



Climate Vulnerability and Water Extent Assessment in Four Salt Lakes in Northwestern Algeria: Suitability for Brine Shrimp *Artemia* Production

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ABSTRACT

Artemia brine shrimp, is a small anostracan crustacean that lives in hypersaline environments, valued as an irreplaceable live food, used in the early larval stages of various aquaculture species. Algeria has more than 24 sites (sabkha, chott, Salt Lake, etc.) that host two strains of *Artemia*: *Artemia salina* (sexual) and *Artemia parthenogenetica* (asexual). The aim of this study is to determine the density of *Artemia* populations (by conducting field sampling) in the natural environment. Four lakes in the northwest Algeria were under consideration to determine the variation in water extent as well as its vulnerability to climatic conditions, through the use of remote sensing platforms, which provide large databases of climatic data (temperature, rainfall ...etc.). However, the normalized difference water index (NDWI) and modified normalized difference water index (MNDWI) were the main indexes based on combination of spectral bands used to extract water bodies in our study, where the variation of surface water extent has been combined to different factors influencing the *Artemia* brine shrimp, to evaluate their production sustainability. The present study highlights that *Artemia* production in northwestern Algeria lakes is under threat not only from drought conditions but also from water shortages and pollution, where the recent recorded patterns indicate a period of low rainfall combined with the lake soil characteristics, subsequently influencing the total biomass of *Artemia* that remained at low abundant throughout the fieldwork period. In the face of these unfavorable conditions against the development of *Artemia*, the northwestern Algerian lake may only provide a very low quantity of its cysts, thereby compromising its sustainability if these conditions persist, which will interfere the proper development and production of *Artemia* for the Algerian market.

INTRODUCTION

In aquaculture, larval stage is the most critical phase (Manchado *et al.*, 2016) that is required to enhance feeding and to ensure proper growth. Moreover, in the earlier

stages, providing high-quality feed in adequate quantities was restricted to *Artemia* brine shrimp which is the smallest Anostraca crustacean, used as live feed (Sorgeloos, 1980).

Annually, there is a huge demand of *Artemia* throughout the world, and large quantities are harvested and supplied not only for its nutrition values, but also for other various utilization, as bioencapsulated products that provide therapeutic agents, toxicity assessment, among others (Maldonado-Montiel & Rodríguez-Canché, 2005; Ibrahim et al., 2012).

The inspection of new *Artemia* production areas and the safeguarding of existing sites have become a necessity. Hypersaline environments hosting this natural bioresource are highly vulnerable to the environmental and climatic imbalances (Morzaria-Luna et al., 2014).

In Algeria, *Artemia* has been reported in several saline sites, the management of these aquatic hypersaline environments has been assigned to salt production companies (ENASEL) in order to exploit and valorize the salt while overlooking the benefits that can be derived from the sustainable production of *Artemia*.

Several previous studies have focused on morphological, biological and ecological characterization (survival, growth and reproduction parameters) (Kara et al., 2004; Amarouayache et al., 2009, 2010; Ghomari et al., 2011; Amarouayache & Kara, 2015, 2017; Benmeddah et al., 2018; Ghomari & Amat, 2020; Chabet Dis et al., 2021), localization and biogeography (Ghomari et al., 2012; Kara & Amarouayache, 2012; Ghomari, 2013), and then on the assessment of nutritional quality and cyst hatching parameters (Amarouayache et al., 2013; Amarouayache & Kara, 2015; Amarouayache et al., 2017; Chabet Dis et al., 2021; Benmehal et al., 2022; Hidouci et al., 2022), while they highlighted the importance of *Artemia* exploitation, without addressing the potential of these sites to meet the requirements for the sustainable development of this natural resource.

Among more than 24 reported hypersaline sites, three sites in the north-west of the country contain *Artemia* with a nutritional quality suitable for live feeding in aquaculture, namely the Great Sabkha of Oran, Arzew Salt Lake – Bethioua (wilaya of Oran) and Sebkh El Melh of Oued Eldjamaa (wilaya of Relizane). Additionally, Telamine Lake (wilaya of Oran) was also explored and examined in our study to determine whether it hosts *Artemia* strains.

The availability and abundance of *Artemia* depend on hydrological and climatic conditions, as well as the environmental quality, which will contribute for a sustainable supply of *Artemia* on the aquaculture market in Algeria.

The seasonal variations of the water mass following climatic conditions, may be helpful in selecting suitable areas for *Artemia* production.

The main objective of our research is to assess the suitability of the four selected locations for the exploitation or production of *Artemia*, according to the three main criteria taken into account in the framework of this work, namely the hydrology of these

sites with regard to drought or permanent flooding factors, their vulnerability to changes in climatic conditions, and finally the stability or degradation of the ecological quality of the environment.

Within this framework, our research adopted a mixed methodological approach, combining two complementary approaches. The first was based on *in situ* studies to determine the density of *Artemia* populations, while the second involved the use of remote sensing techniques and geographic information systems based on spectral band combinations to determine water extent variation, as well as its vulnerability to climate change.

MATERIALS AND METHODS

1. Study area

Four locations in the northwest region of Algeria were selected for our study; three locations were in wilaya of Oran and the fourth was in wilaya of Relizane (Fig. 1): Great sabkha of Oran (35°32'47.6"N 0°49'17.6"W), Telamine Lake (35°43'51.1"N 0°23'12"W), Arzew Salt Lake – Bethioua (35°42'33.8"N 0°17'30.7"W) and Sebkhia El Melh of Oued Eldjamaa (35°50'23.6"N 0°38'51.3"E) (wilaya of Relizane) with a surface of 313.6, 10.5, 28.67 and 14.83 km², respectively.

