)	L: 104.18-122.45 µm W: 4.08-4.09 µm F: 8-11	1	+	+
Nitzschia heufleriana Grunow	Fig. 74	Krammer & Lange-Bertalot (1991a); Hofmann & al. (2011)	L: 119.45 µm W: 6 µm F:12	1, 2, 3	+	+

Table 2. Continued.

Nitzschia linearis W.Smith	Fig. 75	Krammer & Lange-Bertalot (1988)	L: 82.27 µm W: 4.37 µm F: 10	1,2,3,4	+	+
Nitzschia palea (Kützing) W.Smith	Figs 79-80-81	Krammer & Lange-Bertalot (1991a) ; Hofmann & al.(2011)	L: 17.74- 42.52 µm W: 3.71- 4.39 µm F: 12-13	1,2,3,4	+	+
**Nitzschia paleaeformis paleaeformis* Hustedt	Fig. 77	Hofmann & al. (2011)	L: 56.12 µm W: 3.64 µm F: 12	2,3,4	+	+
Nitzschia recta Hantzsch ex Rabenhorst	Fig. 76	Krammer & Lange-Bertalot (1988)	L: 75.73 µm W: 5.67 µm F: 8	2	+	+
Nitzschia sp.	Fig. 65	Hofmann & al. (2011)	L: 27.26 µm W: 4.02 µm F: 12	2	+	+
Tryblionella sp.	Fig. 67	Krammer & Lange-Bertalot (1988)	L: 37.70 µm W: 5.94 µm S: 16	2,3,4	+	-
Catenulaceae						
Amphora pediculus (Kützing) Grunow	Fig. 124	Krammer & Lange-Bertalot (1986); Levkov (2009)	L: 9.32 µm W: 2.45 µm S: 8	2,3,4	+	+
Cocconeidaceae						
Cocconeis lineata Ehrenberg	Figs 32-33	Krammer & Lange-Bertalot (1991b)	L: 13.70-25.39 µm W: 7.95-13.70 µm S:15 -17	1,2,3,4	+	+
Cocconeis placentula var. *euglypta* (Ehrenberg) Grunow	Figs 34-35	Hofmann & al. (2011)	L: 22.91-32.32 µm W: 12.88-17.86 µm S:20	1,2,4	+	+
Cocconeis placentula Ehrenberg	Fig. 36	Krammer & Lange-Bertalot (1991b)	L: 13.79 µm W: 7.67 µm S: 20	1,2,3,4	+	+
Cymbellaceae						
Cymbella affinis var. *neoprocera* W.Silva	Figs 98-99	Krammer (2002)	L: 28.19- 29.95 µm W: 8.4-7.85 µm S: 11-12	1,2,3,4	+	+
Cymbella compacta Østrup	Fig. 69	Krammer (2002)	L: 33.13 µm W: 11.45 µm S: 13	1,2,3,4	+	+
Cymbella excisa Kützing	Figs 95-96	Krammer (2002)	L: 15.71-23.74 µm W: 6.03-7.12 µm S: 12-14	1,2,3,4	+	+
Cymbella exigua Krammer	Fig. 94	Krammer (2002)	L: 29.16 µm W: 8.43µm S: 11	1,2,3,4	+	+
Cymbella cf. *excisiformis* Krammer	Fig. 97	Krammer (2002)	L: 29.59 µm W: 6.21 µm S: 12	1,2,3,4	+	+
Cymbella lange-bertalotii Krammer	Fig. 70	Krammer (2002)	L: 38.19 µm W: 9.64 µm S: 11	1,2,3,4	+	+

Table 2. Continued.

