SPATIAL VARIATION IN BENTHIC DIATOM COMMUNITIES IN RELATION TO SALINITY IN THE ARID DRÂA RIVER BASIN (SOUTHERN MOROCCO)

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Abstract. Many arid rivers worldwide are under increasing human pressures amplified by hydrological drought and climate change. The Oued Drâa River, Southern Morocco, suffers greatly from global warming and human activities' impacts leading to extreme changes in water salinity. This study aims to investigate spatial changes of benthic diatom community composition in the Drâa river and their relation to environmental factors especially water salinity. The results showed that salinity generally increases from upstream to downstream. A total of 86 diatom taxa belonging to 44 genera were recorded. The Upper Drâa sites were poorly productive in biomass and had diatom communities significantly different from those of the Middle Drâa. The Canonical Correspondence Analysis (CCA) showed that salinity, ion contents, pH and nutrients were the most important structuring factors of diatom assemblages. Oued El Malleh, the most natural salty site of Upper Drâa, was dominated by halotolerant diatoms, whereas the Iriri freshwater stream was characterized by halophobic and oligohaline species. However, the diatom composition of Middle Drâa sites was dominated by halophilic species that tolerate moderate salinity from anthropogenic sources. This survey provides a first inventory of the benthic diatom assemblages of Drâa river and highlights their spatial variability and sensitivity to environmental impacts.
Keywords: *desert river, Drâa basin, diatom assemblages, diversity, spatial distribution, salinity*

Introduction

Desert rivers are highly dynamic systems characterized by changing flow regime, hydromorphological and physicochemical features (Kingsford and Thompson, 2006; Harms et al., 2018). These rivers with intermittent flow are strongly shaped by contrasting hydrological events (drought and floods) and are abundant in arid, Mediterranean and North African regions where they are commonly called "wadis" (Wheater and Al Weshah, 2002; Sen, 2008). They are part of the so-called intermittent rivers and ephemeral streams (IRES) that share the common characteristics of water scarcity, cessation of surface flow at some point of time and space as well as high spatial and temporal variability of habitats during the hydrological cycle (Stanley et al., 1997; Datry et al., 2017). In arid and semi-arid regions such North Africa, human pressures on riverscapes are particularly strong and several activities may affect the

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river flow regimes often modified by dam construction, surface and groundwater abstraction and land uses (Malmqvist and Rundle, 2002; Vörösmarty et al., 2010).

The Drâa river, southern Morocco, is one of the most arid river basins in the world spanning from the High Atlas Mountains to the Sahara Desert in the south, with increasing aridity along a north southeast direction (Carrillo-Rivera et al., 2013). Owing to the increasing frequency of dry years and prolonged dry periods, the sustainability of the water supply (drinking water and irrigation) and the oases of the Middle Drâa valley is strongly threatened. Both climate change and the overuse of water resources in the catchment area are leading to falling groundwater levels and increasing salinization of soils and waterways (Speth et al., 2010; Johannsen et al., 2016). In addition, rivers in the Drâa basin are mostly ephemeral, depending on rainfall or snowmelt, and are often naturally saline due to high evaporation and geology (primary salinization) (Bailey et al., 2006). However, this salinization is amplified, especially in the downstream, through anthropogenic changes in the hydrologic cycle (e.g. dams) and in catchment land-use (e.g. agriculture, intensive irrigation) (secondary salinization) (Potapova and Charles, 2003; Cañedo-Argüelles et al., 2013; Nhiwatiwa et al., 2017). Increased salinization in this intermittent river also endangers ecosystem services such as drinking water quality and agricultural yields (Stevenson and Smol, 2015; Berger et al., 2019).

Salinization of rivers is known to affect the species composition of riverine biota through a reduction in biodiversity (Williams, 1987; Piscart et al., 2005; Cañedo-Argüelles et al., 2013; Schröder et al., 2015). For instance, when salinity levels increase, some species react sensitively potentially leading to population decline or disappearance (Williams and Williams, 1998; Piscart et al., 2006). Chemical changes such as variations in salinity affect the physiological response of species in aquatic ecosystems, namely diatoms (Bere and Tundisi, 2011a). In rivers and streams, benthic diatoms are the most widespread, diverse and species-rich group of benthic algae (Lowe and LaLiberte, 2017). Therefore, they form a large portion of total algal biomass and a major source of energy for aquatic food webs as primary producers (Stevenson et al., 1996; Pan et al., 1999). Photosynthesis by periphytic algae, in general, and diatoms in particular, provides oxygen to aerobic organisms (Lowe and LaLiberte, 2017), so that any change in their composition and structure can affect the growth, development, survival and reproduction of many organisms in aquatic ecosystems (Campeau et al., 1994).

Moreover, diatoms are considered as an excellent bioindicator for water quality monitoring (Lange-Bertalot, 1979; Potapova and Charles, 2005; Centis et al., 2010; Stevenson and Smol, 2015). Because they are very sensitive to physical, chemical, pollution and salinity disturbances, their composition and abundance respond to several environmental factors such as nutrients, pH and conductivity (Potapova and Charles, 2002). Benthic diatom-based assessments to quantify river pollution and impairment have been used worldwide, especially in EU countries and the USA (Charles et al., 2021).

Despite the importance of the Drâa basin as one of the most important oasis areas in South of Morocco, benthic algal and diatoms communities in particular, remain poorly understood compared to other aquatic groups such as fish (Qninba et al., 2011; Clavero et al., 2015, 2017), turtles (Loulida et al., 2019), aquatic and semi-aquatic plants (Mostakim et al., 2020), mammals (Riesco et al., 2020) and invertebrates (Berger et al., 2021). Therefore, this study aims to investigate the diversity of benthic diatoms communities in this desert intermittent river and to assess the salinity effects

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on their composition and spatial distribution. This information allows us to better understand the autecology of diatoms in IRES in relation to salinity (conductivity and major ions). Our hypotheses were that, changes in salinity would be reflected in diatom community composition which could be used as bioindicator of salinization and human impacts.

Material and methods

Study area and sampling sites

The study was carried out in the Drâa river basin (~115,000 km²) located in southern Morocco (*Fig. 1*). This river is formed by the confluence of several perennial, intermittent and ephemeral rivers and streams from High Atlas such Dades, Imini, Iriri, El Malleh and from Anti Atlas such Ait Douchen (Warner et al., 2013). The Drâa river basin is subdivided into three sub-basins the Upper Drâa, the Middle Drâa and the Lower Drâa. The Upper Drâa subcatchment is part of the Ouarzazate province, extends from the High Atlas summits to outlet at the Mansour-Eddahbi (ME) reservoir, while the Middle Drâa, belonging to the Zagora province, is drained from ME dam up to the M'hamid oasis (Schulz et al., 2008). The altitude of the basin ranges from 450 to 4071 m above sea level (Diekkrüger et al., 2012). The area is characterized by an increasing north-southeast aridity gradient with average annual precipitation ranging from 600 to 700 mm on the southern slopes of the High Atlas Mountains in the north to 200 mm in the valley, and 60 mm in the southern section, whereas evaporation is very important, varying between 2000 and 3000 mm/year (Karmaoui et al., 2015). Regarding hydrological regime of the Drâa river, the Upper Drâa valley has an undisturbed natural hydrological regime of the semi-arid subtropics, except for Iriri stream, which has been recently (2013) regulated by the Sultan Moulay Ali Cherif dam, while the hydrology of the Middle Drâa subcatchment is controlled by water releases from the ME dam. The Upper and Middle Drâa sub-basins are more densely populated especially alongside the rivers, owing to the water availability for drinking and irrigation (Diekkrüger et al., 2012). The Middle Drâa valley is mainly rural and its economic activities remains highly dependent on irrigated agriculture, oasis and tourism (Karmaoui et al., 2014).

Sampling of benthic diatoms was carried out in March 2018 at seven sites (*Fig. 1* and *Appendix 1*). Three sites (S1, S2 and S3) in the Upper Drâa streams (Iriri, El Malleh and Ait Douchen respectively) and four sites (S4, S5, S 6 and S7) in the Middle Drâa valley (oued Drâa at Kasbah Tamnogalt, Taghzout, Zagoura and Tamgroute localities). *Table 1* provides description of the sampling sites, their substrate type and vegetation.

Hydrological and physicochemical parameters

At each sampling site, water temperature (°C), dissolved oxygen (mg/L), pH, electrical and conductivity (µS/cm) and salinity (g/L) were measured *in situ* at the time of sampling using a Hanna HI98194 multi-parameter device (Hanna Instruments, USA). Flow velocity (m/s) and flow rate (m^3 /s) were determined using current meter (OTT hydromet GmbH, Germany) by taking three measurements across the width of the river for each site.

Water samples from each site were collected in PVC bottles (1 L) already well rinsed, and stored in cooler for transport to the laboratory. According to Rodier et al.

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(2009) analytical methods, the water samples were measured for ammonium (NH_4^+), orthophosphate (PO_4^{3-}), total alkalinity (HCO_3^-), total hardness ($CaCO_3$), sulfate (SO_4^{2-}) and chloride (Cl^-).