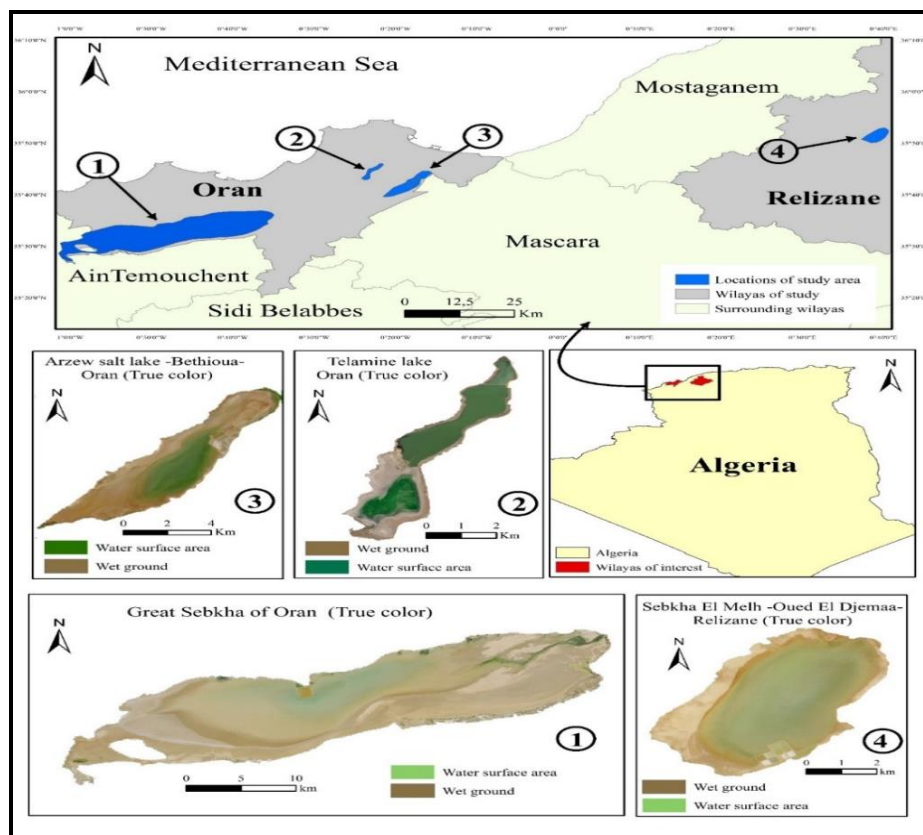


Fig. 1. Locations of study area, 1- Great sabkha of Oran, 2- Telamine Lake, 3- Arzew Salt Lake – Bethioua and 4- Sebkhia El Melh of Oued Eldjamaa (wilaya of Relizane) – Algeria

2. Data collection

2.1. Climatological data

In this study, the Modern-Era Retrospective Analysis for Research and Application, version 2 (MERRA-2 PRECTOTCORR) products over the four lakes was used in order to assess the variation in the temperature and precipitation, which are the main parameters influencing the water extent in the lakes (**Benkesmia et al., 2023**). These parameters are considered as the main factors of drought; they are essentially what determines the degree of aridity of each region.

MERRA-2 was provided at a spatial resolution of 0.5° in latitude and 0.625° in longitude, according to **Xu et al. (2022)**, MERRA-2 PRECTOTCORR generally performs very well at latitudes around 42.5°N or below (this includes our selected area), and tends to outperform datasets like ERA5 in precipitation estimation.

MERRA-2 Data were acquired from the Data Access Viewer (DAV) of NASA POWER (NASA Prediction Of Worldwide Energy Resources; (<https://power.larc.nasa.gov/data-access-viewer/>; accessed on January 2025).

2.2. Lake hydrological data

The analysis of the water surface extent dynamics was facilitated by the use of remote sensing (**Normandin et al., 2023**) since it is useful for monitoring wetlands, safeguarding natural resources and implementing exploitation strategies; in the context of climate change.

From the Copernicus Data Space Ecosystem (<https://browser.dataspace.copernicus.eu/>); we obtained high spatial resolution satellite images from the Sentinel-2a (table 1).

Table 1. Parameters of Sentinel-2 level 2A and the bands used in this research (extracted from Sentinel-2, S2 Applications site)

	Revisit time (day)	Data availability	Bands	Spectral range (nm)	Resolution spatial (m)
S2L2A: Sentinel-2 level 2A	5 days	Europe : Since October 2016	B03	GREEN, 559.8 nm (S2A)	10m
			B08	NIR, 832.8 nm (S2A)	10m
		Global : Since January 2017	B11	SWIR, 1613.7 nm (S2A)	20m
			B12	SWIR, 2202.4 nm (S2A)	20m

The number of images processed in our study was limited; for the big areas; not only by the 10% cloud cover threshold we had defined but also by the fact that they have to be covered by two satellite passes on different dates (means that several dates will have only one satellite pass covering half the area, which reduces the number of images). For the period between 2017 and 2025, 176 images were processed for the Grande sebkha of Oran, 306 images for the Telamine Lake, 327 images for the Arzew Salt Lake and 243 images for the Sebkha El Melh of Oued Eldjamaa, Relizane.

3. Data processing

3.1. Drought classification and characterization

To describe the level of drought in a specific area, the standardized precipitation index (SPI) is widely used to monitor meteorological drought (McKee *et al.*, 1993). According to Bordi *et al.* (2009), the SPI is frequently used to compare different climatic regions or locations, which makes it easier to identify suitable areas for *Artemia* production.

For general drought monitoring, using SPI values over a period of three months or less can provide preliminary insights. When it comes to assessing agricultural drought, a timeframe of up to six months is more appropriate. However, to understand longer-term hydrological effects on water resources like rivers and reservoirs, SPI values over 12 months or more are better suited (Pramudya *et al.*, 2019; Mukama *et al.*, 2025)

Table 2. Standardized precipitation index classification

Drought index value	Drought category
> 0	None
-0.99 to 0	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2.0	Extreme drought

SPI-12 values were calculated with the SPI function from the SPEI package in RStudio. In this analysis, positive values were considered non-drought events (see Table 2), while drought events were identified when the SPI dropped to -1 or lower (McKee *et al.*, 1993).

The duration was defined as the total number of consecutive time steps during which the SPI remains below the threshold. Drought severity is quantified as the cumulative sum of SPI deficits throughout the drought period, while maximum intensity is determined by the most negative SPI value observed during the event.

3.2. Delineation of water extent using MNDWI and NDWI indices

The boundaries of the study area were based on the maximum water level, since *Artemia* lives exclusively in the presence of water.

For atmospheric correction of satellite images, the effects of the atmosphere on the light reflected by the Earth's surface and reaching the sensor are automatically corrected, and 10% cloud cover is attributed (extracted from Sentinel-2 site “Additional Request Parameters”).

On the basis of combinations of spectral bands in S2L2A data, the normalized difference water index (NDWI) below has been calculated (Fig. 2), and was performed using QGIS Desktop 3.22.

$$[1] \quad NDWI = \frac{GREEN(visible\ green) - NIR\ (Near\ Infrared)}{GREEN(visible\ green) + NIR\ (Near\ Infrared)}$$

The NDWI is appropriate for water body mapping (Aml S et al., 2022), where water features have positive values and thus are enhanced, while vegetation and soil usually have zero or negative values and therefore are suppressed (the values of water bodies are larger than 0.5, therefor the modified NDWI (MNDWI) can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise.

MNDWI below is derived from NDWI and was modified by Xu (2006). It uses green and SWIR channels to improve water detection in open hydrographic features and sparsely vegetated areas.

$$[2] \quad MNDWI = \frac{GREEN(visible\ Green) - SWIR\ (Short\ Wave\ Infrared)}{GREEN(visible\ Green) + SWIR\ (Short\ Wave\ Infrared)}$$

Boundaries of the lake water features outcome per NDWI and MNDWI have been drawn and extracted to determine the total surface area, and thereafter water extent time series was obtained over 2017-2025 (S2L2A data are available globally since March 2017).

