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The effect of severe drought on the disappearance of the brine shrimp *Artemia* from Urmia Lake

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Abstract

Urmia Lake has endured continuous water withdrawals for over two decades, significantly impacting its ecosystem. This lake is renowned as the largest habitat for a unique brine shrimp species, *Artemia urmiana*, initially documented by Günther. The primary objective of this study was to assess whether the adverse environmental conditions have led to the elimination of *A. urmiana* from the lake. Six sampling sites were strategically chosen, covering both the northern and southern regions of the lake. Unfortunately, two stations were inaccessible during the sampling campaign due to severe water withdrawal and marshy paths. Sampling activities were conducted monthly from March 2022 to February 2023. The parameters of Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured using an EC-meter (WTW model LF 320) and a multi-meter (WTW model 3410), respectively. Water salinity was determined through a refractometer (ATAGO, Japan, model S-28E). Essential data, including water level, surface area, and volume, were extracted from the East Azarbaijan water resources management company's website. Brine shrimp samples were collected using a net (25×100cm - 100 µ mesh size) at specific distances. The *Artemia* samples underwent detailed examination under a Nikon stereomicroscope. Surprisingly, no observable *Artemia* biomass (Nauplii, Meta-nauplii, young and adult *Artemia*) was noted in this study. Only *Artemia* cysts were observed in Lake Urmia. During the dry season in summer and autumn, cyst density was minimal, recording 0.00216 ± 0.0017 No/l and zero, respectively. In contrast, during the wet season in spring and winter, cyst density increased, measuring 0.364 ± 0.259 and 0.149 ± 0.084 No/l, respectively. In summary, the findings of this study highlight that the surface area, volume, and level of the lake exert significant influences on cyst density, revealing a notable impact of environmental factors on the *Artemia* population in Lake Urmia.

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Introduction

The Lake Urmia (37° 42' N, 45° 19' E) was once the second-largest hypersaline lake globally, covering approximately 5000 km² when it was at full capacity. Located among three Iranian provinces—East Azarbaijan, West Azarbaijan, and Kurdistan—the lake exhibited oligotrophic characteristics (ULRP, 2017; Asem et al., 2018). The brine shrimp species *Artemia urmiana* was initially identified by Günther and scientifically introduced from Lake Urmia (Günther, 1899). Sadly, the largest natural habitat of *A. urmiana*, Urmia Lake, is deteriorating, resulting in the transformation of vast areas into salt deserts. Over 90% of the *A. urmiana* population has been lost due to increasing salinity (Asem et al., 2018). The demise of Urmia Lake and the decline in the genetic diversity and survival of *A. urmiana* can be attributed to reduced rainfall, escalated evaporation, and unfavorable environmental management practices such as the indiscriminate construction of dams and excessive use of surface water resources (Asem et al., 2018).

Six sexual species of brine shrimp from salty lakes include *A. urmiana* from Urmia Lake with accompanying parthenogenetic populations, *A. tibetiana* from the Tibetan plateau, *A. sinica* from China and Magnolia, *A. salina* from the Mediterranean Basin, *Artemia sp*. from Kazakhstan, *A. franciscana*, and *A. persimilis* (Gajardo and Beardmore, 2012). *Artemia* holds great importance in aquaculture as a live food source, with a life history featuring a short generation time, maturation after 15 molts in 17-20 days, high fecundity, substantial embryo production per brood, the potential to produce free-living Nauplii (ovoviviparity) in favorable conditions, and the production of diapausing cysts (oviparity) in harsh conditions (Lenormand et al., 2017).

The Iranian population has doubled in the past four decades, escalating from 37 million to approximately 82 million (World Bank, 2019). This population increase has significantly heightened food and water demands in the region, leading to irregular agricultural development. The establishment of dams, deep and sub-deep wells, underground water pump stations, and diverting pipes has been instrumental in meeting these demands. According to Fathian et al. (2016), over the past 35 years, agriculture, horticulture, and rain-fed agriculture have increased by 412%, 333%, and 627%, respectively. In essence, the expansion of dry agriculture with low returns has resulted in the destruction of natural vegetation. Simultaneously, since 1987, agricultural and urban areas have doubled and tripled, respectively. The water pipeline project, initiated in 1999 to supply drinking water, annually transfers about 3 billion cubic meters of water from the Zarineh River to Tabriz city, significantly reducing the water inflow from the river, which alone contributes 50% of Lake Urmia's water (Khalyani et al., 2014). This study aimed to determine the effects of dystrophic drought on 1) the *Artemia* population in Lake Urmia and 2) the elimination of *Artemia* biomass from the lake.