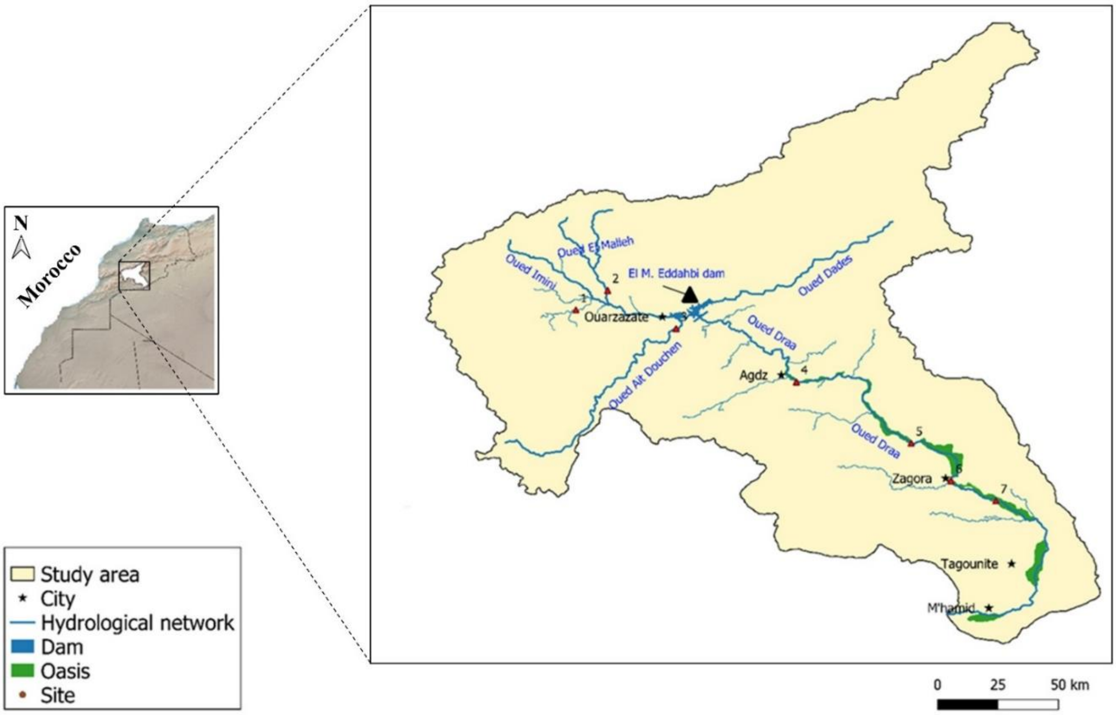

Figure 1. *Location of the study area and sampling sites in Drâa basin*

Table 1. *Description of sampling sites*

Sub-basins	Streams	Sampling site	Coordinates	Altitude (m)	Localization	Substratum type	Vegetation
Upper Drâa	Iriri	1	N: 30°93’75.7” W: 007°21’06.3”	1234	Three Km downstream of the Sultan Moulay Ali Cherif dam	Stones, pebbles and muddy sediments	Aquatic macrophytes, filamentous algae
Upper Drâa	El Malleh	2	N: 31°00’39.6” W: 007°06’0.2”	1028	downstream of Ait Benhaddou Kasbah	Pebbles, silts, clays and muds	*Phragmites australis* and *Tamarix gallica*
Upper Drâa	Ait Douchen	3	N: 30°52’13.7” W: 006°50’54.0”	874	Oued Ait Douchen (near to Tarmigte locality)	Stones, clays and silts	Abundance of vegetation composed mainly of *Nerium oleander*, herbaceous, *Potamogeton nodosus* and filamentous algae floating on the surface
Middle Drâa	Drâa	4	N: 30°40’26.4’’ W: 006°24’21,599”	908	Downstream of Agdz (Kasbah Tamnogalt locality)	Sands, clays strewn with stones and pebbles	Highly developed, *Tamarix gallica*, *Nerium oleander* and *Juncus acutus*
Middle Drâa	Drâa	5	N: 30°26’55.3” W: 005°59’3.1”	781	Just before Ternata oasis (Taghzout locality)	Stones and pebbles	*Phoenix dactylifera* (oasis), *Arundo donax* and *Acacia tortilis*
Middle Drâa	Drâa	6	N: 30°32’23.6” W: 005°83’23.0”	711	At the Zagora city	Stones, pebbles and muddy deposits	Highly degraded vegetation due to human disturbance
Middle Drâa	Drâa	7	N: 30°14’12,5” W: 5°40’21”	678	20 km downstream of the Zagora city (Tamgroute locality)	Stones and pebbles	Highly developed, *Tamarix gallica*

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Benthic diatoms sampling

Epilithic biofilm was sampled at each site by brushing stones with a toothbrush. Prior to sampling of epilithic surfaces, all substrata were gently shaken in stream water to remove any loosely attached sediments and non-epilithic diatoms. The pebble to cobble sized rocks/stones were randomly collected at different points of each sampling site across a 100 m long section to sample all microhabitats in riffles and pools. After brushed, the resulting periphytic suspensions were combined into single sample per site. For quantitative sampling, the biofilm sample was obtained by brushing a defined surface (at least 10 × 10 cm) of the substratum. All samples were divided into defined amounts, placed in labelled plastic bottles and preserved in Lugol solution, except for subsamples subjected to chlorophyll *a* analysis, and all transported to the laboratory for qualitative and quantitative analysis.

Treatment and taxonomic identification of diatoms

After homogenization of biofilm samples, an aliquot from each site was digested using concentrated hydrogen peroxide (30%) and hydrochloric acid (35%) to remove organic matter and calcium carbonates. After repeated rinsing and centrifugation with distilled water, the cleaned diatom suspensions were then mounted on glass slide using Naphrax® (IR = 1.7) high refractive mounting medium for taxonomic identification and counting. Diatoms slides were observed under 400–1000× magnification using a Motic BA210 light microscope (Motic®, China) and species were identified based on (Krammer and Lange-Bertalot, 1986; Krammer and Lange-Bertalot, 1988; Krammer, 1991a, 1991b). Diatom synonymy was updated by Algaebase (Guirry and Guirry, 2020). A minimum of 400 diatom valves were counted from each slide to calculate the relative abundance (in %) of diatom species. Only those taxa with an abundance more than 1% of the total sample were included for further statistical analysis.

Diatom total abundance

To determine the diatom total abundance (cells.cm^{-2}), a known surface of each homogenous biofilm sample was placed in a glass slide (24 × 60 mm). The total of diatom valves was counted from each slide at 1000× magnification using a Motic BA210 light microscope (Motic®, China). Diatom abundance was expressed in number of cells.cm^{-2}.

Diatom diversity and similarity indices

Diatom species richness (S), Shannon diversity index (H’) (Shannon and Weaver, 1963), Pielou’s species evenness (E) (Pielou, 1966) and Simpson’s diversity index (SDI) (also known as Species Diversity Index) (Simpson, 1949) were calculated. H’ is more subtle to rare species than SDI, gave more weight to common species, while E gave an indication of the equitability of species in the population (homogeneity). Similarity in taxonomic composition of diatom community between the sites was analyzed using Sorensen index (Sorensen, 1948). The formulas are as follows (*Eqs. 1, 2, 3* and *4*):

Shannon–Weaver diversity (H’) index:

$$H' = -\sum P_i log_2 P_i ; \quad P_i = {n_i}/{N} \qquad \text{(Eq.1)}$$

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where n_i = number of individuals of species *i*; *N* = total number of individuals in the site.

Pielou's evenness index (E):

$$E = H'/\log_2 S \quad \text{(Eq.2)}$$

where *H*': Shannon index; *S*: number of species present.

Simpson Diversity Index (SDI):

$$SDI = 1 - \sum p^2 \quad \text{(Eq.3)}$$

where *p* = the proportion (*n*/*N*) of individuals of one particular species found (*n*) divided by the total number of individuals found (*N*).

Sorensen (Qs) index:

$$Q_s = 2j/a + b \quad \text{(Eq.4)}$$

where *a* = total number of species at site A; *b* = total number of species at site B; *j* = total number of common species between the two sites A and B.

Biofilm biomass

Dry weight measurement

A known surface of each homogenous biofilm sample was centrifugated at 6000 rpm for 15 min, then the pellet was dried in an oven at 105 °C to constant weight (dry weight, W1) using a previously weighed porcelain capsules (W0). The biofilm dry weight (DW) was then calculated on the basis of the difference between W1 and W0 and values expressed as mg dw.cm^{-2}**.** The porcelain capsules were then transferred to a muffle furnace type N3/R (Nabertherm®, Germany) at 550 °C and ashed for 5 h. Ash-free dry weight (AFDW) (i.e. organic matter dry mass) was calculated by the difference between the weight of the residue calcined at 550 °C (W2) and (W1).

Chlorophyll a analysis

Biofilm biomass was determined by measuring Chlorophyll *a* (Chl-*a*) content according to the protocol of (Millerioux, 1975). Chlorophyll *a* content was measured spectrophotometrically by recording absorbance at 630, 664 and 750 nm and using the equation of Jeffrey and Humphrey (1975), as follows (*Eq. 5*):

$$Chl - a\left(\mu g/ml\right) = 11.47(A_{630} \times A_{750}) - 0.4(A_{664} \times A_{750}) \quad \text{(Eq.5)}$$

Chlorophyll *a* is expressed in µg/ml and converted to µg/cm².

Statistical analysis

The analysis of water physicochemical and algal biomass parameters was done in triplicate and the results are given in mean ± standard error (SE). Pearson's correlation was used to determine the relationships between environmental variables and diatom diversity indices (species richness S, H', E and SDI). One-way analysis of variance

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ANOVA and Tukey's honest significance test were used to find significant differences between sampling sites. Canonical correspondence analysis (CCA) was performed to assess the correlations between diatom assemblages and environmental variables and identify the main explanatory factors for their diversity and distribution (Šmilauer and Lepš, 2014). The Pearson correlation and cluster dendrogram were carried out using PAST version 4.02. The ANOVA was performed using SPSS Statistics, Version 23.0. The CCA analysis was carried out using Canoco software version 5.

Results

Hydrological and physicochemical parameters

The hydrological and physicochemical parameters measured *in situ* or in laboratory (mean ± SD) are reported in *Table 2*.

Table 2. *Physicochemical and hydrological parameters of sampled sites*

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Water T (°C)	22.8	21.7	15.9	18.4	26.6	22.3	20.3
pH	8.7	7.77	8.22	7.89	7.9	7.96	7.91
EC (µS.cm^{-1})	385.5	7090	1154	2050	5670	4533	3110
Salinity (g.L^{-1})	0.194	4.187	0.704	1.211	2.961	2.561	1.798
Dissolved oxygen (mg.L^{-1})	8.64	8.4	9.26	9.1	12.56	9.22	6.99
NH_4^+(µg.L^{-1})	24.36±0.003	0±0.00	5.96±0.001	22.87±0.001	0±0.00	11.43±0.003	13.42±0.00
PO_4^{3-}(µg.L^{-1})	44.88±3.73	52.53±1.30	181.30±37.98	47.38±3.92	72.53±20.06	28.25±0.37	90.88±4.38
HCO_3^- (mg.L^{-1})	194±2.82	132±5.65	190±2.82	184± 5.60	78±2.82	172±5.65	164±5.65
$CaCO_3$(mg. L^{-1})	178.67±6.11	1832±0.00	429.33±4.61	793.33±2.30	693.33±2.30	1492±0.00	546.66±2.30
SO_4^{2-}(mg.L^{-1})	8.97±0.067	77.39±0.87	10.45±0.68	31.82±0.22	19.73±0.13	46.41±2.60	30.58±0.93
Cl^- (g.L^{-1})	0.02±0.008	1.88±0.00	0.16±0.008	0.29±0.008	1.29±0.00	0.96±0.008	0.47±0.01
Flow velocity (m.s^{-1})	0.7544±0.12	0.603±0.15	0.0134±0.5	0.390±0.25	0.327±0.25	0.288±0.3	0.146±0.2
Flow rate (m^3.s^{-1})	1.30±0.25	0.9±0.2	0.0104±0.06	0.708±0.25	0.315±0.85	0.32±1.58	0.269±0.105

The hydrological variables showed spatial variation and significant differences between the Upper Drâa and Middle Drâa sites. The flow velocity values varied between 0.7544 m.s^{-1} in site 1 and 0.146 m.s^{-1} in site 7 with a significantly decreasing upstream-downstream gradient. In the downstream part of the Ait Douchene (site 3), the stream was mainly dominated by large pools and the water flow is extremely low (0.0134 m.s^{-1}). The Upper Drâa sites showed highest flow rates compared to the Middle Drâa sites which are regulated by the large ME reservoir and by small weirs throughout the southern oases. These hydraulic systems cause significant changes in runoff and a great hydro-morphological heterogeneity of the surface flow and habitats which was mostly reduced to isolated or weakly connected pools with varying degrees of intermittency.

The water physicochemical parameters showed spatial variability and significant differences between the Upper Drâa and Middle Drâa sites. The electrical conductivity values showed spatial variability ranging from 385.5 µS.cm$^-$ to 7090 µS.cm^{-1}. Except for site 2 of Oued El Malleh with a significantly high salinity (4.187 g/L), water conductivity and salinity increase gradually from the Upper to the Middle Drâa basin. The major anions (Cl^-, SO_4^{2-}, CO_3^-) showed the same spatial variation with the highest contents in oued El Malleh and the Middle Drâa downstream sites. The water pH ranged from 7.77 to 8.7 with highest values at sites 1 and 3. Ammonium concentrations were

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very low at all sampling sites, however sites 1 (24.36 µg.L^{-1}), site 4 (22.87 µg.L^{-1}) and site 7 (13.42 µg.L^{-1}) had the highest values compared to the other sites. For phosphorus, site 3 had the highest content (181.30 µg.L^{-1}) compared to the other sites, followed by site 7 (97.88 µg.L-1), both of these sites recorded values greater than 76 µg.L^{-1} which indicates a highly productive or eutrophic system according to The Trophic Status Classification of U.S. Streams (Stackpoole et al., 2019).