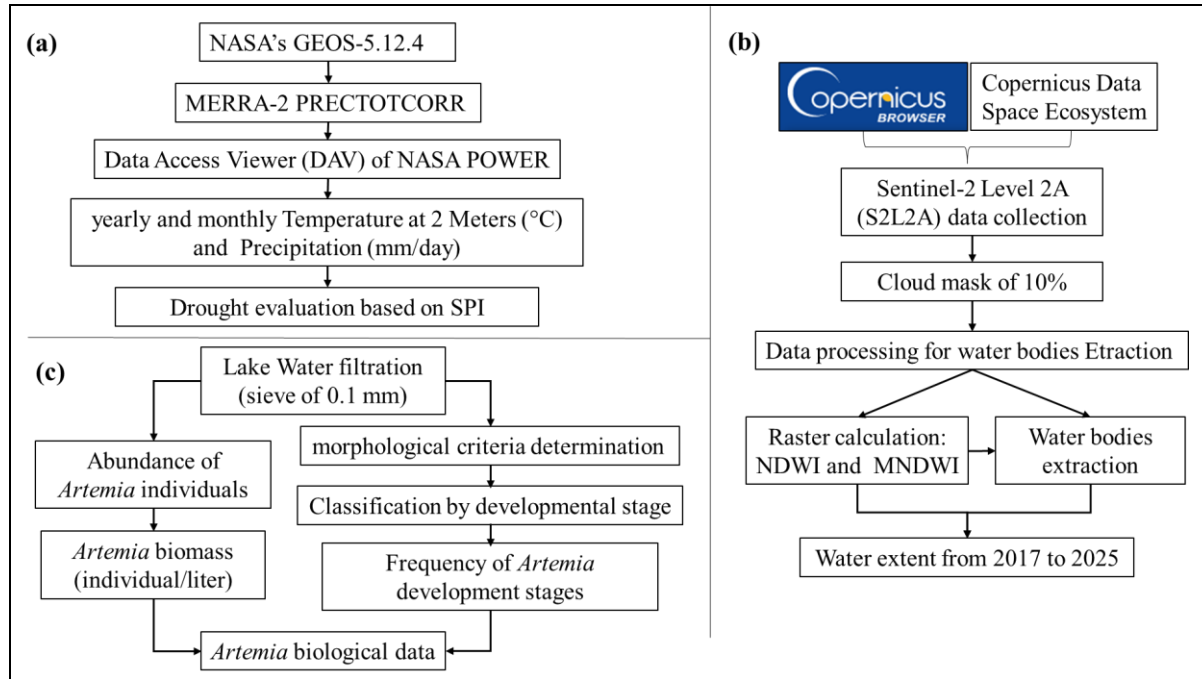


Fig. 2. Flow shart methodology: (a) Climat data extraction and analysis, (b) Water extent delineation using Copernicus Data, (c) Biological data collection

3.3. *Artemia* biomass and abundance

Depending on the abundance of *Artemia* individuals during the wet period when the water was present in the lakes, volumes of water were filtered through a 0.1mm sieve and measured (the volumes depended on the quantity of *Artemia* present in the lake).

Three different points were established at each lake to determine the average *Artemia* density (individual/liter) every month where *Artemia* were present (Fig. 2). Samples were preserved in 4% formalin and processed in the laboratory. On the basis the morphological criteria outlined by **Sorgeloos *et al.* (1986)** and **Van Stappen *et al.* (2024)** a classification was determined according to developmental stage (1: nauplii and metanauplii (instar I – instar IV), 2: juveniles (instar V – instar XIV), and 3: adults) and counting under a magnifying loupe fitted with an optical camera and processed by measuring software (Toupview) and the demographic structure *Artemia* population and the relative frequency development stages were carried out.

$$\text{Frequency (\%)} = 100 * \frac{\text{Number of individual for each stage}}{\text{Total number}}$$

RESULTS

1. Variation of climatological parameter in the lakes between 2012-2022

Recent monthly temperature records (Fig. 3B) from the northwestern regions of Algeria, near our selected lakes, reveal a clear and consistent seasonal cycle. Temperatures rise and fall in a regular pattern each year, ranging from around 7°C during the colder winter months to about 33°C at the peak of summer. From 2012 to 2022, this pattern remained steady, with the highest temperatures occurring at roughly the same time each year, highlighting a strong seasonal rhythm. Nevertheless, the slight upward trend visible from 2015 to 2022 (Fig. 3A) could suggest a subtle warming trend in the northwestern region.

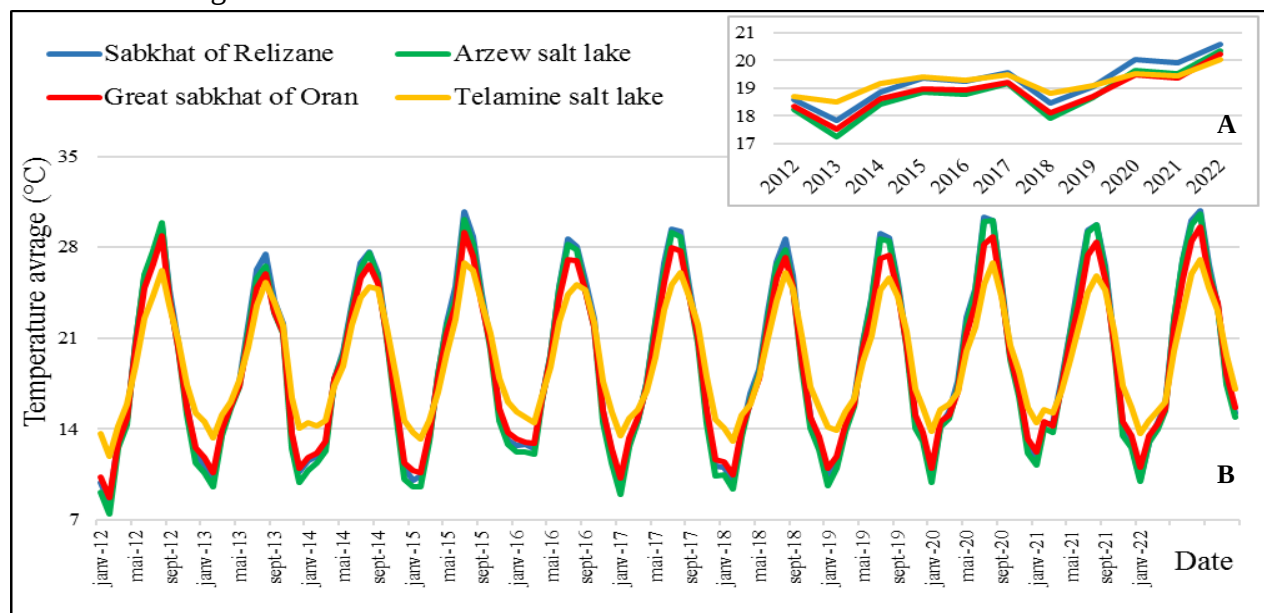


Fig. 3. Variations in annual (A) and monthly (B) average temperature in the northwestern lakes in Algeria (2012-2022)

As shown in the precipitation graph (Fig. 4), all four lakes follow a similar and highly variable pattern, with noticeable highs and lows throughout the year. This reflects the strong seasonal nature of rainfall in the region, where heavy rains typically occur during the winter season, followed by long dry spells in the warmer seasons; typical pattern of semi-arid Mediterranean climates. Between 2012 and 2023, these fluctuations have become more pronounced, and the prolonged dry period that began after 2018 highlights growing ecological and hydrological pressures in the area.