Cymbella tumida (Brébisson) Van Heurck	Fig. 71	Krammer (2002)	L: 44.58 µm W: 14.46 µm S: 12	1,3	+	+
Cymbopleura cf. *anglica* (Lagerstedt) Krammer	Fig. 105	Krammer (2003)	L: 27.27 µm W: 8.93 µm S: 14	1,2,3	+	+
Cymbellales inceratae sedis						
Gomphonella olivacea (Hornemann) Rabenhorst	Figs 106-107	Krammer & Lange-Bertalot (1986); Hofmann & al. (2011); Rabenhorst (1853)	L: 16.34 19.79 µm W: 5.16- 5.78 µm S: 9-10	1,2,3,4	+	+
Gomphonella sp.$_1$	Fig. 113	Rabenhorst (1853)	L: 15.73 µm W: 2.83µm S: 11	1,2,3	+	+
Gomphonella sp.$_2$	Fig. 120	Rabenhorst (1853)	L: 30.55 µm W: 3.58 µm S: 10	1,2,3,4	+	+
Gomphonella sp.$_3$	Fig. 121	Rabenhorst (1853)	L: 24.86 µm W: 3.49 µm S: 10	1,2,4	+	+
Gomphonella sp.$_4$	Figs 110-111	Rabenhorst (1853)	L: 16.34 19.79 µm W: 5.16- 5.78 µm S: 9-10	1,2,3,4	+	+
Eunotiaceae						
Eunotia sp.	Fig. 31	Hofmann & al. (2011)	L: 17.45 µm W: 1.82 µm	2	+	-
Gomphonemataceae						
Encyonema minutum (Hilse) D.G.Mann	Figs 91-92	Krammer (1997a)	L: 14.72- 12.02 µm W: 5.28- 4.79µm S: 16	1,2,3,4	+	+
Encyonema lange-bertalotii Krammer morphotype 1	Fig. 93	Krammer (1997a)	L: 15.34 µm W: 5.62µm S: 18	2	+	-
Encyonema silesiacum (Bleisch) D.G.Mann	Figs 87-88	Krammer (1997a)	L: 17.67- 28.22 µm W: 5.52- 6. 38µm S: 13-15	1,3,4	+	+
Encyonema ventricosum (C.Agardh) Grunow	Figs 89-90	Krammer (1997a)	L: 16.44- 21.10 µm W: 6.14- 7.12µm S: 14-16	1,2,3,4	+	+
Encyonopsis microcephala (Grunow) Krammer	Fig. 103	Krammer (1997b)	L: 13.86 µm W: 3.01µm S:24	3,4	+	+
Encyonopsis minuta Krammer & E.Reichardt	Figs 101-102	Krammer (1997b)	L: 12.53-15.33 µm W: 3.01- 3.23µm S:23-25	1,2,3	+	+
Encyonopsis sp.	Fig. 100	Hofmann (2011)	L: 17.64 µm W: 4 µm	4	+	-

Table 2. Continued.