Benthic diatoms diversity analysis

Diatom composition

A total of 86 diatom species belonging to 44 genera were identified in all prospected sites as illustrated in *Table 3*. There were a few taxa that could not be identified to the species level because of their very small size, which requires further in-depth morphological investigations. These unidentified species belong mainly to the genera *Navicula* and *Nitzschia*. The Drâa phytobenthic community was mostly represented by pennate diatoms while centric diatoms were represented by only two taxa only (*Fig. 2*). The highest number of taxa belonged to *Nitzschia* (15 species) followed by *Navicula* (9 species), *Caloneis* (4 species), *Amphora* and *Sellaphora* with 3 species for each one.

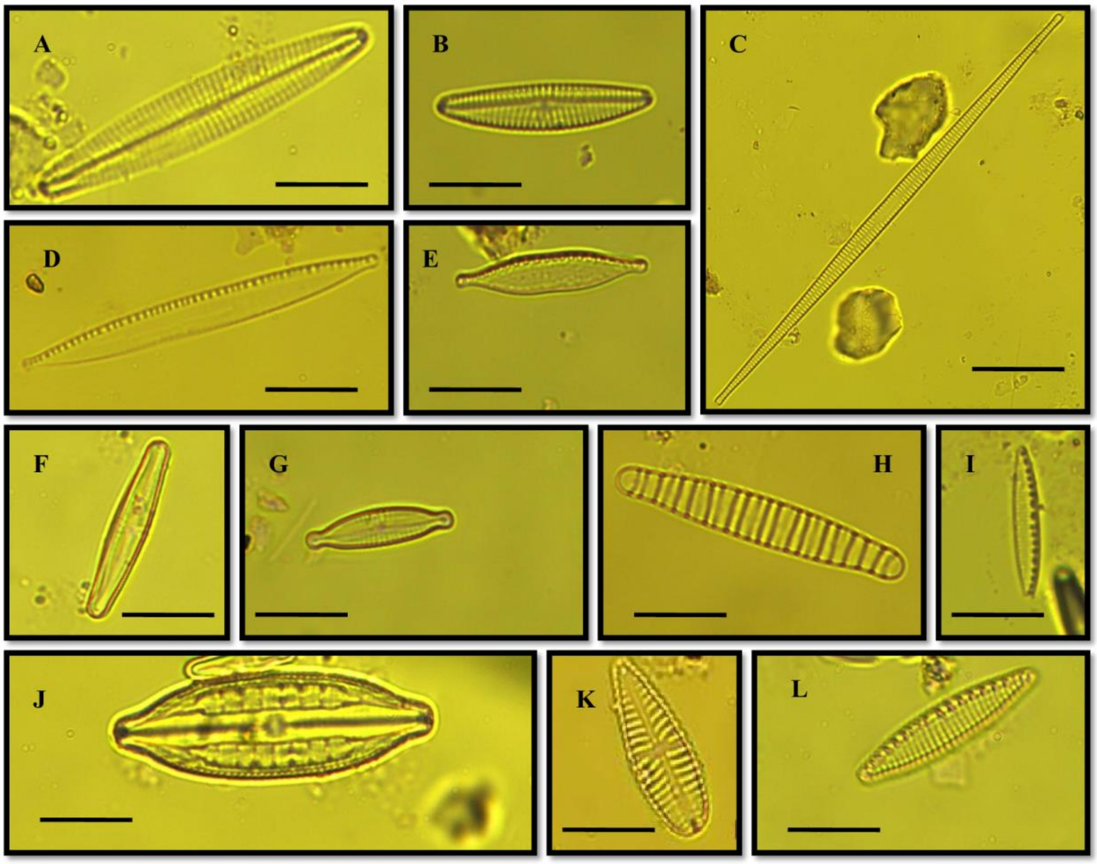

Figure 2. *LM photomicrographs of some characteristic diatoms. A: Haslea stundlii; B: Navicymbula pusilla; C: Ulnaria acus; D: Nitzschia palea; E: Nitzschia elegantula; F: Achnanthidium minutissimum; G: Encyonopsis microcephala; H: Diatoma moniliformis; I: Nitzschia frustulum; J: Mastogloia smithii; K: Gomphonella olivacea; L: Homoeocladia amphibia. Scale bar:10 µm*

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Table 3. *List of the identified diatoms in the sampling sites. (+) presence*

Taxon/site	Code	1	2	3	4	5	6	7
Pennate diatoms								
G/Achnanthidium								
Achnanthidium minutissimum (kützing) Czarnecki	ADMI	+	+	+	+	+	+	+
G/Amphora								
Amphora coffeaeformis var. *acutiuscula* (Kützing) Rabenhorst	ACOFA		+					
Amphora inariensis Krammer	AINA					+		
Amphora pediculus (Kützing) Grunow	APED			+	+	+		
G/Anomoeoneis								
Anomoeoneis vitrea (Grunow) R.Ross	AVIT				+	+	+	
G/Bacillaria								
Bacillaria paxillifera (O.F.Müller) T.Marsson	BPAX				+			
G/Caloneis								
Caloneis amphisbaena (Bory) Cleve	CAMH			+	+	+	+	+
Caloneis macedonica Hustedt	CMAC							+
Caloneis silicula (Ehrenb.) Cleve	CSIL			+	+	+	+	
Caloneis thermalis (Grunow) Krammer	CTHE				+			
G/Cocconeis								
Cocconeis pediculus Ehrenberg	CPED	+		+	+			
Cocconeis placentula Ehrenberg	CPLA	+		+	+	+		
G/Craticula								
Craticula riparia (Hustedt) Lange-Bertalot	CRIP			+				
Craticula subminuscula (Manguin) C.E.Wetzel & Ector	CSUB		+	+				
G/Ctenophora								
Ctenophora pulchella (Ralfs ex Kützing) D.M.Williams & Round	CPUL		+	+				
G/Cymatopleura								
Cymatopleura solea (Brébisson) W.Smith	CSOL			+				
G/Cymbella								
Cymbella affinis (Krammer)	CAFF	+	+		+	+	+	+
Cymbella proxima Reimer	CPRO			+		+		
G/Cymbopleura								
Cymbopleura amphicephala (Nägeli ex Kützing) Krammer	CAMP		+		+	+		
G/Diatoma								
Diatoma moniliformis (Kützing) D.M.Williams	DMON	+		+	+	+	+	+
G/Diploneis								
Diploneis elliptica (Kützing) Cleve	DELL				+	+		
Diploneis ovalis (Hilse) Cleve	DOVA	+			+	+	+	+
G/Encyonopsis								
Encyonopsis microcephala (Grunow) Krammer	EMIC	+	+	+	+	+	+	+
G/Entomoneis								
Entomoneis paludosa (W.Smith) Reimer	EPAL				+		+	+
G/Epithemia								
Epithemia sorex Kützing	ESOR			+				
G/Fallacia								
Fallacia pygmaea (Kützing) Stickle & D.G.Mann	FPYG			+	+	+	+	
G/Fragilaria								
Fragilaria capucina var. *vaucheriae* (Kützing) Lange-Bertalot	FCAPV	+			+	+	+	+
Fragilaria crotonensis Kitton	FCRO	+						
G/Geissleria								
Geissleria acceptata (Hust.) Lange-Bert. and Metzeltin	GACC		+					
G/Gomphonella								
Gomphonella olivacea (Hornemann) Rabenhorst	GOLI	+		+	+	+		
Gomphonella calcarea (Cleve) R.Jahn & N.Abarca	GCAL	+		+				
G/Gomphonema								

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Gomphonema angustum C.Agardh	GANG	+		+	+			
Gomphonema parvulum (Kützing) Kützing	GPAR	+		+		+	+	+
G/Gyrosigma								
Gyrosigma scalproides (Rabenhorst) Cleve	GSCA	+	+				+	
G/Halamphora								
Halamphora coffeaeformis (C.Agardh) Mereschkowsky	HCOF		+					
Halamphora veneta (Kützing) Levkov	HVEN			+				
G/Hantzschia								
Hantzschia amphioxys (Ehrenberg) Grunow	HAMP							+
Hantzschia virgata (Roper) Grunow	HVIR							+
G/Haslea								
Haslea stundlii (Hustedt) Blanco, Borrego-Ramos & Olenici	HSTU		+			+	+	
G/Homoeocladia								
Homoeocladia amphibia (Grunow) Kuntze	HAMP			+				
G/Luticola								
Luticola mutica (Kützing) D.G.Mann	LMUT		+					
G/Mastogloia								
Mastogloia elliptica (C.Agardh) Cleve	MELL		+			+		
Mastogloia smithii Thwaites ex W.Smith	MSMI		+				+	
G/Melosira								
Melosira varians C.Agardh	MVAR	+			+			
G/Navicula								
Navicula cryptocephala Kützing	NCRY				+			
Navicula cryptotenella Lange-Bertalot	NCRT	+	+		+	+		
Navicula gregaria Donkin	NGRE		+		+			+
Navicula phyllepta Kützing	NPHY	+	+		+	+	+	
Navicula recens (Lange-Bertalot) Lange-Bertalot	NREC		+		+			
Navicula tripunctata (O.F.Müller)Bory	NTRI		+	+			+	
Navicula veneta Kützing	NVEN		+	+			+	+
Navicula sp1	NSP1			+				
Navicula sp2	NSP2			+				
G/Navicymbula								
Navicymbula pusilla (Grunow) Krammer	NPUS		+			+	+	+
G/Navigeia								
Navigeia decussis (Østrup) Bukhtiyarova	NDEC		+	+				
G/Nitzschia								
Nitzschia bergii Cleve-Euler	NBER		+		+	+		+
Nitzschia clausii Hantzsch	NCLA		+		+			
Nitzschia communis Rabenhorst	NCOM		+					
Nitzschia constricta (Kützing)	NCON	+	+	+	+	+		
Nitzschia denticula Grunow	NDEN					+	+	+
Nitzschia dissipata (Kützing) Rabenhorst	NDIS				+	+		+
Nitzschia dubia W.Smith	NDUB		+		+			
Nitzschia elegantula Grunow	NELE		+			+	+	+
Nitzschia frustulum (Kützing) Grunow	NFRU		+					
Nitzschia homburgiensis Lange-Bertalot	NHOM							+
Nitzschia inconspicua Grunow	NINC			+				
Nitzschia microcephala Grunow	NMIC		+					+
Nitzschia palea (kützing) W. smith	NPAL		+	+	+	+	+	+
Nitzschia tryblionella Hantzsch	NTRY				+			
Nitzschia sp.	NSPE		+			+	+	+
G/Planothidium								
Planothidium lanceolatum (Brébisson ex Kützing) Lange-Bertalot	PLAN			+	+			
G/Pseudostaurosira								
Pseudostaurosira brevistriata (Grunow) D.M.Williams & Round	PBRE			+	+			+
G/Tabularia								