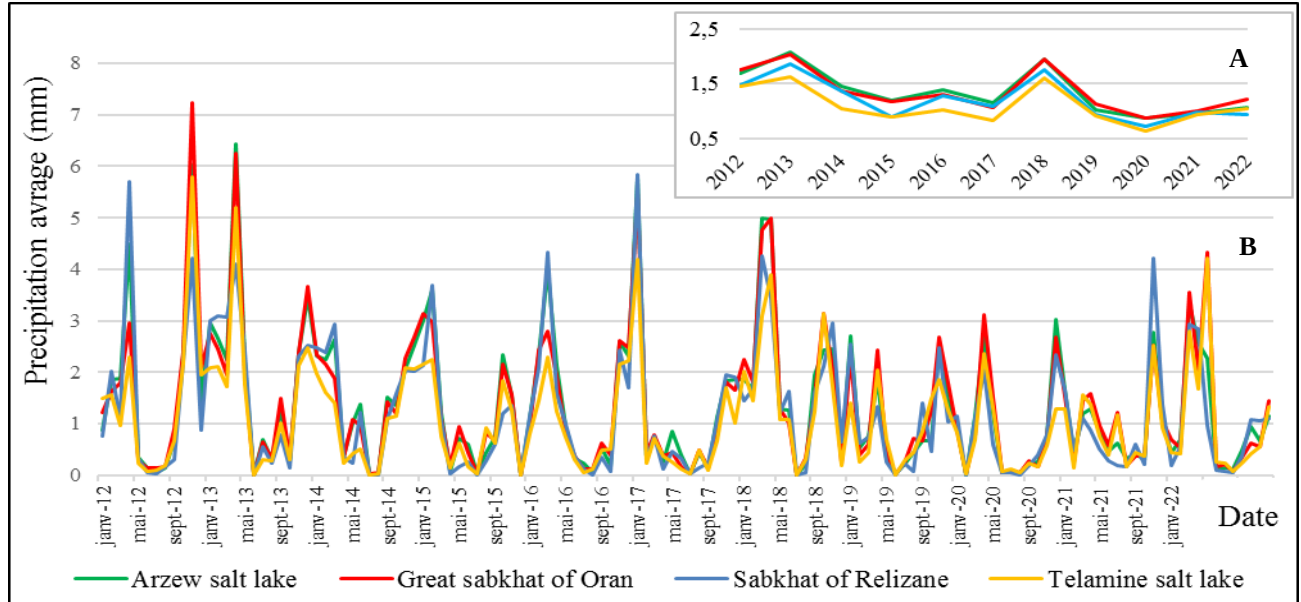


Fig. 4. Variations in annual (A) and monthly (B) average precipitation in the northwestern lakes in Algeria (2012-2022)

2. Drought analysis for Algerian Sabkha regions (1990–2024)

Over the last three decades, all sites were affected by serious droughts in the early 1990s (Fig. 5), in which Sebkh El Melh of Oued Eldjamaa - Relizane was the most severely impacted, both in terms of duration and intensity (Table 3), characterized by sustained SPI values below -1.5. However, this was followed by a period of relative climatic stability between 2003 and 2015, marked by consistent wet conditions with a positive SPI at all sites, suggesting a return to normal or above-normal rainfall across the region (Fig. 3).

However since 2019, a worrying change has emerged; all regions have entered a phase of prolonged drought. In particular, Oran has the highest drought intensity in recent years, while Relizane continues to show a recurring pattern of long-term severe drought, reinforcing its vulnerability (Table 4). Also according to the precipitation and temperature variation since 2019, Arzew Salt Lake has the largest range of temperature (has the highest temperature in the dry period showing by the green color in Fig (3B) and also the lowest in the wet period); combined with the low precipitation (Fig. 4), Arzew

Salt Lake undergoes the severest and sustained drought characterized by long negative SPI values reaching the -2.5.