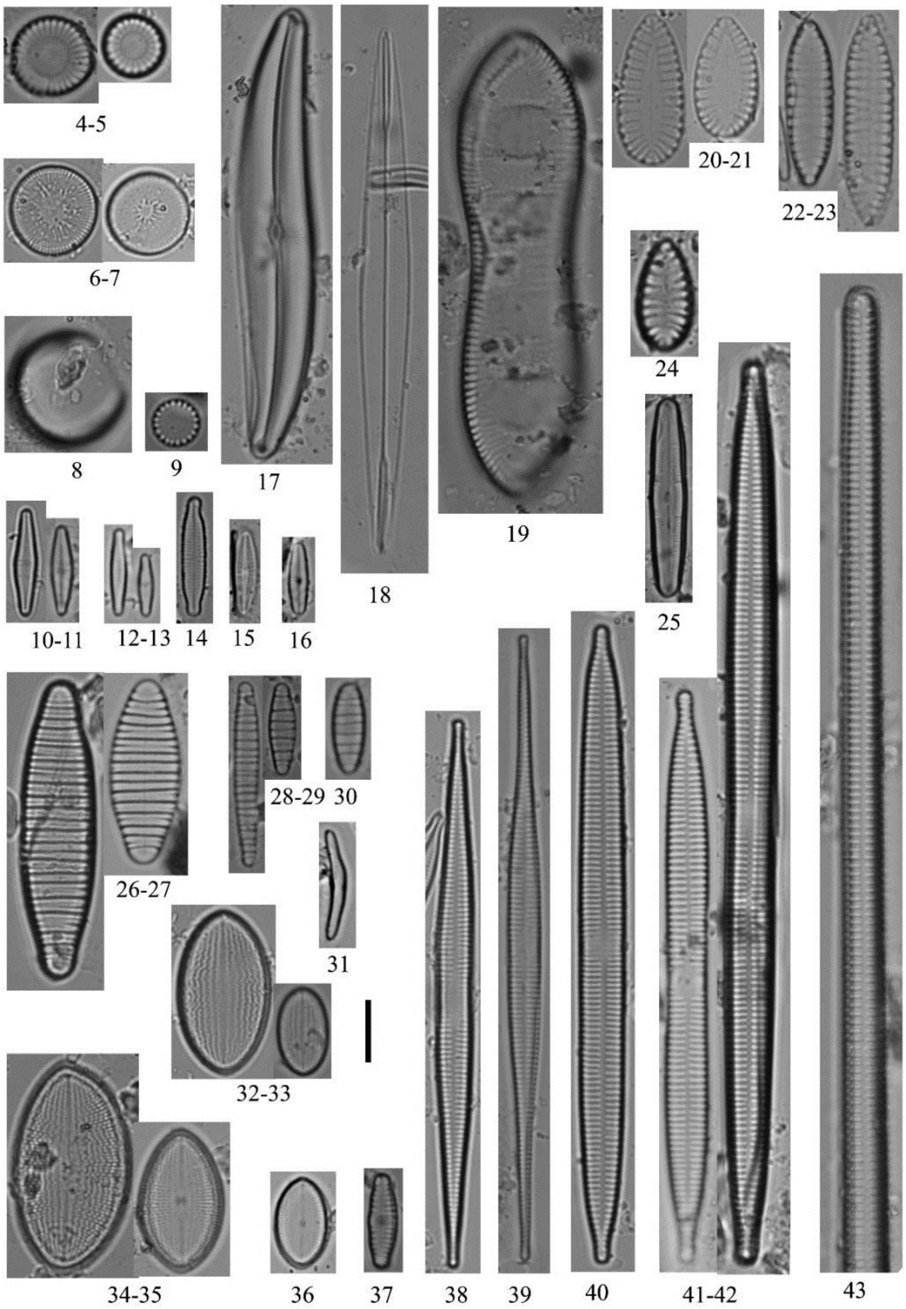
Encyonopsis subminuta Krammer & E.Reichardt	Fig. 104	Krammer (1997b)	L: 10.84 µm W: 2.89µm S:25	2,4	+	-
Gomphonema cf. *dichotomum* Kützing	Figs 116-117	Krammer & Lange-Bertalot (1986)	L: 31.83- 34.95 µm W: 4.59 µm S: 10	1,3	+	+
Gomphonema cf. *cymbelliclinum* E.Reichardt & Lange-Bertalot	Fig. 114	Hafmann(2011); Krammer & Lange-Bertalot (1986)	L: 9.82 µm W: 4.04 µm S: 5	1,3	+	+
Gomphonema micropus Kützing	Fig. 123	Hofmann & al. (2011)	L: 31.83 µm W: 5.60 µm S: 11	2	+	+
Gomphonema parvulum (Kützing) Kützing	Figs 108-109	Krammer & Lange-Bertalot (1986)	L: 16.95- 20.40 µm W:4.92- 5.90 µm S: 13-16	1,2,3,4	+	+
Gomphonema productum (Grunow) Lange-Bertalot & E.Reichardt	Fig. 122	Hofmann & al. (2011)	L: 30 µm W: 4.77 µm S: 11	3	+	+
Gomphonema tergestinum (Grunow) Fricke	Fig. 112	Krammer & Lange-Bertalot (1986)	L: 18.06 µm W: 6.27µm S: 12	1,2,3	+	+