Materials and Methods

Samplings were performed monthly for 12 months from March 2022 to February 2023. Considering sever shrinking, morphometric characteristics and outcropping of a large section of the Urmia lake bed, six sampling sites were selected in northern and southern parts of the lake: 1- Zanbil, 2- Agh Gonbad 3- Myan Gozar, 4- Kazem Dashi, 5- Gholmankhane and 6- Rashakan (Figure 1). Due to significant water withdrawal and the presence of a marshy path and muddy area, access to Gholmankhane and Rashakan stations was impeded during the sampling campaign. Consequently, the sampling sites were consolidated to four locations.

Figure 1. The sampling sites in Urmia Lake: 1- Zanbil, 2- Agh Gonbad 3- Myan Gozar, 4- Kazem Dashi, 5- Golmankhane and 6- Rashakan.

Table 1 shows the geographical coordinates of sampling sites were. Ecological condition of Urmia Lake was so harsh, and in some stations particularly in the dry season the lake become shrank as isolated water patches.

Table 1. The geographical coordinates of sampling sites in Urmia Lake.

Station	1-Zanbil	2- Agh Gonbad	3- Myan gozar	4- Kazem dashi
Latitude	37° 47´ 6.38″ N	37° 47´ 40.44″	37° 47´ 26.00″ N	38° 03´ 07.52″ N
Longitude	45° 21´ 37.13″ E	45° 23´ 11.40″ E	45° 21´ 40.47″ E	45° 12´ 08.67″ E

Several parameters were measured in situ using portable instruments: water temperature was recorded with a digital thermometer. Electric Conductivity (EC) and Total Dissolved Solids (TDS) were determined using an EC-meter (WTW model LF 320) and a multi-meter (WTW model 3410), respectively. Water salinity was measured using a refractometer (ATAGO, Japan, model S-28E). Since the water salinity exceeded the refractometer's measurement range in all samples, the samples were initially diluted 2-3 times with distilled water to account for the salinity. The water level, surface area, and volume of Lake Urmia were obtained from the East Azarbaijan Water Resources Management Company (RWCEA) website. Brine shrimp biomass and cyst samples were collected using a net (25 × 100 cm length-width, 100 µ mesh size) at a defined distance of about 40 meters. The sectional area of the collecting net allowed for the easy calculation of the volume of water passing through the net. The collected samples were transported to the laboratory in refrigerated boxes and examined under a stereomicroscope (Hafezieh, 2003, Nikon). Pearson correlation coefficients and equations were calculated using Excel software. Multivariate analysis of the data was conducted using PAST 3.04 software (Hammer et al., 2001). Before analysis, data were log-transformed and subjected to Principal Component Analysis (PCA). The percentages of PCA components influencing the variations of parameters were determined. Biplots were generated for each PCA, and loadings of environmental parameters were calculated.

Results

Water level of Urmia Lake shows seasonal fluctuations during wet and dry seasons

(Figure 2). However, in this study, the average water level was lower than its ecological limit (1274 m). Figures 2, 3 and 4 indicate water level, surface area and volume changes of the lake respectively, (Mars 2022-Feb 2023). The highest and lowest water level were observed in May and November 2023.