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Tabularia fasciculata (C.Agardh) D.M.Williams & Round	TFAS	+		+	+	+	+	+
G/Tryblionella								
Tryblionella calida (Grunow) D.G.Mann	TCAL				+		+	+
G/Rhoicosphenia								
Rhoicosphenia abbreviata (C.Agardh) Lange-Bertalot	RABB	+	+	+	+			
G/Rhopalodia								
Rhopalodia gibba (Ehrenberg) Otto Müller	RGIB	+		+	+	+	+	+
Rhopalodia gibberula (Ehrenberg) Otto Müller	RGBB		+		+			+
G/Sellaphora								
Sellaphora bacillum (Ehrenberg) D.G.Mann	SBAC			+				
Sellaphora pupula (Kützing) Mereschkovsky	SPUP			+		+	+	
Sellaphora stroemii (Hustedt) H.Kobayasi	SSTR				+	+		
G/Surirella								
Surirella brebissonii Krammer& Lange-Bertalot	SBRE		+					
Surirella peisonis Pantocsek	SPEI			+				
G/Ulnaria								
Ulnaria acus (Kützing) Lange-Bertalot	UACU			+	+	+	+	
Ulnaria ulna (Nitzsch) Lange-Bertalot	UULN	+			+	+	+	+
Centric diatoms								
G/Cyclotella								
Cyclotella meneghiniana Kützing	CMEN			+	+	+	+	+
G/Pantocsekiella								
Pantocsekiella ocellata (Pantocsek) K.T.Kiss & Ács	POCE	+			+	+	+	+
Total species = 86		23	35	39	45	38	31	31

Species richness and diversity indices

The species richness (S), Shannon–Weaver diversity (H'), Pielou's species evenness (E) and Simpson indices of diatom community are shown in *Table 4*. The highest species richness was found in Middle Drâa at site 4 (45 taxa), while the lowest value was recorded in the Upper Drâa at site 1 (23 taxa). The Shannon index was much higher in Middle Drâa sites (especially at S4 and S5) and rather low in the upstream sites of the basin (2.19 at site 1). Similarly, the highest species evenness values were recorded in the Middle Drâa sites (0.74 at site 5). Simpson diversity index followed the same trend as Shannon index with the highest diversity value at site 4.

The Pearson correlation analysis was further used to elucidate the relationships between diatoms diversity indices (H', SDI and E) and the environmental variables (*Fig. 3*). The results showed that diatom species richness was negatively correlated with pH (r = -0.61). No significant correlation was detected between diatom species richness and salinity or major ions contents.

Table 4. *Species richness (S), Shannon–Weaver diversity (H'), Pielou's species evenness (E) and Simpson indices of diatom community in each sampling site*

Indices	S1	S2	S3	S4	S5	S6	S7
Species richness (S)	23	35	39	45	38	31	31
Shannon (H')	2.19	2.47	2.49	2.72	2.70	2.51	2.38
Evenness (E)	0.70	0.69	0.68	0.71	0.74	0.73	0.69
Simpson (SDI)	0.85	0.85	0.86	0.91	0.89	0.87	0.83

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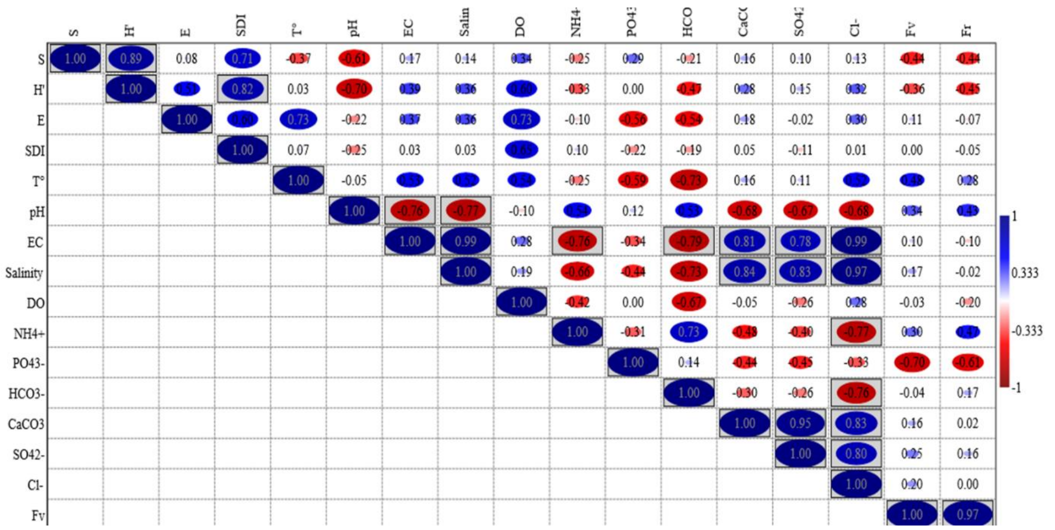

Figure 3. *Pearson correlation coefficient values of biological indices with environmental variables. S. Species richness, H'. Shannon index, E. Evenness, SDI. Simpson index, Sal. Salinity, EC. Conductivity, Fv. Flow velocity, Fr. Flow rate. Boxed Circle with coloration: correlation is significant at the 0.05 level (2-tailed). blue circle: positive correlation, red: negative correlation*

In order to compare the different sites and to evaluate the variation of benthic diatom diversity along the upstream-downstream gradient, we calculated the Sorensen similarity index. The results of the inter-sites similarity matrix are given in *Table 5*. The most similar sites (Qs ranging from 0.53 to 0.72) are located in the Middle Drâa, whereas the least similar are those of the Upper Drâa, particularly sites 2 and 3. *Figure 4* shows a dendrogram grouping the sampling sites according to their similarities. The dendogram distinguished three clusters. The first cluster corresponds to site 3 characterized by diatoms only found at this site namely *Cymatopleura solea*, *Epithemia sorex*, *Homoeocladia amphibia*, *Halamphora veneta* and *Nitzschia inconspicua*. The second cluster includes all the sites of Middle Drâa (4, 5, 6 and 7) plus the site 1 of Upper Drâa. All these sites were characterized by numerous common diatom species such as *Cymbella affinis*, *Diploneis ovalis*, *Diatoma moniliformis*, *Pantocsekiella ocellata*, *Ulnaria ulna* and *Fragilaria capucina* var. *vaucheriae.* The third cluster corresponds to site 2 characterized by typical halotolerant species such as *Nitzschia frustulum*, *Nitzschia communis*, *Halamphora coffeaeformis*, *Geissleria acceptata*, *Luticola mutica* and *Surirella brebissonii*. Only *Achnanthidium minutissimum* and *Encyonopsis microcephala* were common to all sites with variable relative abundances.

Table 5. *Sorenson similarity matrix of the studied sites*

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
S1	**1**	0.28	0.42	0.57	0.52	0.48	0.44
S2	0.28	**1**	0.27	0.38	0.38	0.39	0.33
S3	0.42	0.27	**1**	0.48	0.47	0.43	0.31
S4	0.57	0.38	0.48	**1**	0.66	0.53	0.56
S5	0.52	0.38	0.47	0.66	**1**	0.72	0.58
S6	0.48	0.39	0.43	0.53	0.72	**1**	0.68
S7	0.44	0.33	0.31	0.56	0.58	0.68	**1**

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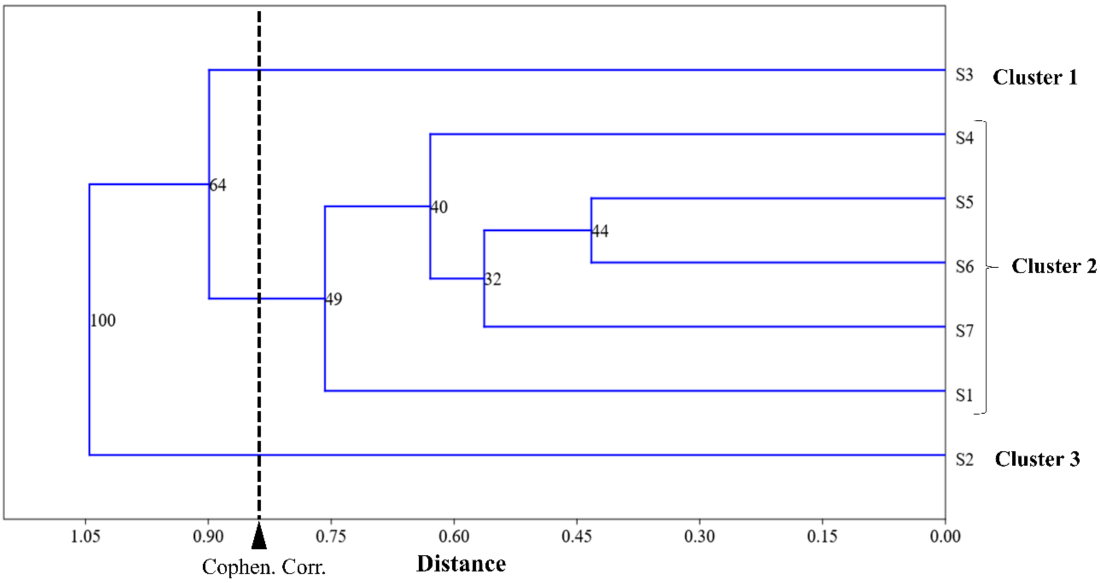

Figure 4. *Cluster dendrogram of inter-sites similarity. Cophenetic correlation coefficient at 0.86*

Quantitative diatoms analysis

Diatoms relative abundance

The distribution of diatom species relative abundances varied significantly between the different sites (*Fig. 5*). The diatom community of site 1 was mainly dominated by *Gomphonella olivacea* (26%), *Diatoma moniliformis* (25%), *Cymbella affinis* (16%) and *Ulnaria ulna* (14%). In site 2, *Nitzschia frustulum* was the most dominant species (30%) and was only found at this site followed by *Achnanthidium minutissimum* (18%), *Mastogloia smithii* (11%), *Navicymbula pusilla* (10%) and *Nitzschia microcephala* (8%). *Gomphonema angustum*, *Achnanthidium minutissimum*, *Encyonopsis microcephala*, *Homoeocladia amphibia* and *Nitzschia inconspicua* were the dominant species at site 3 with 25%, 23%, 16%, 7% and 5%, respectively. In site 4, *Ulnaria ulna* (21%), *Diatoma moniliformis* (16%) *Fragilaria capucina var. vaucheriae* (16%), *Cyclotella meneghiniana* (9%), *Tabularia fasciculata* (8%) and *Nitzschia dissipata* (7%) were the dominant species. At site 5, the abundant species were *Nitzschia elegantula* (21%), *Achnanthidium minutissimum* (17%) and *Encyonopsis microcephala* (14%). *Achnanthidium minutissimum* was the most dominant species in site 6 (28%) followed by *Nitzschia elegantula* (13%), *Gomphonema parvulum* (11%) and *Ulnaria ulna* (11%). This latter species also dominated (27%) the diatom assemblage at site 7 followed by *Rhopalodia gibba* (12%), *Navicula veneta* (9%) and *Nitzschia palea* (6%).

Biofilm total biomass

The biofilm biomass parameters (DW, AFDW, Chl *a* and cell diatoms.cm^{-2}) showed spatial variation and significant differences ($p < 0.05$) were observed between the sampling sites (*Table 6*). The biofilm DW showed a significant difference between all study sites with the lowest values (ranging from 0.32 to 3.06 mg/cm²), observed in

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the Upper Drâa sites (S1, S2 and S3) and the highest values (ranging from 20.2 to 87.67 mg/cm²) in the Middle Drâa sites except for site 6 where the DW was extremely low (3.82 mg/cm²). The AFDW showed the same variation with the highest value found in site 7 (77.37 ± 0.01 mg/cm²) and the lowest value in site 1 (0.32 ± 0.01 mg/cm²). Similarly, the chlorophyll *a* concentration showed significant spatial variation between the Upper Drâa and Middle Drâa sites. The number of cell diatoms per cm^2 showed a significant difference between all sampling sites with the lowest value (1091.51 cells.cm^{-2}) observed in site 1 and the highest one (13627.75 cells.cm^{-2}) in site 4.