Gomphonema sp.$_1$	Fig. 115	Hofmann & al. (2011)	L: 48.90 µm W: 6.42 µm S: 10	1,3	+	+
Gomphonema sp.$_2$	Fig. 118	Hofmann & al. (2011)	L: 30.83 µm W: 4.31 µm S: 14	1,2,3,4	+	+
Gomphonema sp.$_3$	Fig. 119	Hofmann & al. (2011)	L: 23.21 µm W: 3.30 µm S: 14	1,2,3,4	+	+
Reimeria sinuata (W.Gregory) Kociolek & Stoermer	Fig.37	Krammer & Lange-Bertalot (1986)	L: 14.73 µm W: 4.43 µm S: 11	2	+	-
Naviculaceae						
Caloneis bacillum (Grunow) Cleve	Fig. 25	Krammer and Lange-bertalot (1986)	L: 31.64 µm W: 5.21 µm S: 20	4	+	-
Gyrosigma sp.	Fig. 17	Hofmann & al. (2011)	L: 73.07 µm W: 11.60 µm	4	+	-
Navicula cf. *antonii* Lange-Bertalot	Fig. 55	Lange-Bertalot (2001)	L: 12 µm W: 5.5 µm S: 16	2,4	+	+
Navicula broetzii Lange-Bertalot & E.Reichardt	Figs 49-50	Lange-Bertalot (2001)	L: 31.22 µm W: 5.49 µm S: 15	1,2,3,4	+	+
**Navicula caterva* Hohn & Hellermann	Fig. 53	Hofmann & al. (2011)	L: 16.59 µm W: 4.76 µm S: 17	1,2,3,4	+	+