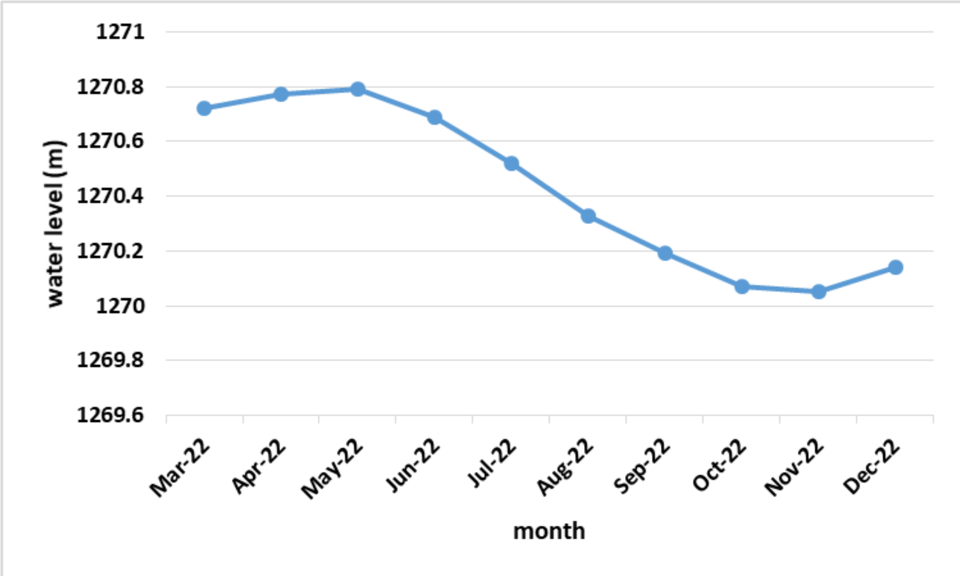

Figure 2. Urmia lake water level fluctuations during Mars - December 2022

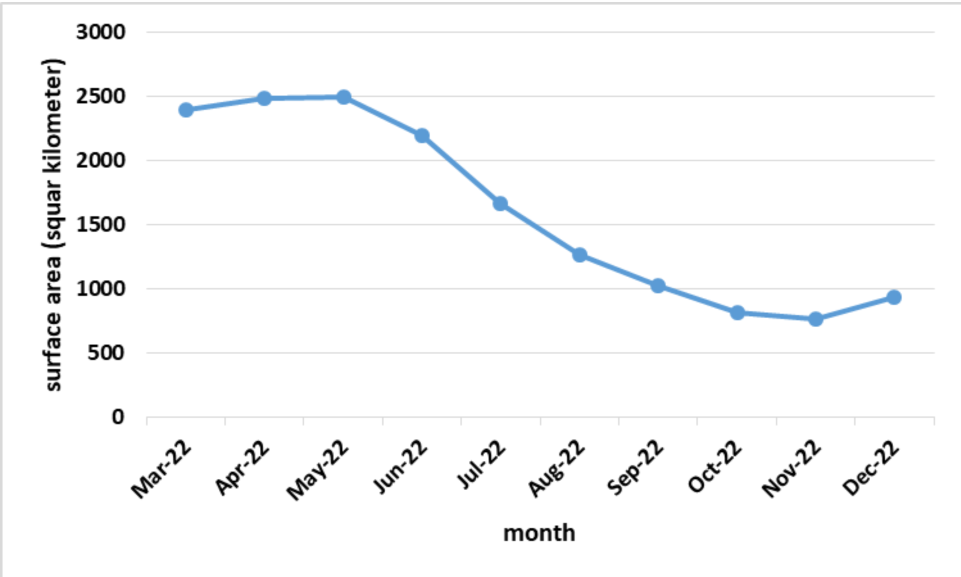

Figure 3. Urmia Lake surface area fluctuations during Mars - December 2022

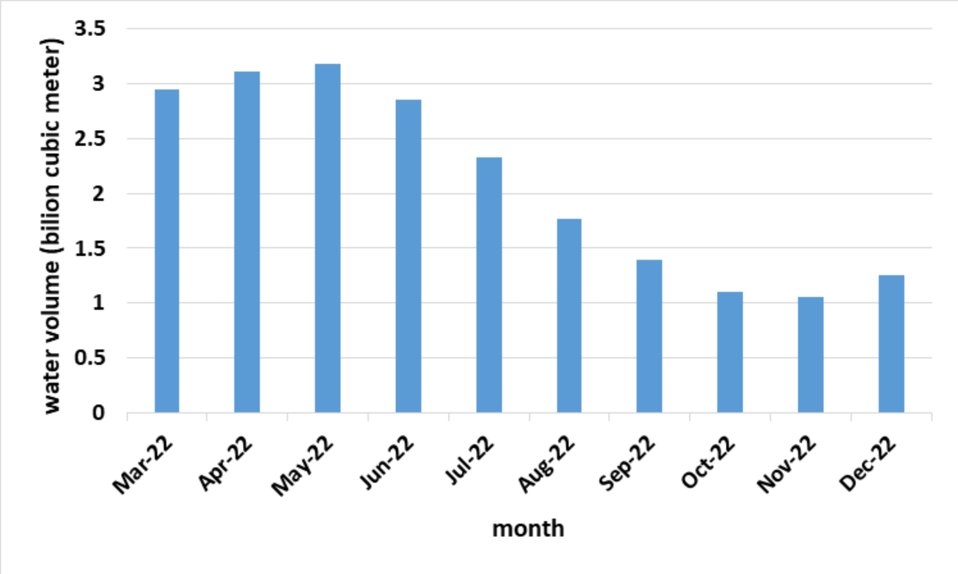

Figure 4. Urmia lake volume fluctuations during Mars - December 2022

Seasonal variations were evident in the surface area and volume of Lake Urmia. The maximum and minimum surface areas were recorded in May and November 2022, measuring 2502.2 and 768 km2, respectively. Similarly, the highest and lowest water volumes were noted as 3.18 and 1.05 billion m3 in May and November 2022, respectively. The salinity of Lake Urmia exhibited seasonal fluctuations, with the highest and lowest values recorded as 470 ± 9 and 338 ± 18.6 g/l in September 2022 and February 2023, respectively. The average salinity for the lake was 385.5 ± 46.4 g/l. Regarding Total Dissolved Solids (TDS), the lowest and highest annual averages were 394.7 ± 13.3 and 576.5 ± 44.7 mg/l, corresponding to March and September 2022, respectively. The annual average TDS in Lake Urmia was 472.6 ± 58.2 mg/l. Station-wise, Agh Gonbad recorded the lowest TDS at 380 mg/l in March 2022, while the highest was 643 mg/l in the same station in September 2022. Kazem Dashi and Zanbil stations had the lowest and highest annual average TDS values, with 464 and 479 mg/l, respectively.

Electrical Conductivity (EC) also displayed seasonal variations, with the lowest and highest annual averages being 532.3 ± 21.7 and 905.7 ± 70.0 µmos/cm, corresponding to March and September 2022, respectively. The annual average EC in Lake Urmia was 750.7 ± 102.3 µmos/cm. Agh Gonbad station recorded the lowest and highest EC values, measuring 509 and 1010 µmos/cm in March 2022 and September 2022, respectively. The Myan Gozar station had the lowest annual average EC at 750 ± 110.1 µmos/cm, while the highest was 763 ± 71.4 µmos/cm at the Kazem Dashi station. The