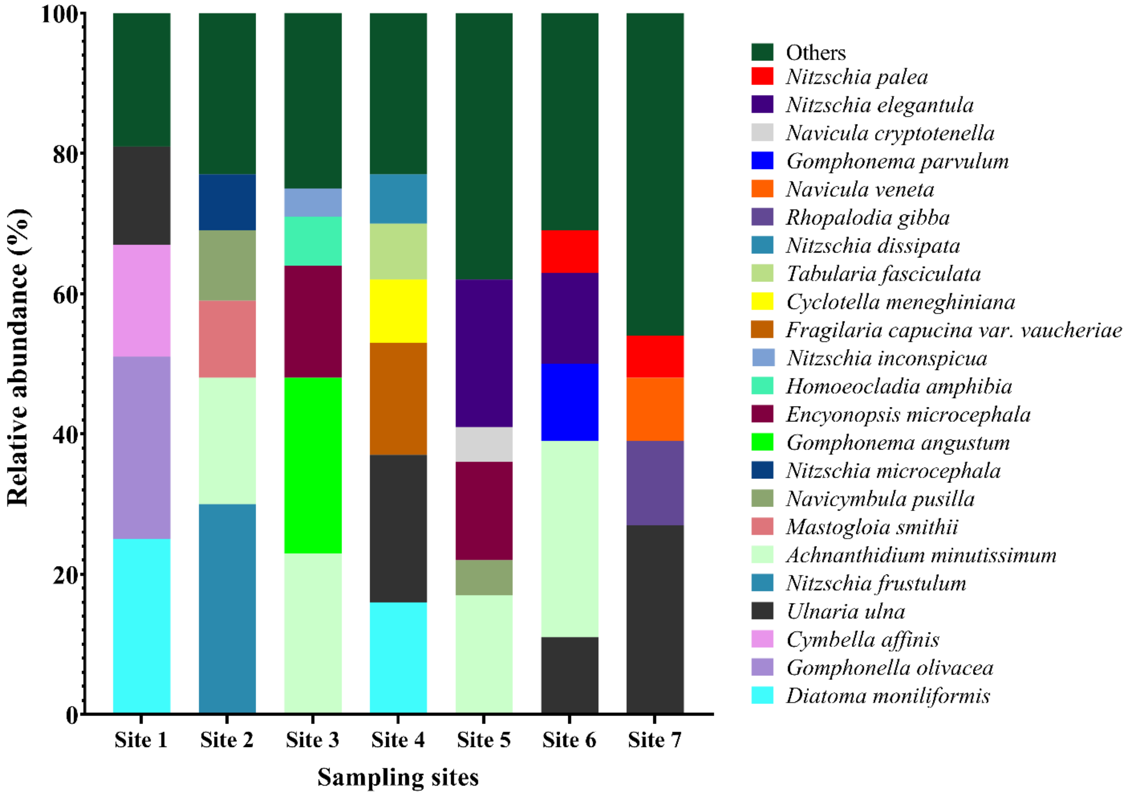

Figure 5. *Relative abundances of main diatoms species in each sampling site*

Table 6. *Biofilm biomass expressed as dry weight, ash−free dry weight, chlorophyll a and number of diatom cells per cm^2 in each sampling sites*

Sampling site	Biofilm DW mg.cm^{-2}	AFDW mg.cm^{-2}	Chlorophyll a µg.cm^{-2}	Diatom cells.cm^{-2}
1	0.32 ± 0.01^a	0.31 ± 0^a	0.04 ± 0^a	1092 ± 2.3^a
2	3.06 ± 0.01^c	2.73 ± 0.01^c	0.15 ± 0^c	2376 ± 75.7^b
3	2.17 ± 0.02^b	1.71 ± 0.1^b	0.11 ± 0.01^b	1263 ± 72.91^c
4	39.19 ± 0.02^f	33.54 ± 0.1^e	0.62 ± 0^f	13628 ± 122.86^g
5	20.2 ± 0.01^e	17.09 ± 0.01^d	0.30 ± 0^d	11854 ± 6.62^f
6	3.82 ± 0.01^d	2.64 ± 0^c	0.1 ± 0^b	8075 ± 94.12^e
7	87.67 ± 0.01^g	77.37 ± 0.01^f	0.61 ± 0^f	6400 ± 138.14^d

Values with the same letter were not significantly different according to Tukey’s test ($p > 0.05$)

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Relationships between diatom community composition and environmental parameters

Canonical correspondence analysis (CCA) was used to investigated the relationships between diatom assemblages and environmental variables. Among 86 taxa inventoried, 39 species with relative abundance higher than 1% were included in this analysis. The ordination of dominant diatom species and their determining environmental factors in the CCA diagram is given in *Figure 6*.

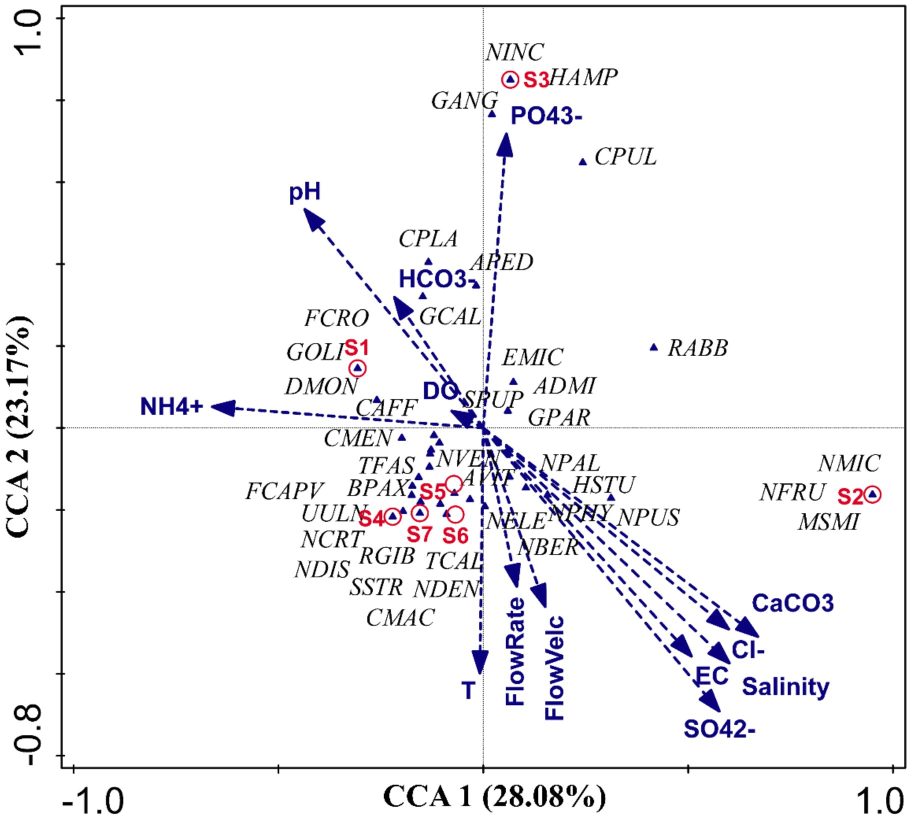

Figure 6. *Canonical correspondence analysis (CCA) ordination diagram of benthic diatoms and environmental variables (arrows) in the seven sampling sites. The direction of the arrow indicates the direction of maximum correlation, and length the strength of this correlation; DO: Dissolved oxygen, T: Temperature, FlowVelc: Flow velocity, SO42-: Sulfate, CaCO3: Total hardness, Cl-: Chloride, EC: Conductivity, HCO3-: total alkalinity, PO43-: Orthophosphate, NH4+: Ammonium ion. The species codes are represented in Table 3*

The first two axes F1 and F2 explained 51.1% of the variance in the data found. The first axis F1 with 28.01% of total variance was related to conductivity, salinity, SO_4^{2-}, Cl^-, $CaCO_3$ and ammonium ion (NH_4^+). The second axis F2 with 23.17% of total variance where PO_4^{3-} and pH have the highest contribution. The SO_4^{2-} value was the largest positive correlation with first axis followed by the salinity, $CaCO_3$ and Cl^-, and the NH_4^+ was largest negative with the first axis, while the PO_4^{3-} value was the largest positive correlation with second axis followed by pH. The arrow lengths in CCA ordination showed that the distribution of benthic diatoms was mainly affected by salinity, major ions (SO_4^{2-}, Cl^-, $CaCO_3$) and nutrients (PO_4^{3-}, NH_4^+). CCA axis 1 and 2 separated the Middle Drâa river sites (S4, S5, S6 and S7) from the Upper Drâa sites (S1,

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S2 and S3) into four clusters. The first cluster includes site 1 characterized by high values of pH and NH_4^+ where the biofilm was dominated by freshwater diatoms such as *Fragilaria crotonensis, Gomphonella olivacea, Diatoma moniliformis* and *Cocconeis placentula.* The second cluster corresponds to site 2 characterized by high values of EC, salinity, Cl^-, SO_4^{2-} and $CaCO_3$ where the biofilm was marked by euryhaline and halotolerant diatoms namely *Nitzschia frustulum*, *Mastogloia smithii* and *Nitzschia microcephala.* The cluster 3 includes site 3 marked by low current velocity with high values of PO_4^{3-} and pH and characterized by *Nitzschia inconspicua*, *Homoeocladia amphibia*, *Gomphonema angustum* and *Ctenophora pulchella.* The cluster 4 includes all Middle Drâa sites 4, 5, 6 and 7 highly impacted by agricultural and domestic activities (six downstream palm oases) and characterized by a gradual increase in water salinity. Diatom assemblages in these sites were characterized by a mixture of halophilic and eutrophic taxa namely *Rhopalodia gibba*, *Tryblionella calida*, *Sellaphora stroemii, Nitzschia dissipata, Cyclotella meneghiniana, Navicula cryptonella, Ulnaria ulna*, *Nitzschia palea*, *Nitzschia elegantula, Navicula veneta, Bacillaria paxillifera, Anomoeoneis vitrea, Fragilaria capucina* var. *vaucheriae.*

It is interesting to note that halophilic diatom species (e.g., *Nitzschia elegantula*, *Nitzchia bergii*, *Navicymbula pusilla* and *Haslea stundlii*) were commonly found in some brackish sites of the Middle Drâa and site 2 and were mainly related to high values of SO_4^{2-}, EC, salinity, $CaCO_3$ and Cl^-.

Discussion

Arid rivers provide important services to humans and society such as drinking water, domestic and irrigation water, food (fish), climate regulation, and recreation (Malmqvist and Rundle, 2002; Vörösmarty et al., 2010; Berger et al., 2019). These environmental stressors contribute in various ways to water physicochemical changes, including salinization.