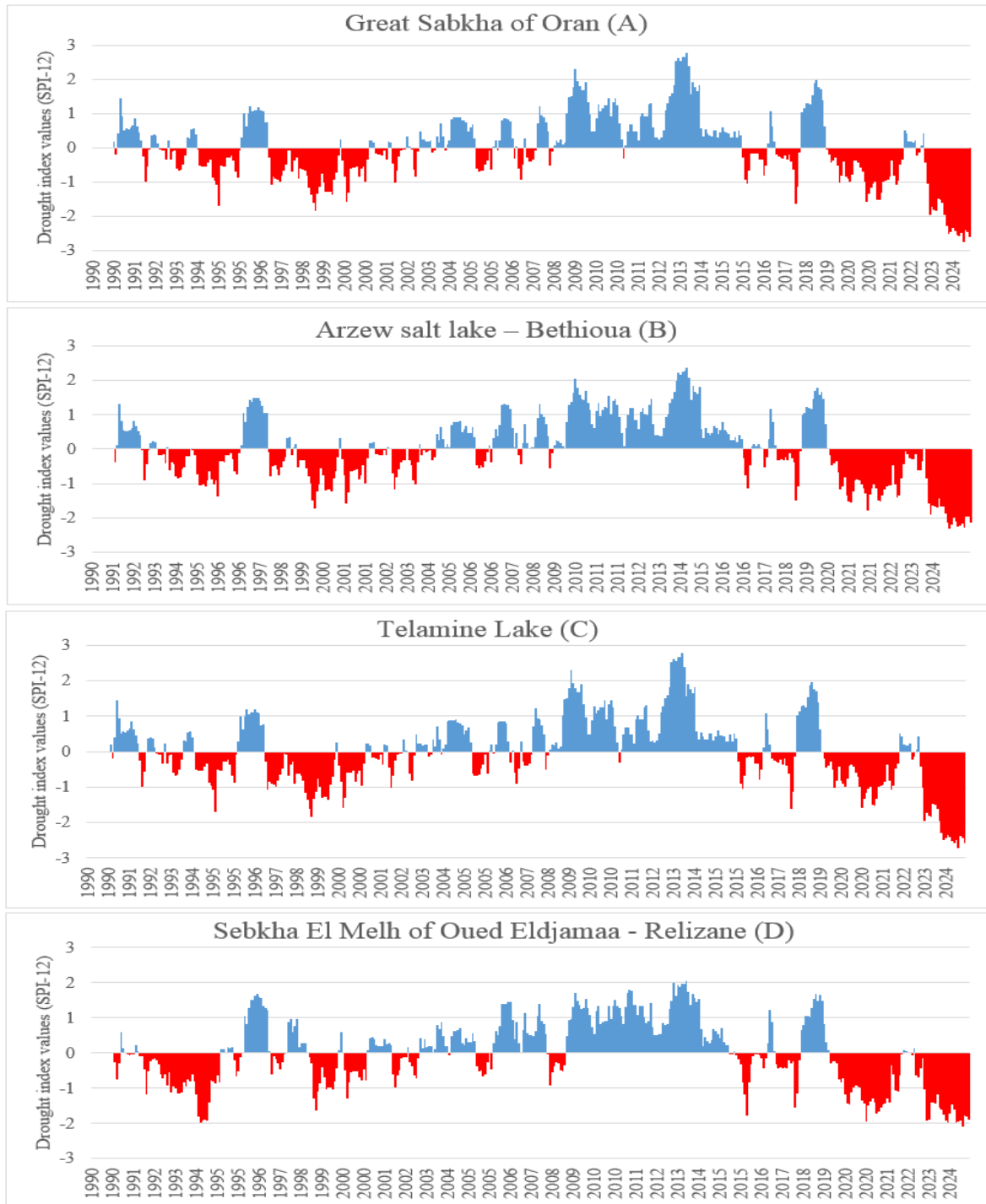


Fig. 5. Drought index values: Great sabkha of Oran (A), Arzew Salt Lake – Bethioua (B), Telamine Lake (C) (wilaya of Oran) and Sebkhah El Melh of Oued Eldjamaa (D) (wilaya of Relizane, calculated from NDWI and MNDWI boundaries area

Table 3. Sabkha drought characteristics based on SPI-12 (1990–2024)

Time frame	Characteristics of drought	Sebkha El Melh of Oued Eldjamaa	Great Sabkha Oran and Telamine lake	Arzew Salt Lake
Last 20 years (2002–2022)	Number of drought events	20	18	18
	Average severity	(−1.3)	(−1.4)	(−1.3)
	Average duration (months)	1.5	1.8	1.7
Entire period (1990–2024)	Number of drought events	35 – 40	30 – 35	30 – 35
	Average severity	(−1.6) to (−2)	(−1.7) to (−2.2)	(−1.6) to (−2.1)
	Average duration (months)	2 – 3	2.5	2.3

Table 4. Comparative summary of drought phases and severity across the northwestern lakes in Algeria (1990–2024)

Region	Early 1990s Drought	Wet Period (2003–2015)	Recent Drought (2019–2024)	Overall Severity
Sebkha El Melh of Oued Eldjamaa - Relizane	Severe, long duration	Wet and stable	Severe and persistent	High
Great Sabkha Oran and Telamine Lake	Long and fragmented	Wet with strong peaks	Extremely severe and extended	Very high
Arzew Salt Lake	Moderate to severe	Wet with strong peaks more stable	Severe and sustained	Moderate to high

3. Temporal analysis of water extent for the northwestern Algerian Sabkha (2016–2025)

The effect of declined flows of precipitation combined with unfavorable conditions such as those under consideration, particularly in closed lakes, water extent will be affected/ Fig. (6) highlights significant fluctuations in the water surface of Arzew Salt Lake over the period (2022–2023). During this period, the lake only reached about one-third of its full surface area in February and March, when a decrease in precipitation was recorded (Fig. 4), whereas the lake either dried up completely or barely filled to one-eighth of its surface area for the rest of the year.

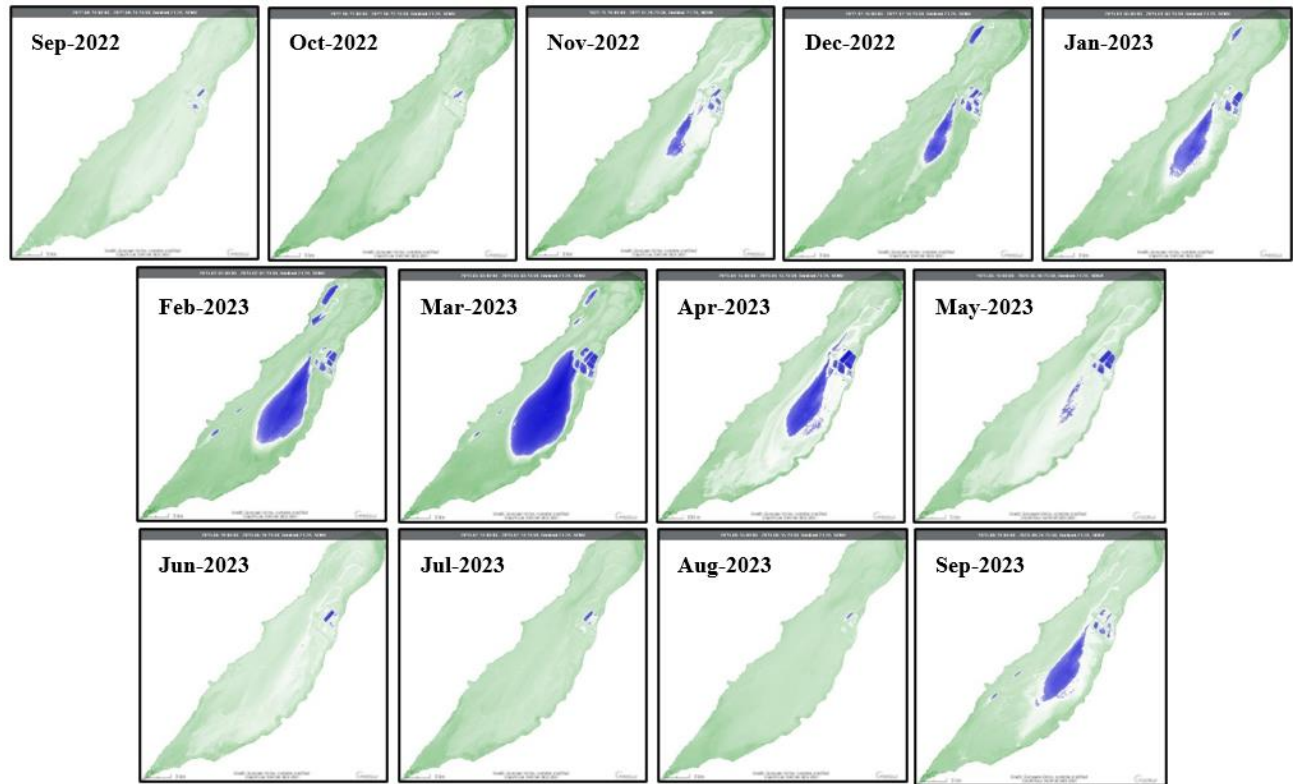


Fig. 6. Illustrative images of index NDWI of Arzew Salt Lake (Normalized difference water index) extracted from the Copernicus Data Space Ecosystem (between 2022-2023)

However, water extent time series in the Arzew Salt Lake (Fig. 7) reaches higher levels during the months of heaviest rainfall only (with a highest value in March 2017) with a water surface area of about 14.01 km².