cyst stocking density varied across stations, with Kazem Dashi station having the lowest annual cyst density at 0.024 ± 0.06 cysts/l and Myan Gozar station having the highest at 0.226 ± 0.49 cysts/l. Zanbil and Agh Gonbad stations fell in the middle ranks, with 0.143± 0.23 and 0.122 ± 0.23 cysts per liter, respectively. The annual average cyst density for Lake Urmia was 0.129 ± 0.081 cysts per liter. Analyzing cyst density across seasons revealed that in autumn, the average cyst density was zero, indicating an absence of cysts in Lake Urmia during this season. Conversely, the highest seasonal density was 0.364 ± 0.26 cysts/l. In summer and winter, cyst densities of 0.00216 ± 0.002 and 0.149 ± 0.084 cysts/l were observed in Lake Urmia. Overall, lower cyst densities were observed in summer and autumn compared to winter and spring 2022-23 (Table 2).

Table 2. Seasonal cyst density in sampling sites of Urmia Lake (Mars 2022- Feb 2023) (Abbreviations: zan = zanbil; ago = agh gonbad; myg = myan gozar; kaz = kazem dashi)

season	spring	summer	autumn	winter
zan	0.360667	0.002667	0	0.208333
ago	0.324	0.002	0	0.163333
myg	0.701	0.004	0	0.2
kaz	0.070667	0	0	0.026667
Average	0.364083	0.002167	0	0.149583

From September to December 2022, no cysts were recorded or observed in Lake Urmia (Table 3). Zanbil and Agh Gonbad stations also showed no cysts from September to January 2022 (Table 3). Similarly, Myan Gozar station recorded no cysts from September to December, and there were no cysts at this station in February either. Kazem Dashi station exhibited an absence of cysts from July to February 2022, covering 9 months of the year. The highest number of cysts observed in this study was 0.78 per liter in May 2022, while the lowest was 0.002 per liter in July and August 2022 (Table 3), both recorded in Agh Gonbad. March and April 2022, with an average of 0.315 ± 0.19 and 0.78 ± 0.65 cysts per liter, were the months with the highest cyst densities in this study.