The physico-chemical analysis showed a spatial variability with a gradual increase of water salinity and ions composition along the Drâa river. Overall, the water salinity showed an increasing gradient in the Drâa river, especially downstream of the Mansour Eddahbi dam. Previous studies have highlighted the rise of salinity along the course of the Drâa from the ME dam to the downstream area through the succession of six large oases (Warner et al., 2013). During the last decades, the salinity of Draa river has increased due to water abstraction, land use, irrigation and sequence of drought episodes (Warner et al., 2013). This salinization originates from natural (geological) and various anthropogenic drivers further is significantly amplified by climate changes. Indeed, the modeling and climate scenario for the period 2000-2029 showed a mean decrease in precipitation (-11%) and especially snowfall (-31%) in the Upper Draa valley leading to a significant decrease in runoff and available water resources (Johannsen et al., 2016). In a recent paper, Berger et al. (2021) have monitored the changes in the water surface area (calculated from satellite images) of ME reservoir from 2015 until 2020 as a proxy for surface water availability in the Draa valley. By referring to these data, the time of water and diatoms sampling coincided with a period of receding water availability in the valley.

The total ion content in the river can be reflected by the conductivity (EC) as a good indicator. The lowest value (385.5 $\mu S.cm^{-1}$) was observed in oued Iriri (site 1) a freshwater perennial stream located at the Upper Drâa basin that drains surface

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discharge originating in the High Atlas Mountain to the Mansour Eddahbi reservoir. The high EC value (7090 μS.cm^{-1}), was measured in oued El Malleh (Site 2) followed by the Middle Drâa river (S5 with 5670 μS.cm^{-1}). Oued El Malleh, an ephemeral stream depending on rainfall or snowmelt, was characterized by high salt water content. Numerous previous studies have indicated that El Malleh stream is characterized by significantly high salinity with high content of Cl^- and SO_4^{2-} (Schulz et al., 2008; Warner et al., 2013; Clavero et al., 2017). The site 5 located just before the oasis of Ternata (Ouled Yaoub) is also rather salty which could be due to the high salinity of the soil (about 5.6 mS. cm^{-1}) (Schulz et al., 2008).

On the other hand, nutrient contents (NH_4^+ and PO_4^{3-}) are rather high, especially in certain sites of Middle Drâa affected by direct human impact (diffuse wastes, washing clothes and animal keeping). Our findings are in agreement with Berger et al. (2021) who found that of the 92% of farmers in the Upper Drâa assess water quality as good for agricultural production while only 67% in the Northern Middle Drâa think that water has good quality for agriculture, decreasing to 35% in the Southern Middle Drâa.

The spatial variability of water temperature in Drâa river depends on aquatic stages, degrees of intermittency, river depth and time of measurement. Indeed, the lowest temperature value was measured in isolated or weakly connected pools such as site 3 (15.9 °C) and the highest value was recorded in eurheic habitats with surface flow and abundant riffles as site 1 (22.8 °C).

Despite the low number of samples, this first study of benthic diatoms of Drâa river highlighted significant diatom species richness dominated by pennate taxa. The analysis of diatom composition revealed the presence of 86 diatom species belonging to 44 genera. Among the 26 genera observed, *Nitzschia* and *Navicula* were the genera with the highest number of species. The common species to all sites were *Achnanthidium minutissimum and Encyonopsis microcephala* which are cosmopolitan, in particular *A. minutissimum.* This later diatom is a very ubiquitous species showing a wide range of ecological tolerance and can be found in all types of watercourse (Krammer, 1991b; Taylor et al., 2007; Bey and Ector, 2013; Hofmann et al., 2013; Stubbington et al., 2019).

The spatial variability of benthic diatoms showed that oued Iriri (site 1) had the lowest species richness. This could be due to competition (especially for light and nutrients) with the well-developed macrophytes in this site as well as high flow velocity and water releases from the dam. Conversely, site 4 of the Middle Drâa, has the highest species richness, which can be explained by the low flow and the frequency of pools microhabitats compared to riffle. Stubbington et al. (2017) state that taxa richness in temperate rivers can initially increase when the flow ceases and pools form, as lentic colonists join lotic refugees, and then decrease as results of poor habitat suitability, reduced water quality and intensive biotic interactions. Shannon, Simpson and Pielou's diversity indices showed relatively higher diversity and structural stability within the diatom communities especially in the Middle Drâa river. No significant correlation was detected between diatom species richness and salinity or major ions contents. In contrast, diatoms diversity index (Shannon–Weaver diversity index) and species richness were negatively correlated with pH. As species richness was rather similar between the study sites, it is not sufficient to significantly differentiate them (i.e., it cannot differentiate between abundant and rare species and two sites with different salinity could have the same species richness). However, the composition of diatom communities was affected by salinity and major ions contents as the relative abundance

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of some diatom taxa was significantly correlated with salinity and major ions contents. For instance, *Mastogloia smithii* (abundant at site 2) and *Navicymbula pusilla* (abundant at site 2 and site 5) were positively correlated ($r \geq 0.76$) with conductivity, salinity and chloride. In addition, *Nitzshia frustulum* and *Nitzshia microcephala* that were abundant at site 2 had a positive correlation ($r = 0.84$) with sulfate concentration. However, salinity was negatively correlated with *Cymbella affinis* ($r = -0.80$) that was abundant at site 1.

The analysis of inter-sites similarity and its illustration in a dendogram separated the sampling sites into three clusters. The cluster including El Malleh site (site 2) is the least similar to any other sites owing to the presence of characteristic euryhaline and halotolerant diatoms such as *Nitzschia frustulum, Nitzschia communis, Halamphora coffeaeformis, Geissleria acceptata, Luticola mutica* and *Surirella brebissonii* usually found in electrolyte-rich and brackish waters (Lange-Bertalot, 1996; Taylor et al., 2007). The cluster of site 3, downstream of Ait Douchen intermittent stream with abundant pools, was characterized by both eutrophic and halophilic diatoms that were found only in this site such *as Cymatopleura solea, Epithemia sorex, Homoeocladia amphibia, Halamphora veneta*, *Craticula riparia*, *Surirella peisonis* and *Nitzschia inconspicua*. Some of these species are characteristic of eutrophic habitats (Taylor et al., 2007; Delgado et al., 2012) while others such as *Epithemia sorex*, *Craticula riparia*, *Surirella peisonis* were found in brackish water rich of HCO_3^- (Krammer and Lange-Bertalot, 1999; Bey and Ector, 2013; Hofmann et al., 2013). The clustering of the Middle Drâa sites and Iriri stream (site 1) in the same group can be explained by the presence of several common species such as *Diatoma moniliformis*, *Cymbella affinis*, *Diploneis ovalis, Ulnaria ulna, Rhopalodia gibba* and *Fragilaria capucina var. vaucheriae* characteristic of freshwaters habitats (Reynolds et al., 2002; Taylor et al., 2007; Padisák et al., 2009).

The CCA analysis showed that diatoms spatial distribution in Drâa basin appear to be mainly determined by variations in ion composition (SO_4^{2-}, Cl^-, $CaCO_3$), salinity, pH, nutrient content (PO_4^{3-}, NH_4^+) (*Fig. 5*). Previous studies have highlighted the effects of these environmental variables on changes in diatom composition in lotic and lentic ecosystems (Potapova and Charles, 2003; Bere and Tundisi, 2009, 2011a; Smucker and Vis, 2011; Bere and Mangadze, 2014; Ingebrigtsen et al., 2016; Mangadze et al., 2017).

Based on CCA results, site 2 (Oued El Malleh), which was the most saline, was associated with high levels of Cl-, SO_4^{2-}, CaCO3, salinity and was characterized by diatoms known by their preference for electrolyte-rich waters and brackish habitats (Taylor et al., 2007; Sivaci et al., 2008; Lengyel et al., 2015). Site 3 with abundant pools in downstream of Ait douchen high level of PO_4^{3-} and pH was characterized by the occurence of eutrophic taxa such as *Nitzschia inconspicua*, *Homoeocladia amphibia* which are a good indicator of a high level of trophic pollution (Van Dam et al., 1994; Taylor et al., 2007; Delgado et al., 2012; Shen et al., 2018), while *Ctenophora pulchella* can be found in waters affected by industrial and mining wastes (Taylor et al., 2007). Site 1 (Iriri stream) with low salt concentrations, high values of pH and NH_4^+ was characterized by oligohaline and oligo- to mesotrophic diatoms (Saros et al., 2003, 2005; Ranković et al., 2006; Taylor et al., 2007; Licursi et al., 2016). *Gomphonella olivacea* is considered as a good indicator of eutrophic waters with moderate conductivity (Krammer and Lange-Bertalot, 1999; Bey and Ector, 2013; Hofmann et al., 2013). Similary, *Diatoma moniliformis* has been described as representative species of eu-polytrophic conditions (Schneider et al., 2000). While *Cocconeis placentula* lives in

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freshwater/brackish habitats and is considered as an alkaliphilous species (Pienitz et al., 1991; Vouilloud, 2003).

The Middle Drâa river sites (S4, S5, S6 and S7) with moderate salt and nutrients contents were characterized by diatom assemblage frequently observed in eutrophic and/or electrolyte rich waters (Reynolds et al., 2002; Fránková-Kozáková et al., 2007; Taylor et al., 2007; Padisák et al., 2009). *Nitzschia palea* was considered as a representative species of eutrophic and very heavily polluted to extremely polluted waters with moderate to high electrolyte content (Van Dam et al., 1994; Krammer and Lange-Bertalot, 1999; Taylor et al., 2007; Bey and Ector, 2013; Hofmann et al., 2013). It has also been associated with high conductivity and eutrophication sites in Brazil (Bere and Tundisi, 2011b), South Africa (Mangadze et al., 2017) and China (Shen et al., 2018). *Ulnaria ulna* has been considered as a dominant species in moderate and high trophic levels (Krammer and Lange-Bertalot, 2000; Taylor et al., 2007; Bey and Ector, 2013; Hofmann et al., 2013). *Nitzschia elegantula* has been described as representative species of electrolyte rich waters (Taylor et al., 2007).

The effects of ionic strength and salinity on diatom communities structure can be impacted by combined effects of environmental factors namely nutrients contents and eutrophication (Bere and Tundisi, 2011a). Moreover, Saros and Fritz (2000) showed that nutrient enrichment can broaden the high end of a taxon’s salinity tolerance range. However, the separation of ionic strength and conductivity effects from other variables on diatom communities has not been thoroughly studied in situ. This study provides additional data and baseline information on salinity impacts on diatom assemblages in an intermittent desert river in southern Morocco.

Conclusion

This exploratory survey provides a first inventory, data ecology and distribution of the benthic diatom assemblages in arid Drâa river, South of Morocco. The physico-chemical parameters monitoring showed a spatial variability with a gradual increase of water salinity and ions composition along the Drâa river. This study reveals the existence of a significant diatom richness (86 taxa) and notable differences between the Middle Drâa valley which had diatom communities significantly different from those of the Upper Drâa streams with higher diversity and evenness of taxa.

The composition and spatial distribution of benthic diatoms was mainly determined by salinity, ion content (chloride and sulfate), pH, flow velocity and nutrients (NH_4^+, PO_4^{3-}). Thus, benthic diatoms are a good tool for monitoring ecological quality of intermittent rivers and ephemeral streams (IRES) during the period of water stability. We therefore recommend in-depth studies including spatio-temporal monitoring of benthic diatoms with other groups of algae taking into account other factors such as hydrological drought (dry phase and aquatic stage) that have been shown to influence benthic diatoms assemblage structure in intermittent river, but which were not assessed in this study.