It is observed (Fig. 7) that there has been a decrease in water bodies (calculated from NDWI and MNDWI boundaries area) from 2016 to 2025, following exactly the precipitation curve in the three of the lakes under consideration in this study (Great sabkha of Oran, Arzew Salt Lake and Sebkha El Melh of Oued Eldjamaa) except for Telamine Lake, suggesting an additional flow of water into the Telamine Lake, which in turn impacts the lake overall volume.

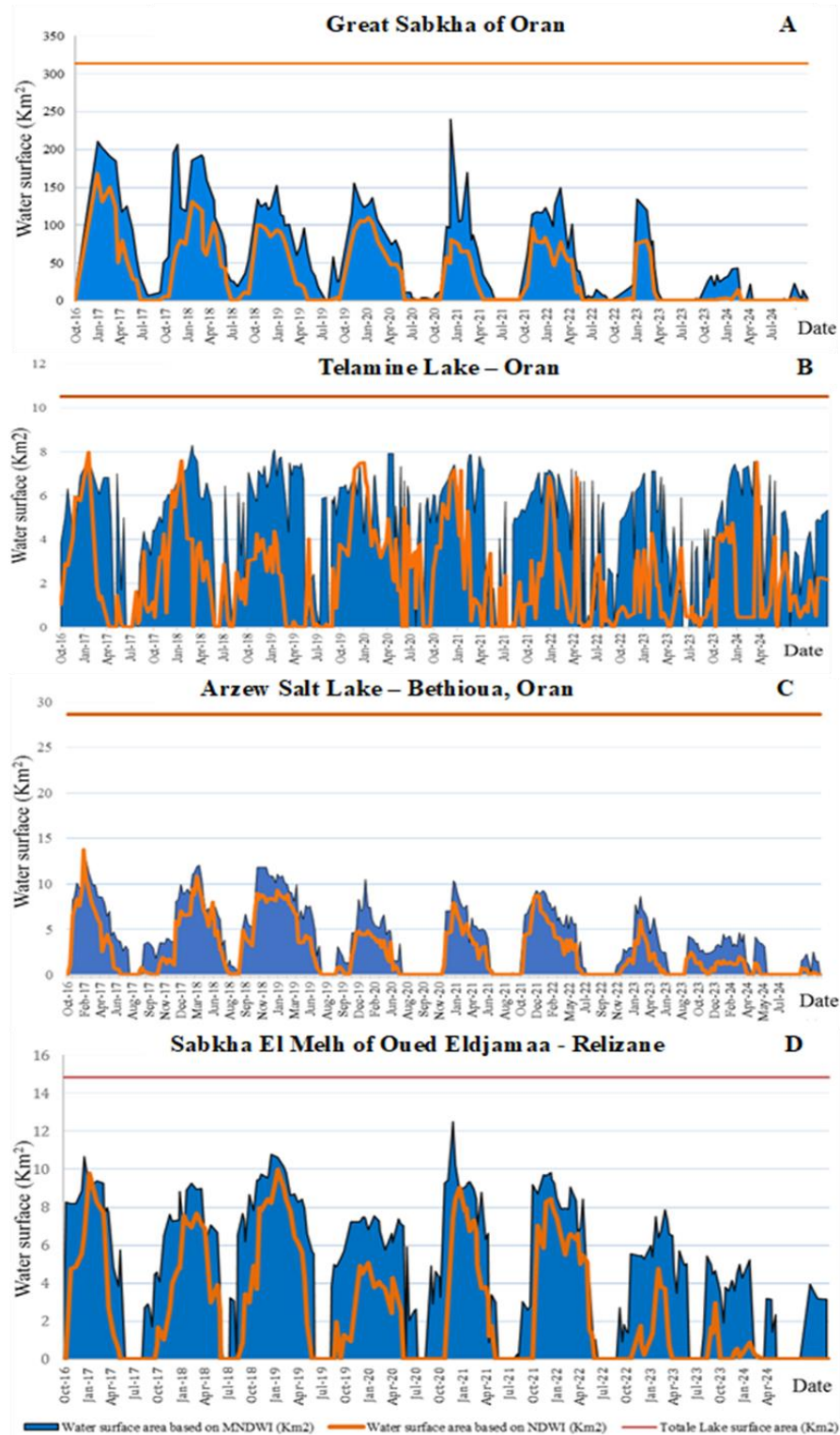


Fig. 7. Extent water body (Km²) of the Great sabkha of Oran (A), Telamine Lake (B), Arzew Salt Lake – Bethioua (C) (wilaya of Oran) and Sebkhia El Melh of Oued Eldjamaa (D) (wilaya of Relizane, calculated from NDWI and MNDWI boundaries area)

All water extent based on NDWI follow the same curve of water extent based on MNDWI with just small over estimation in surface area, except for Telamine Lake, where it reveals multiple periods with values tending toward zero for the NDWI water extent inversely to MNDWI water extent. Fig. (7) gives an illustrative result thus providing unambiguous evidence regarding the fullness of the lake (detected by MNDWI and overlooked by NDWI), which coincides exactly with the observation in our fieldwork on the 21/02/2024. This result corroborates the findings of **Benkesmia et al. (2023)**, who demonstrated that the extraction of water body using the NDWI is frequently compromised by noise (e.g., wet, salty and polluted soil, and certain types of vegetation), inversely to the Modified NDWI (MNDWI) that can improve water information over NDWI by removing detected noise.

Long-term *in-situ* monitoring to further confirm the result would be preferable; we had only a few days that supported the result confirming that MNDWI is more preferable for improving water information by removing noise.