Table 2. Continued.

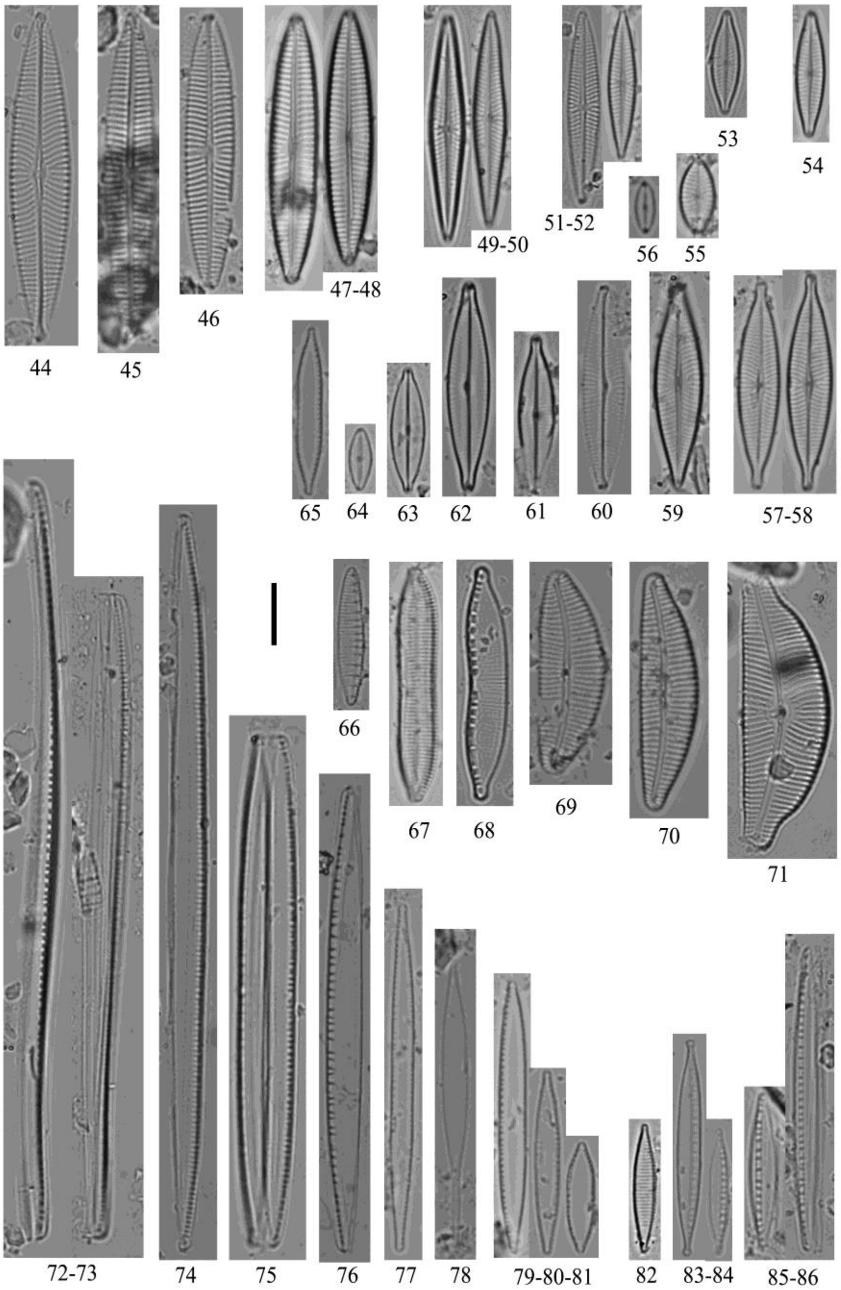
Navicula capitatoradiata H.Germain ex Gasse	Figs 57-58	Krammer & Lange-Bertalot (1986)	L: 33.54- 34.88 µm W: 6.59- 7.07 µm S: 15	1,2,3,4	+	+
Navicula cryptotenella Lange-Bertalot	Figs 51-52	Lange-Bertalot (2001); Hofmann & al. (2011)	L: 29.65-22.94 µm W: 5.12-4.24 µm S: 15-16	1,2,3,4	+	+
Navicula gregaria Donkin	Fig. 61	Krammer & Lange-Bertalot (1986); Lange-Bertalot (2001)	L: 25.40 µm W: 6.13 µm S: 14	1,2	+	+
Navicula radiosa Kützing	Fig.44	Krammer & Lange-Bertalot (1991a); Hofmann & al. (2011)	L: 53.66 µm W: 10.12 µm S: 10	1	+	+
Navicula sp.$_1$	Fig. 56	Hofmann & al. (2011)	L: 8.09 µm W: 3.18 µm	1,2,3	+	+
Navicula sp.$_2$	Fig. 45	Hofmann & al. (2011)	L: 53.41 µm W: 8.41 µm S: 11	1	+	+
Navicula sp.$_3$	Fig. 62	Hofmann & al. (2011)	L: 33.74 µm W: 6.99 µm S: 14	2,3	+	+
Navicula trivialis Lange-Bertalot	Fig. 59	Hofmann & al. (2011)	L: 33.62 µm W: 7.98 µm S: 14	2,4	+	+
Navicula tripunctata sensu Bey and Ector 2013	Fig. 46	Bey and Ector (2013a)	L: 42.88 µm W: 8.12 µm S: 11	2	+	+
Navicula tripunctata (O.F.Müller) Bory	Fig. 47-48	Krammer & Lange-Bertalot (1986); Lange-Bertalot (2001)	L: 41.76-43.90 µm W: 7.56 µm S: 11	1,2,3,4	+	+
Navicula erifuga sensu Bey and Ector 2013	Fig. 60	Bey and Ector (2013a)	L: 33.29 µm W: 7.07 µm S: 14	2,3	+	+
Navicula vandamii Sensu Bey and Ector 2013	Fig. 54	Bey and Ector (2013a)	L: 20.49 µm W: 4.76 µm S: 16	1,2,3,4	+	+
Stauroneidaceae						
Craticula cf. *accomoda* (Hustedt) D.G.Mann	Fig. 63	Hofmann & al. (2011)	L: 20.36 µm W: 5.70 µm	1,4	+	+
Craticula sp.	Fig.64	Hofmann & al. (2011)	L: 9.82 µm W: 3.73 µm	2,3,4	+	+
Surirellaceae						
Surirella angusta Kützing	Figs 22-23	Krammer & Lange-Bertalot (1988)	L: 28.16-28.21 µm W: 7.19-8.78 µm F: 8	1,3	+	+
Surirella lacrimula J.D.English	Figs 20-21	Bey & Ector (2013b)	L: 19.09-24 µm W: 10 µm F: 8-9	1,2,3,4	+	+

Table 2. Continued.