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REFERENCES

[1] Bailey, P. C. E., Boon, P. I., Blinn, D. W., Williams, W. D. (2006): Salinisation as an Ecological Perturbation to Rivers, Streams and Wetlands of Arid and Semi-Arid Regions. – In: Kingsford, R. (ed.) Ecology of Desert Rivers .Cambridge University Press, Cambridge, pp. 280-314.

[2] Bere, T., Tundisi, J. G. (2011a): Influence of ionic strength and conductivity on benthic diatom communities in a tropical river (Monjolinho), São Carlos-SP, Brazil. – Hydrobiologia 661: 261-276.

[3] Bere, T., Tundisi, J. G. (2011b): Influence of land-use patterns on benthic diatom communities and water quality in the tropical Monjolinho hydrological basin, São Carlos-SP, Brazil. – Water Sa 37: 93-102.

[4] Bere, T., Tundisi, J. G. (2009): Weighted average regression and calibration of conductivity and pH of benthic diatom assemblages in streams influenced by urban pollution–São Carlos/SP, Brazil. – Acta Limnol. Bras 21: 317-325.

[5] Bere, T., Mangadze, T. (2014): Diatom communities in streams draining urban areas: community structure in relation to environmental variables. – Tropical Ecology 55: 271-281.

[6] Berger, E., Frör, O., Schäfer, R. B. (2019): Salinity impacts on river ecosystem processes: a critical mini-review. – Philosophical Transactions of the Royal Society B 374: 20180010.

[7] Berger, E., Bossenbroek, L., Beermann, A. J., Schäfer, R. B., Znari, M., Riethmüller, S., Sidhu, N., Kaczmarek, N., Benaissa, H., Ghamizi, M. (2021): Social-ecological interactions in the Draa River Basin, southern Morocco: towards nature conservation and human well-being using the IPBES framework. – Science of the Total Environment 769: 144492.

[8] Bey, M. Y., Ector, L. (2013): Atlas of River Diatoms the Rhone Alpes Region. – Agence Française pour la Biodiversité, Vincennes (in French).

[9] Campeau, S., Murkin, H. – R., Titman, R. D. (1994): Relative importance of algae and emergent plant litter to freshwater marsh invertebrates. – Canadian Journal of Fisheries and Aquatic Sciences 51: 681-692.

[10] Cañedo-Argüelles, M., Kefford, B. J., Piscart, C., Prat, N., Schäfer, R. B., Schulz C-J. (2013): Salinisation of rivers: an urgent ecological issue. – Environmental Pollution 173: 157-167.

[11] Carrillo-Rivera, J. J., Ouysse, S., Hernández-Garcia, G. J. (2013): Integrative approach for studying water sources and their vulnerability to climate change in semi-arid regions (Drâa Basin, Morocco). – Int J Water Resour Arid Environ 2: 26-36.

[12] Centis, B., Tolotti, M., Salmaso, N. (2010): Structure of the diatom community of the River Adige (North-Eastern Italy) along a hydrological gradient. – Hydrobiologia 639: 37-42.

[13] Charles, D. F., Kelly, M. G., Stevenson, R. J., Poikane, S., Theroux, S., Zgrundo, A., Cantonati, M. (2021): Benthic algae assessments in the EU and the US: striving for consistency in the face of great ecological diversity. – Ecological Indicators 121: 107082.

[14] Clavero, M., Esquivias, J., Qninba, A., Riesco, M., Calzada, J., Ribeiro, F., Fernández, N., Delibes, M. (2015): Fish invading deserts: non-native species in arid Moroccan rivers. – Aquatic Conservation: Marine and Freshwater Ecosystems 25: 49-60.

[15] Clavero, M., Qninba, A., Riesco, M., Esquivias, J., Calzada, J., Delibes, M. (2017): Moroccan desert rivers: fish on the arid extreme of Mediterranean streams. – FiSHMED 3: 21.

[16] Datry, T., Singer, G., Sauquet, E., Capdevilla, D. J., Von Schiller, D., Subbington, R., Magrand, C., Paril, P., Milisa, M., Acuña, V. (2017): Science and management of intermittent rivers and ephemeral streams (SMIRES). – Research Ideas and Outcomes 3: 23.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37093736

[17] Delgado, C., Pardo, I., García, L. (2012): Diatom communities as indicators of ecological status in Mediterranean temporary streams (Balearic Islands, Spain). – Ecological Indicators 15: 131-139.

[18] Diekkrüger, B., Busche, H., Klose, A., Klose, S., Rademacher, C., Schulz, O. (2012): Impact of global change on hydrology and soil degradation—scenario analysis for the semi-arid Drâa catchment (South Morocco). – River Basins and Change: 21-26.

[19] Fránková-Kozáková, M., Marvan, P., Geriš, R. (2007): Halophilous diatoms in Czech running waters: Pleurosira laevis and Bacillaria paxillifera. – In: Proceedings of the 1st Central European Diatom Meeting. Berlin, Germany, pp. 39-44.

[20] Guiry, M. D., Guiry, G. M. (2022): AlgaeBase. – World-Wide Electronic Publication, National University of Ireland, Galway. https://www.algaebase.org (accessed on 8 Feb 2022).

[21] Harms, T. K., Sponseller, R. A., Grimm, N. B. (2018): Desert Streams. – In: Jørgensen, S. E., Fath, B. D. (eds.) Encyclopedia of Ecology. Elsevier, Amsterdam, pp. 439-446.

[22] Hofmann, G., Lange-Bertalot, H., Werum, M. (2013): Diatomeen im Süßwasser-Benthos von Mitteleuropa. 2. Corrected Edition. – Koeltz Scientific Books, Königstein.

[23] Ingebrigtsen, R. A., Hansen, E., Andersen, J. H., Eilertsen, H. C. (2016): Light and temperature effects on bioactivity in diatoms. – Journal of Applied Phycology 28: 939-950.

[24] Jeffrey, S. W., Humphrey, G. F. (1975): New spectrophotometric equations for determining chlorophylls a, b, c1 and c2 in higher plants, algae and natural phytoplankton. – Biochemie und Physiologie der Pflanzen 167: 191-194.

[25] Johannsen, I. M., Hengst, J. C., Goll, A., Höllermann, B., Diekkrüger, B. (2016): Future of water supply and demand in the Middle Drâa Valley, Morocco, under climate and land use change. – Water 8: 313.

[26] Karmaoui, A., Messouli, M., Khebiza, Y. M., Ifaadassan, I. (2014): Environmental vulnerability to climate change and anthropogenic impacts in dryland, (pilot study: Middle Draa Valley, South Morocco). – Journal of Earth Science & Climatic Change: 1.

[27] Karmaoui, A., Ifaadassan, I., Messouli, M., Khebiza, M. Y. (2015): Characterization of common environmental indicators of the Moroccan Oasean Biome. Pilot study in the reserve biosphere of Oases in Southern Morocco. – Adv. Res 5: 1-15.

[28] Kingsford, R. T., Thompson, J. R. (2006): Desert or Dryland Rivers of the World. An Introduction. – Cambridge University Press, Cambridge.

[29] Krammer, K. (1991a). Suβwasserflora von Mitteleuropa. Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. Süβwasserflora von Mitteleuropa. – Gustav Fischer Verlag, Stuttgart.

[30] Krammer, K. (1991b). Bacillariophyceae 4. Teil: Achnanthaceae, Kritische Erganzungen zu Navicula (Lineolatae) und Gomphonema. Süβwasserflora von Mitteleuropa 2. – Gustav Fischer Verlag, Stuttgart.

[31] Krammer, K., Lange-Bertalot, H. (1986): 1986: Bacillariophyceae. 1. Teil: Naviculaceae. – In: Ettl, H., Gerloff, J., Heynig, H. and Mollenhauer, D. (eds.) Süßwasser flora von Mitteleuropa, Band 2/1. Gustav Fischer Verlag, Stuttgart.

[32] Krammer, K., Lange-Bertalot, H. (1988): Süsswasser-Flora von Mitteleuropa. Bacillariophyceae, 2. Teil: Epithemiaceae, Surirellaceae. – Gustav Fischer Verlag, Stuttgart.

[33] Krammer, K., Lange-Bertalot, H. (1999): Süßwasserflora von Mitteleuropa II: 1, Bacillariophyceae. Naviculaceae. – Gustav Fischer Verlag, Stuttgart.

[34] Krammer, K., Lange-Bertalot, H. (2000): ‘Centrales’,’Fragilariaceae’,’Eunotiaceae’. – Spektrum, Heidelberg.

[35] Lange-Bertalot, H. (1979): Pollution tolerance of diatoms as a criterion for water quality estimation. – Nova Hedwigia, Beih. 64: 285-304.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37093736

[36] Lange-Bertalot, H. (1996): Indicators of oligotrophy. 800 taxa representative of three ecologically distinct lake types. Carbonate buffered-oligodys-trophic-weakly buffered soft water. – Iconogr. Diatomol 2: 390.
[37] Lengyel, E., Kovács, A. W., Padisák, J., Stenger-Kovács, C. (2015): Photosynthetic characteristics of the benthic diatom species Nitzschia frustulum (Kützing) Grunow isolated from a soda pan along temperature-, sulfate-and chloride gradients. – Aquatic Ecology 49: 401-416.
[38] Licursi, M., Gomez, N., Sabater, S. (2016): Effects of nutrient enrichment on epipelic diatom assemblages in a nutrient-rich lowland stream, Pampa Region, Argentina. – Hydrobiologia 766: 135-150.
[39] Loulida, S., Naimi, M., Znari, M., Bendami, S. (2019): Tolerance to salinity and dehydration in the Sahara Desert blue-eyed turtle, Mauremys leprosa saharica (Testudines: Geoemydidae) from a brackish pond in the Lower Draa basin, southern Morocco. – African Journal of Herpetology 68: 58-76.
[40] Lowe, R. L., LaLiberte, G. D. (2017): Benthic Stream Algae: Distribution and Structure. – In: Hauer, F., Lamberti, G. (eds.) Methods in Stream Ecology. Volume 1. Elsevier, Amsterdam, pp. 193-221.
[41] Malmqvist, B., Rundle, S. (2002): Threats to the running water ecosystems of the world. – Environmental Conservation 29: 134-153.
[42] Mangadze, T., Wasserman, R. J., Dalu, T. (2017): Use of diatom communities as indicators of conductivity and ionic composition in a small austral temperate river system. – Water, Air, & Soil Pollution 228: 1-11.
[43] Millerioux, G. (1975): Projet alpin OCDE pour la lutte contre l'eutrophisation. Lacs du massif central francais. IV. Le lac d'Aydat, interrelations entre parametres. – OCDE, Paris.
[44] Mostakim, L., Fetnassi, N., Rassam, H., Benaissa, H., Berger, E., Ghamizi, M. (2020): Assessment of aquatic and semi-aquatic plants in arid regions: testing factors affecting riparian plant distribution in the Draa Basin, Morocco. – EurAsian Journal of BioSciences 14: 4735-4741.
[45] Nhiwatiwa, T., Dalu, T., Brendonck, L. (2017): Impact of irrigation based sugarcane cultivation on the Chiredzi and Runde Rivers quality, Zimbabwe. – Science of the Total Environment 587: 316-325.
[46] Padisák, J., Crossetti, L. O., Naselli-Flores, L. (2009): Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. – Hydrobiologia 621: 1-19.
[47] Pan, Y., Stevenson, R. J., Hill, B. H., Kaufmann, P. R., Herlihy, A. T. (1999): Spatial patterns and ecological determinants of benthic algal assemblages in Mid-Atlantic streams, USA. – Journal of Phycology 35: 460-468.
[48] Pielou, E. C. (1966): Species-diversity and pattern-diversity in the study of ecological succession. – Journal of Theoretical Biology 10: 370-383.
[49] Pienitz, R., Lortie, G., Allard, M. (1991): Isolation of lacustrine basins and marine regression in the Kuujjuaq area, northern Québec, as inferred from diatom analysis. – Géographie Physique et Quaternaire 45: 155-174.
[50] Piscart, C., Moreteau, J.-C., Beisel J-N. (2005): Biodiversity and structure of macroinvertebrate communities along a small permanent salinity gradient (Meurthe River, France). – Hydrobiologia 551: 227-236.
[51] Piscart, C., Usseglio-Polatera, P., Moreteau, J.-C. B. (2006): The role of salinity in the selection of biological traits of freshwater invertebrates. – Archiv für Hydrobiologie: 185-198.
[52] Potapova, M. G., Charles, D. F. (2002): Benthic diatoms in USA rivers: distributions along spatial and environmental gradients. – Journal of Biogeography 29: 167-187.
[53] Potapova, M., Charles, D. F. (2003): Distribution of benthic diatoms in US rivers in relation to conductivity and ionic composition. – Freshwater Biology 48: 1311-1328.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37093736