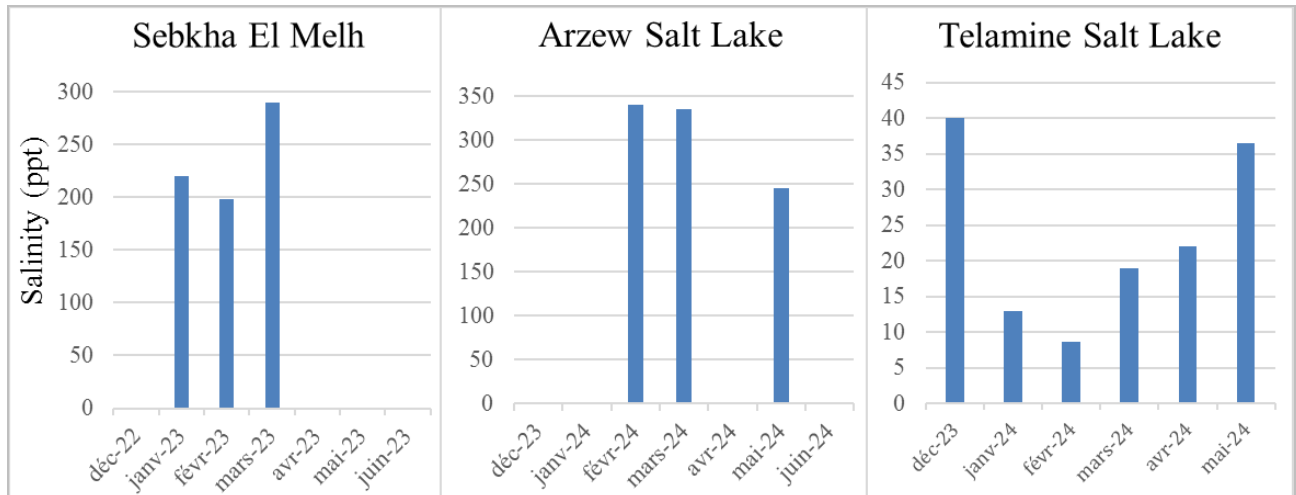


Fig. 8. *In situ* salinity during the fieldworks period (2022/2023 for sabkha El Melh, Relizane and 2023/2024 for Arzew Salt Lake and Telamine Lake, Oran)

The *in-situ* salinity of the Telamine Lake is not indicative of the Salt Lake itself (Fig. 8), where it is important to note that the range of salinity levels that have been shown to be beneficial for brine shrimp *Artemia* is reported to be between 90 and 130g/ L (**Utah Division of Forestry, Fire and State Lands (UDFFSL), 2013**) and any changes in salinity, dissolved oxygen, nutrients, and contaminants, especially when entrained into the upper layers of the water lake, have the potential to inflict harm upon brine shrimp *Artemia* and other species, which is unfortunately the reverse of what we saw in our fieldwork (sewage and other types of solid pollution). The true color satellite image in Fig. (9) shows the green water (micro-algae proliferation caused by high levels of nitrogenous matter discharged in the lake).

The *in-situ* observed pollution in Telamine Lake, from an unidentified origin, accompanied by a decrease in salinity levels within the lake, has undoubtedly influenced the development of *Artemia* (previously reported), as demonstrated by the absence of any trace of *Artemia* in our conducted fieldwork.



Fig. 9. Illustrative images of Telamine Lake (21/02/2024); True color based on bands B4, B3, B2, **Bleu color:** MNDWI based on bands B3 and B11, **Green color:** NDWI based on bands B3 and B8

4. Spatiotemporal dynamics of *Artemia* development in northwestern Algerian Sabkhas (2023/2024)

Unlike of Telamine Lake, a humble development of *Artemia* has been recorded in the Arzew Salt Lake and Sebkh El Melh of Oued Eldjamaa (Fig. 10) and all developmental stages (nauplii, juveniles, adults) were present over the wet months (February, March, and May, 2024 and January, February and March 2023) for every lake, respectively. The variation in their frequency is illustrated by the majority of young individuals (nauplii/Meta-nauplii and juveniles) compared to adults in Arzew Salt Lake,

due to high reproduction activity and the short wet periods in which the lake dried rapidly (in April 2024, illustrated in Fig. (7.C)); followed by another short pluviometry period in May that gives an imbalance in the total biomasses which prevented *Artemia* to reach the adult stage.

Regarding Sebkhia El Melh of Oued Eldjamaa, where the growth conditions were all reunited simultaneously, it was observed that the development was sustained marked with all stages in a perfect *Artemia* cycle (successive stages: nauplii, juveniles until adults' stage). However, the total *Artemia* biomass collected (Fig. 10) is constrained and has declined over time, where it disappeared completely after the wet months in both lakes.

The coincidence of the dried period in Great Oran Sabkha (from April 2023) with our fieldwork period was a barrier of evaluation of total *Artemia* biomass in this area, without denies that previously, the lake had been flooded on prior occasions (Fig. 7A).