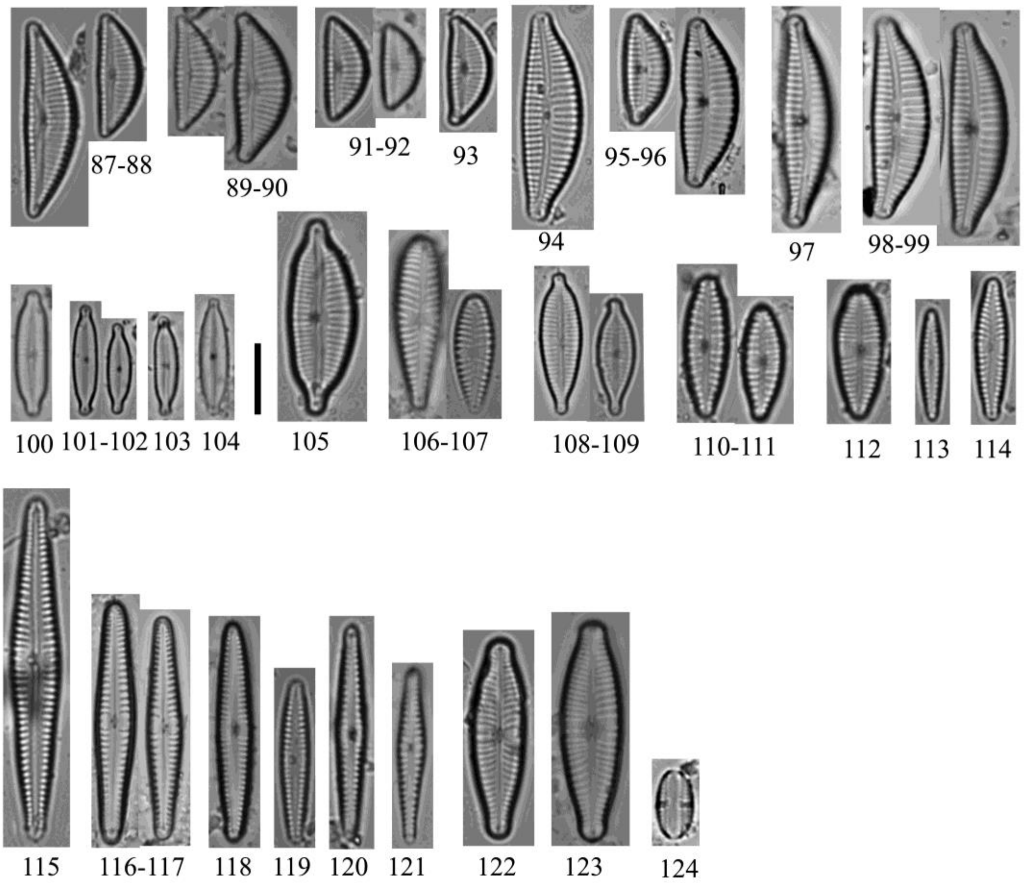
Surirella librile (Ehrenberg) Ehrenberg	Fig.19	Hofmann & al. (2011)	L: 74.63 µm W: 15.91 µm D: 10	2	+	+
Surirella sp.	Fig. 24	Krammer & Lange-Bertalot (1988)	L: 17.64 µm W: 8 µm F: 7	2	+	+
Tabellariaceae						
Diatoma moniliformis (Kützing) D.M.Williams	Figs 28-29	Krammer & Lange-Bertalot (1991b)	L: 14.97-29.82 µm W: 3.68-4.42 µm C: 7-9	1,2,3,4	+	+
Diatoma sp.	Fig.30	Hofmann & al. (2011)	L: 14.48 µm W: 4.91 µm C: 7	2,4	+	+
Diatoma vulgaris Bory	Figs 26-27	Krammer & Lange-Bertalot (1991b)	L: 29.95-47.48 µm W: 10.96-11.04 µm C: 6-8	1,2,3,4	+	+
Ulnariaceae						
Ulnaria acus (Kützing) Aboal	Fig. 38	Krammer & Lange-Bertalot (1991a)	L: 87.81 µm W: 4.21 µm S: 12	1,4	+	+
Ulnaria biceps (Kützing) Compère	Figs 43	Krammer & Lange-Bertalot (1991a)	L: 260 µm W: 5.61 µm S: 9	1,2,3	+	+
**Ulnaria contracta* (Østrup) E.A.Morales & M.L.Vis	Fig. 41-42	Morales & Vis (2007)	L: 192.48-103.30 µm W: 6.97 µm S: 10-12	1,2,3,4	+	+
Ulnaria cf. *rhombus* D.M.Williams	Fig. 39	Liu & al. (2019)	L: 101.29 µm W: 5.14 µm S: 13	3	+	+
Ulnaria ulna (Nitzsch) Compère	Fig. 40	Krammer & Lange-Bertalot (1991a)	L: 192.48-103.30 µm W: 6.97 µm S: 10-12	1,2,3,4	+	+
Cosinodiscophyceae						
Melosiraceae						
Melosira varians C.Agardh	Fig. 8	Krammer & Lange-Bertalot (1991a)	D:17.13 µm	2,3	+	-
Mediophyceae						
Stephanodiscaceae						
Cyclotella atomus Hustedt	Fig. 9	Krammer and Lange-Bertalot (1991a)	D: 7.31 µm S: 10	2	+	+
Cyclotella meneghiniana Kützing	Figs 4-5	Krammer and Lange-Bertalot (1991a)	D: 9.74-12.66 µm S:9-11	3,4	+	-
Pantocsekiella iranica Nejadsattari, Kheiri, Spaulding & Edlund	Figs 6-7	Kheiri & al. (2018a)	D:12.98-13.98 µm S: 5	2	-	+