[54] Potapova, M., Charles, D. F. (2005): Choice of substrate in algae-based water-quality assessment. – Journal of the North American Benthological Society 24: 415-427.
[55] Qninba, A., Lieron, V., Dieuleveut, T., Amairat, M., Yahyaoui, A. (2011): Sur la présence de l'Anguille Anguilla anguilla (Linnaeus, 1758) dans l'Oued Tissint, un affluent de l'Oued Dr'a (Maroc). – Bulletin Institut Scientifique Rabat 33: 65-66.
[56] Ranković, B., Simić, S., Bogdanović, D. (2006): Phytoplankton as indicator of water quality of lakes Bubanj and Šumarice during autumn. – Prirodno-Matematički Fakultet, Univerzitet k Kragujevcu, Kragujevac.
[57] Reynolds, C. S., Huszar, V., Kruk, C., Naselli-Flores, L., Melo, S. (2002): Towards a functional classification of the freshwater phytoplankton. – Journal of Plankton Research 24: 417-428.
[58] Riesco, M., Delibes, M., Calzada, J., Esquivias, J., Qninba, A., Clavero, M. (2020): Desert otters: Distribution, habitat use and feeding ecology in arid rivers of Morocco. – Journal of Arid Environments 178: 104165.
[59] Rodier, J., Legube, B., Merlet, N., Brunet, R., Mialocq, J. C., Leroy, P., Houssin, M., Lavison, G., Bechemin, C., Vincent, M. (2009): L'analyse de l'eau-9e éd. Eaux naturelles, eaux résiduaires, eau de mer. – Dunod, Paris, pp. 564-571.
[60] Saros, J. E., Fritz, S. C. (2000): Nutrients as a link between ionic concentration/composition and diatom distributions in saline lakes. – Journal of Paleolimnology 23: 449-453.
[61] Saros, J. E., Interlandi, S. J., Wolfe, A. P., Engstrom, D. R. (2003): Recent changes in the diatom community structure of lakes in the Beartooth Mountain Range, USA. – Arctic, Antarctic, and Alpine Research 35: 18-23.
[62] Saros, J. E., Michel, T. J., Interlandi, S. J., Wolfe, A. P. (2005): Resource requirements of Asterionella formosa and Fragilaria crotonensis in oligotrophic alpine lakes: implications for recent phytoplankton community reorganizations. – Canadian Journal of Fisheries and Aquatic Sciences 62: 1681-1689.
[63] Schneider, S., Schranz, C., Melzer, A. (2000): Indicating the trophic state of running waters by submersed macrophytes and epilithic diatoms: exemplary implementation of a new classification of taxa into trophic classes. – Limnologica-Ecology and Management of Inland Waters 30: 1-8.
[64] Schröder, M., Sondermann, M., Sures, B., Hering, D. (2015): Effects of salinity gradients on benthic invertebrate and diatom communities in a German lowland river. – Ecological Indicators 57: 236-248.
[65] Schulz, O., Reichert, B., Diekkrüger, B. (2008): L'approche IMPETUS: Recherche et outils pour la gestion de l'eau. – http://hdl.handle.net/123456789/31401.
[66] Sen, Z. (2008): Wadi Hydrology. – CRC Press, Boca Raton, FL.
[67] Shannon CB, Weaver, W. (1963): The Mathematical Theory of Communication. – Univ. of Illinois Press, Urbana, IL.
[68] Shen, R., Ren, H., Yu, P., You, Q., Pang, W., Wang, Q. (2018): Benthic diatoms of the Ying River (Huaihe River Basin, China) and their application in water trophic status assessment. – Water 10: 1013.
[69] Simpson, E. H. (1949): Measurement of diversity. – Nature 163: 688.
[70] Sivaci, E. R., Cankaya, E., Kilinc, S., Dere, S. (2008): Seasonal assessment of epiphytic diatom distribution and diversity in relation to environmental factors in a karstic lake (Central Turkey). – Nova Hedwigia 86: 215-230.
[71] Šmilauer, P., Lepš, J. (2014): Multivariate Analysis of Ecological Data Using CANOCO 5. – Cambridge University Press, Cambridge.
[72] Smucker, N. J., Vis, M. L. (2011): Contributions of habitat sampling and alkalinity to diatom diversity and distributional patterns in streams: implications for conservation. – Biodiversity and Conservation 20: 643-661.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2005_37093736

[73] Sorensen, T. A. (1948): A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. – Biol. Skar. 5: 1-34.
[74] Speth, P., Christoph, M., Diekkrüger, B. (2010): Impacts of Global Change on the Hydrological Cycle in West and Northwest Africa. – Springer Science & Business Media, Berlin.
[75] Stackpoole, S. M., Stets, E. G., Sprague, L. A. (2019): Variable impacts of contemporary versus legacy agricultural phosphorus on US river water quality. – Proceedings of the National Academy of Sciences 116(41): 20562-20567.
[76] Stanley, E. H., Fisher, S. G., Grimm, N. B. (1997): Ecosystem expansion and contraction in streams. – BioScience 47: 427-435.
[77] Stevenson, R. J., Smol, J. P. (2015): Use of Algae in Ecological Assessments. – In: Wehr, J. D., Sheath, R. G. (eds.) Freshwater Algae of North America. Elsevier, Amsterdam, pp. 921-962.
[78] Stevenson, R. J., Bothwell, M. L., Lowe, R. L., Thorp, J. H. (1996): Algal Ecology: Freshwater Benthic Ecosystem. – Academic Press, Cambridge, MA.
[79] Stubbington, R., England, J., Wood, P. J., Sefton, C. E. M. (2017): Temporary streams in temperate zones: recognizing, monitoring and restoring transitional aquatic-terrestrial ecosystems. Wiley Interdisciplinary Reviews. – Water 4: e1223.
[80] Stubbington, R., Paillex, A., England, J., Barthès, A., Bouchez, A., Rimet, F., Sánchez-Montoya, M. M., Westwood, C. G., Datry, T. (2019): A comparison of biotic groups as dry-phase indicators of ecological quality in intermittent rivers and ephemeral streams. – Ecological Indicators 97: 165-174.
[81] Taylor, J. C., Prygiel, J., Vosloo, A., de la Rey, P. A., van Rensburg, L. (2007): Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area. – Hydrobiologia 592: 455-464.
[82] Van Dam, H., Mertens, A., Sinkeldam, J. (1994): A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. – Netherland Journal of Aquatic Ecology 28: 117-133.
[83] Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R. (2010): Global threats to human water security and river biodiversity. – Nature 467: 555-561.
[84] Vouilloud, A. A. (2003): Catálogo de diatomeas continentales y marinas de Argentina. –
[85] Warner, N., Lgourna, Z., Bouchaou, L., Boutaleb, S., Tagma, T., Hsaissoune, M., Vengosh, A. (2013): Integration of geochemical and isotopic tracers for elucidating water sources and salinization of shallow aquifers in the sub-Saharan Drâa Basin, Morocco. – Applied Geochemistry 34: 140-151.
[86] Wheater, H., Al Weshah, R. (2002): Hydrology of wadi systems. – Technical Documents in Hydrology No. 55. UNESCO, Paris
[87] Williams, W. D. (1987): Salinization of rivers and streams: an important environmental hazard. – Ambio 15: 180-185.
[88] Williams, D. D., Williams, N. E. (1998). Aquatic insects in an estuarine environment: densities, distribution and salinity tolerance. – Freshwater Biology 39: 411-421.

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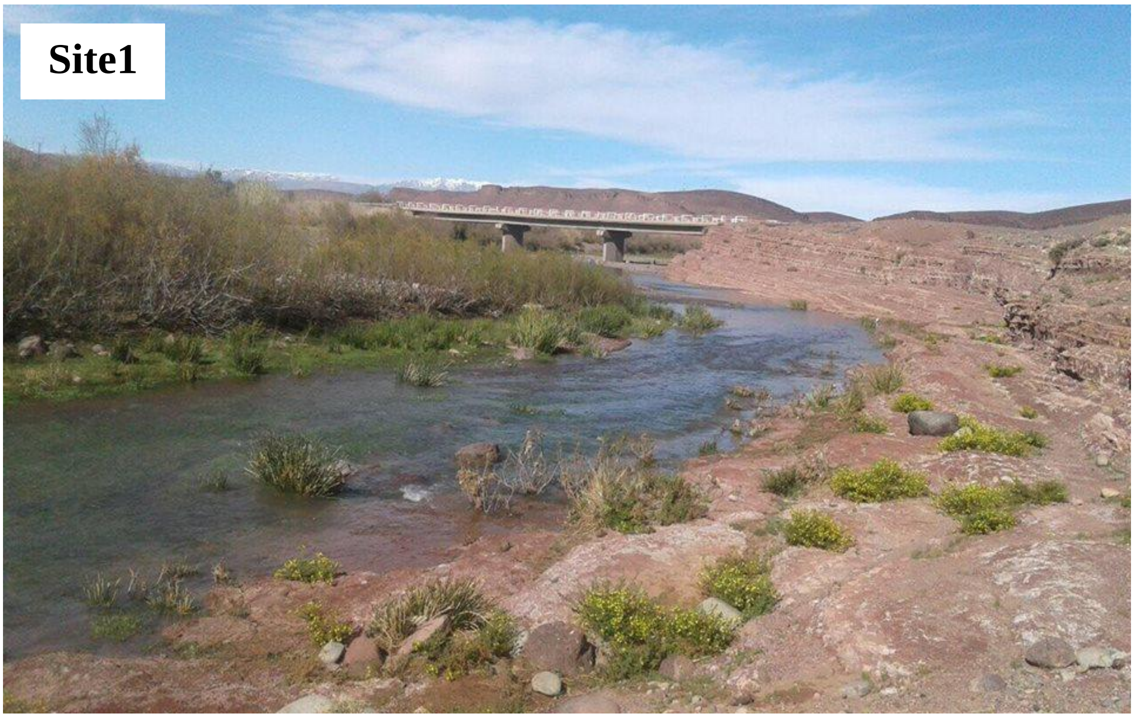
APPENDIX

Appendix 1. *Photos of the sampling sites:*



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Site 5


Site 6

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