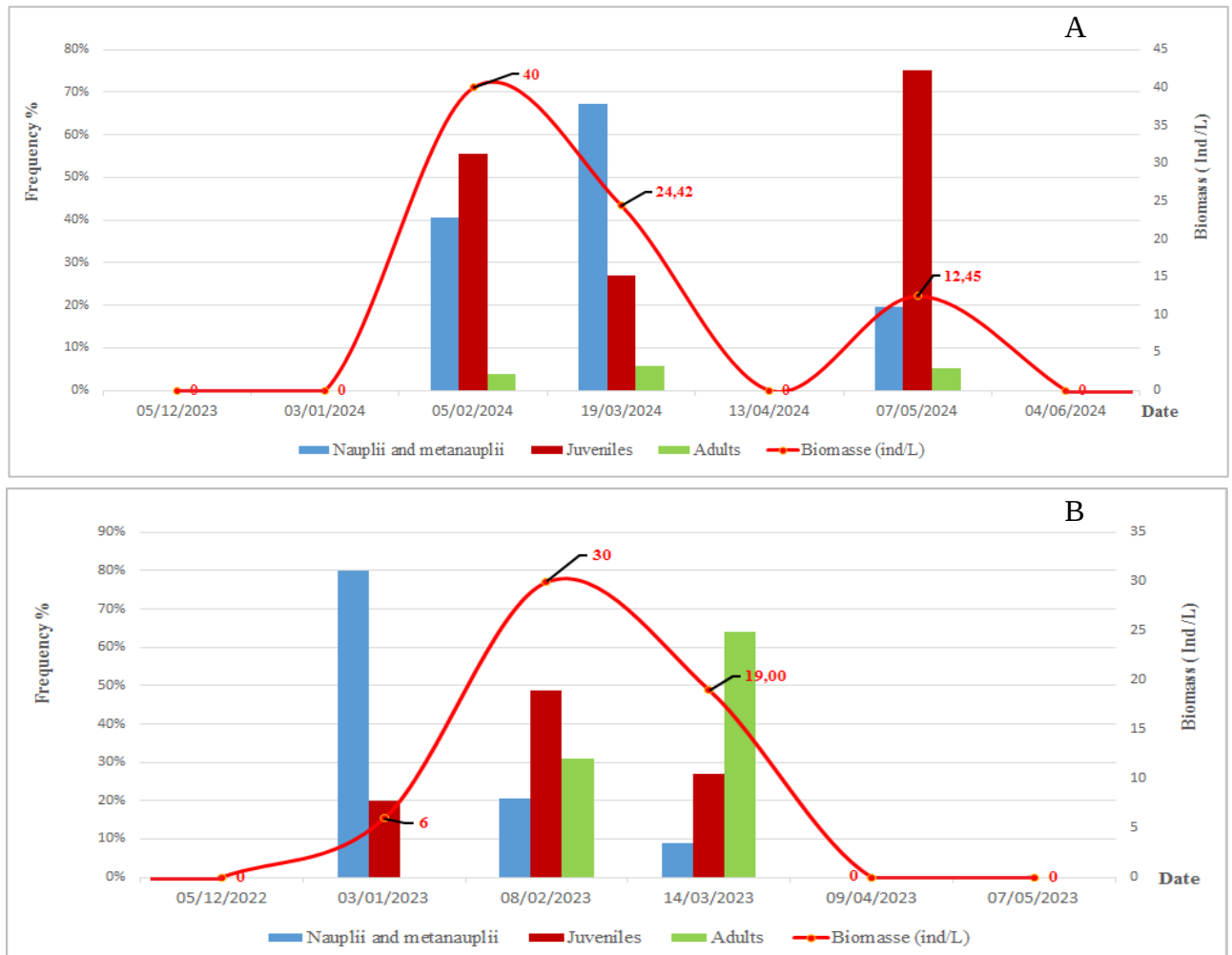


Fig. 8. Frequency % of *Artemia* development stages and their biomass over the wet period in: A) the Sebkhia of Arzew, (2024) and B) the Sebkhia El Melh of Oued Eldjamaa - Relizane, (2023)

DISCUSSION

Brine shrimp *Artemia*, in cyst form, is able to resist under unfavorable conditions (abiotic as well as biotic factors) usually characterized by the high salinity, low oxygen levels, temperature stress, food depletion, etc. But the live swimming *Artemia* are very sensitive to any change in their environmental parameters, (for this reason *Artemia* has become a model for lethality bioassays).

To maintain the growth of the *Artemia* population in the northwestern Algerian Sabkhas, favorable conditions must be reunited, otherwise they will become peril and their density will decline, subsequently influencing the provisioning of cysts for the aquaculture industry. While natural factors remain largely beyond human control, a possible approach is to pump filtered water (designed to prevent contamination and ecological imbalance) from nearby marine or freshwater sources during extended dry periods. However, the geomorphological characteristics of the Sabkhas with their high infiltration rates may limit the retention of added water. Despite this, these measures could still help protect these hypersaline ecosystems and make sure there is more surface water for longer periods. These interventions should be incorporated within a comprehensive, scientifically based national management strategy to ensure ecological sustainability and long-term resource viability.

Drought events with the increases in temperature and decline in precipitation are key climate stressors that can significantly impact freshwater availability. These changes not only reduce overall water input but also intensify evaporation rates, leading to the gradual decline of lake water levels in our case. As a result, salinity concentrations in these water bodies tend to increase which poses a serious threat to aquatic life, particularly to *Artemia* populations if salinity levels exceed the optimal range (330 gL⁻¹), as it has been reported in several previous research ((Domenech, 1979; Alal et al., 2017).

Most *Artemia* strains indicate that they cannot withstand temperatures below 6°C except for cyst stage. As it has been repeatedly reported, *Artemia* populations are able to live with maximum temperatures close to 35°C (Persoone & Sorgeloos, 1987). Encouragingly, all the recorded temperatures in the northwestern Algerian Sabkhas fall within the range that the brine shrimp *Artemia* can tolerate. Even if these changes are minor, they could influence the *Artemia* population in the long term. Warmer temperatures (<28°C) could lead to an earlier start to reproductive cycles or could favorize the parthenogenesis reproduction, but prolonged warmth (>28°C) could reduce the availability of dissolved oxygen, influence other parameters (e.g., salinity, Ph) in the water and reduce reproductive success (e.g. the metabolic resumption of dormant *Artemia* cysts, and the resulting imbalance in hatching parameters, was evident in Telamine Lake, where there was an imbalance in salinity, as demonstrated in several previous studies (Sorgeloos, 1980; Vanhaecke et al., 1984; Naceur et al., 2011; Browne et al., 2018; Dey et al., 2023; Xue et al., 2024), which could lead to a long-term decline in the *Artemia* population if temperatures consistently rise above the species tolerance threshold.

In the context of aquaculture and other ecological studies, understanding the influence temperature variations and determining the optimal pluviometry period can provide guidance to select the period in which *Artemia* will be in high level of productivity. A notable example is following intense rainfall when the lakes are dry with optimal favorable conditions, trigger metabolic recovery of dormant *Artemia* cysts, which is highlighted in the Sebkha El Melh of Oued Eldjamaa - Relizane, over the wet period of 2023 (Fig. 10B); however, the intense precipitation over a filled lakes lead to decrease salinity which can subsequently disrupt the adequate development of the swimming brine shrimp *Artemia*.

Such knowledge facilitates the prediction of population trends and assists in the formulation of management strategies for sustainable harvesting and conservation efforts. As long as lakes were filled with water, *Artemia* biomass was present in the northwestern Algerian Sabkhas, once environmental conditions were favorable. Unfortunately, the drop in rainfall has reduced the inflow of fresh water periodically for every lake under consideration, combined with periods of drought that have contributed to a reduction in water surface area, which led to the decline of the environmental quality for *Artemia* populations or drying out of the totality of the lake.

CONCLUSION

This work enabled an assessment of climate vulnerability and water extent in four hypersaline water bodies located in northwestern Algeria, with a view to promoting and producing *Artemia* as fish feed. A mixed approach was adopted, combining *in situ* surveys and sampling with laboratory analyses and spatio-temporal analysis of geospatial and climate data. This approach enabled the determination of *Artemia* population density and, consequently, the variation in water extent and its vulnerability to climatic conditions.

The findings of this study demonstrated that years with low rainfall resulted in a substantial decline in freshwater supply. Recent periods of drought in the lakes under investigation have indicated increased evaporation during the hottest months, as evidenced by the decline in water levels at three sites (Great sabkha of Oran, Arzew Salt Lake – Bethioua -wilaya of Oran and Sebkha El Melh of Oued Eldjamaa - wilaya of Relizane, where no evident pollution was recorded.

The findings of our research indicate that *Artemia* production in the lakes of northwestern Algeria is under threat. Water scarcity and unfavorable climatic conditions have indeed had a disruptive effect on the life cycle of *Artemia*, as well as on the entire food chain and ecological functions.

It is recommended that the ENASEL company instigate a period of suspension of salt extraction and exploitation activities. This is to be undertaken in order to promote the natural regeneration of the environment, which is necessary for the harvesting of *Artemia* cysts and salt production.

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