Figs 4-43. Light Micrographs. 4-5, *Cyclotella meneghiniana*; 6-7, *Pantocsekiella iranica*; 8, *Melosira varians*; 9, *Cyclotella atomus*;10-11, *Achnanthidium* sp.$_1$; 12-13, *Achnanthidium minutissimum*; 14, *Achnanthidium gracillimum*; 15, *Achnanthidium* cf. *pyrenaicum*; 16, *Achnanthidium* sp.$_2$; 17, *Gyrosigma* sp.; 18, *Amphipleura pellucida*; 19, *Surirella librile;* 20-21, *Surirella lacrimula*; 22-23, *Surirella angusta*; 24, *Surirella* sp.; 25, *Caloneis bacillum*; 26-27, *Diatoma vulgaris*; 28-29, *Diatoma moniliformis*; 30, *Diatoma* sp.; 31, *Eunotia* sp.; 32-33, *Cocconeis lineata*; 34-35, *Cocconeis placentula* var. *euglypta*; 36, *Cocconeis placentula*; 37, *Reimeria sinuata*; 38, *Ulnaria acus*; 39, *Ulnaria* cf. *rhombus*; 40, *Ulnaria ulna*; 41-42, *Ulnaria contracta*; 43, *Ulnaria biceps*. Scale bar 10µm.



Figs 44-86. Light Micrographs. 44, *Navicula radiosa*; 45, *Navicula* sp.$_2$; 46, *Navicula tripunctata* sensu Bey & Ector (2013); 47-48, *Navicula tripunctata*; 49-50, *Navicula broetzii;* 51-52, *Navicula cryptotenella*; 53, *Navicula caterva*; 54, *Navicula vandamii* sensu Bey & Ector (2013); 55, *Navicula* cf. *antonii*; 56, *Navicula* sp.$_1$; 57-58, *Navicula capitatoradiata*; 59, *Navicula trivialis*; 60, *Navicula erifuga* sensu Bey & Ector(2013); 61, *Navicula gregaria*; 62, *Navicula* sp.$_3$; 63, *Craticula* cf. *accomoda*; 64, *Craticula* sp.; 65, *Nitzschia* sp.; 66, *Denticula kuetzingii*; 67, *Tryblionella* sp.; 68, *Hantzschia abundans*; 69, *Cymbella compacta*; 70, *Cymbella lange-bertalotii*; 71, *Cymbella tumida*; 72-73, *Nitzschia flexa*; 74, *Nitzschia heufleriana*; 75, *Nitzschia linearis*; 76, *Nitzschia recta*; 77, *Nitzschia paleaeformis*; 78, *Nitzschia* cf. *acicularis*; 79-80-81, *Nitzschia palea*; 82, *Nitzschia* cf. *desertorum*; 83-84, *Nitzschia dissipata*; 85-86, *Nitzschia dissipata* var. *media*. Scale bar 10µm.



Figs 87-124. Light Micrographs.87-88, *Encyonema silesiacum*; 89-90, *Encyonema ventricosum*; 91-92, *Encyonema minutum*; 93 *Encyonema lange-bertalotii* morphotype1; 94, *Cymbella exigua*; 95-96, *Cymbella excisa*; 97, *Cymbella* cf. *excisiformis*; 98-99, *Cymbella affinis* var. *neoprocera*; 100, *Encyonopsis* sp.; 101-102, *Encyonopsis minuta*; 103, *Encyonopsis microcephala*; 104, *Encyonopsis subminuta*; 105, *Cymbopleura* cf. *anglica*; 106-107, *Gomphonella olivacea;* 108-109, *Gomphonema parvulum*; 110-111, *Gomphonella* sp.$_{4}$; 112, *Gomphonema tergestinum*; 113, *Gomphonella* sp.$_{1}$; 114, *Gomphonema* cf. *cymbelliclinum*; 115, *Gomphonema* sp.$_{1}$; 116- 117, *Gomphonema* cf. *dichotomum*; 118, *Gomphonema* sp.$_{2}$; 119, *Gomphonema* sp.$_{3}$; 120, *Gomphonella* sp.$_{2}$; 121, *Gomphonella* sp.$_{3}$; 122, *Gomphonema productum*; 123, *Gomphonema micropus*; 124, *Amphora pediculus*. Scale bar 10µm.

Physicochemical data did not show large variation among the sites. Based on the majority of the widespread species found in the sites along the river, it can be concluded that the sites do show a slight difference in diatom assemblage from upstream to downstream of the river. The follow-up work will be the multi-variate analysis of sites, species and water quality variables to demonstrate the detailed distribution of the species along the main environmetal gradients.

This study is the baseline for the diatom biodiversity in the Zagros Mountains. Regarding to the Zagros Mountains as one of the major hotspots of endemism and biodiversity for the biota in the world (Noroozi & al. 2019a; Noroozi & al. 2019b), we could predict many new records and new taxa from this area. The comparison of the environmental values in this study with the *Water Health Organization* (WHO)'s standards, presented that the water quality in the river is good. It is important to note that based on physiocochemical data, the Kashkan River is characterized as an oligotrophic (Rott & al. 1997; Lamparelli 2004; OECD 1984), alkaline and mesothermal river (Van dam & al. 1994; Low 1974). With regard to the studies about the water trophy, many species found in the Kashkan River are reported from other oligotrophic aquatic ecosystems worldwide (Ramachandra & al. 2015; Venkatachalapathy & Karthikeyan 2015). Some olighotrophic species identified in the Kashkan River include *Achnanthidium minutissimum*, *Gomphonema parvulum*, *Nitzschia palea*, *Cyclotella meneghiniana*, *Encyonema minutum*, *Melosira varians* and *Surirella angusta*. They were also recorded as the elements of mesothermal rivers (Hall 1986).

Table 3. Physicochemical parameters in the Kashkan River, Spring 2019.

	Stations of KashkanRiver						
Parameters	1	2	3	4	Range (minimum–maximum) and mean ± SE	Water Standards	References
EC μScm^{-1}	330	350	337	331	330-350 337± 0.49	-	-
pH	8.23	8.25	8.30	8.49	8.23-8.49 8.31 ± 0.006	6.5-9.5	WHO, 2008
T °C	25	21	25	26	21-26 24.25 ± 0.12	-	-
NTU mg L^{-1}	**60**	**64.5**	**81.5**	**110**	60-110 79 ± 1.22	Less than 5	WHO, 2008
TDS mg L^{-1}	237	243	233	232	232-243 236.25 ± 0.27	1000	WHO, 2008
TSS mg L^{-1}	68	56	70	84	56-84 69.5 ± 0.62	-	-
NH_4 mg L^{-1}	0.40	0.24	0.14	0.14	0.14-0.4 0.23 ± 0.006	1.5	WHO, 2008
NO_3 mg L^{-1}	2	2.42	2.35	2.45	2-2.45 2.30 ± 0.01	50	WHO, 2008
NO_2 mg L^{-1}	0.02	0.02	0.019	0.018	0.018-0.02 0.019 ± 5.1	3	WHO, 2008
T N mg L^{-1}	2.56	3.39	3.86	3.07	2.56-3.86 3.22 ± 0.02	-	-
Organic nitrogen mg L^{-1}	0.13	0.71	1.36	0.46	0.13-1.36 0.66 ± 0.02	-	-
T PO_4 mg L^{-1}	0.05	0.19	0.12	0.20	0.05-0.2 0.14 ± 0.003	-	-

Factors higher than standards are marked with bold number.

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