Table 3. Monthly cyst density (NO/l) in sampling sites of Urmia Lake (Mars 2022- Feb 2023) (Abbreviations as Table 2)

month	zan	ago	myg	kaz
Mar-22	0.205	0.21	0.53	0.08
Apr-22	0.64	0.18	0.42	0.21
May-22	0.44	0.78	1.68	0.002
Jun-22	0.002	0.012	0.003	0
Jul-22	0.005	0.002	0.006	0
Aug-22	0.003	0.004	0.006	0
Sep-22	0	0	0	0
Oct-22	0	0	0	0
Nov-22	0	0	0	0
Dec-22	0	0	0	0
Jan-23	0	0	0.07	0
23-Feb	0.42	0.28	0	0
Average	0.142917	0.122333	0.22625	0.024333

The lowest and highest numbers of cysts counted in Zanbil station were 0.002 and 0.64 cysts per liter, respectively, in the months of June and April 2022. At Agh Gonbad station, the lowest and highest cyst density was observed in July and May 2022, respectively, with 0.002 and 0.78 cysts per liter. Additionally, the lowest and highest cysts observed at the Myan Gozar station were 0.003 and 1.68 cysts per liter, related to June and May 2022, respectively. Finally, Kazem Dashi station showed the lowest cyst density with 0.002 cysts/liter in June and 0.21 cysts/liter in May 2022.

As shown in Table 4, the correlation coefficients between salinity and three morphometric parameters were approximately equal to R2 = 0.77. This indicates a high and negative relationship among these parameters. In other words, a small increase in these parameters resulted in a sharp drop in salinity, and vice versa. The correlation coefficients between cyst density and water level, surface area, and volume were 0.688, 0.728, and 0.702, respectively (Table 5). The high relationship between cyst density and these morphometric parameters underscores their significance in the cyst suspension caused by water entering the lake.

Table 4. Correlation coefficients of the salinity and morphometric parameters in Urmia Lake (Mars 2022- Feb 2023)

parameter	Salinity (R^2)	Salinity (R)	Correlation
Water level	0.7765	- 0.881	High
surface area	0.7771	- 0.882	High
volume	0.7715	- 0.878	High

Table 5. Correlation coefficients of the cyst density and morphometric parameters in Urmia Lake (Mars 2022- Feb 2023)

parameter	Cyst density (R^2)	Cyst density (R)	Correlation
Water level	0.4741	0.688	Relatively high
surface area	0.5295	0.728	Relatively high
volume	0.4934	0.702	Intermediate

The lowest and highest average water temperature were 5.6 ± 0.63 and 31.25 ± 1.5 ℃ that was recorded in January and Jun 2022, respectively. In general, in this study, none of the biological forms of *Artemia*, including Neaplii, Metanauplii, young and adult *Artemia*, were observed and recorded in Lake Urmia. Collections and samplings were only *Artemia* cysts, which were invisible in some seasons and months due to the harsh conditions prevailing the lake.

Cyst density exhibited correlations with salinity, TDS, and EC, indicating that as the values of these variables decrease, the cyst density of the lake increases, and vice versa. In other words, an increase in the values of these variables results in a reduction in cyst density. The correlation coefficients between these three factors and cyst density indicated a weak to moderate influence. Specifically, the correlation coefficients between the number of cysts and salinity, TDS, and EC were calculated as R = -0.544, R = -0.588, and R = -0.463, respectively. The correlation relationship between the level, surface area, and volume of Lake Urmia with cyst density demonstrated that these three variables have a relatively strong effect on the cyst count in the lake (refer to Figure 5, 6, and 7). The correlation coefficients between cyst density and the level, surface area, and volume of the lake were determined as R = 0.689, R = 0.728, and R = 0.702, respectively. These coefficients' values indicated that the correlation between the three variables—level, surface area, and water volume of Lake Urmia—and the number of cysts per unit volume is relatively significant.

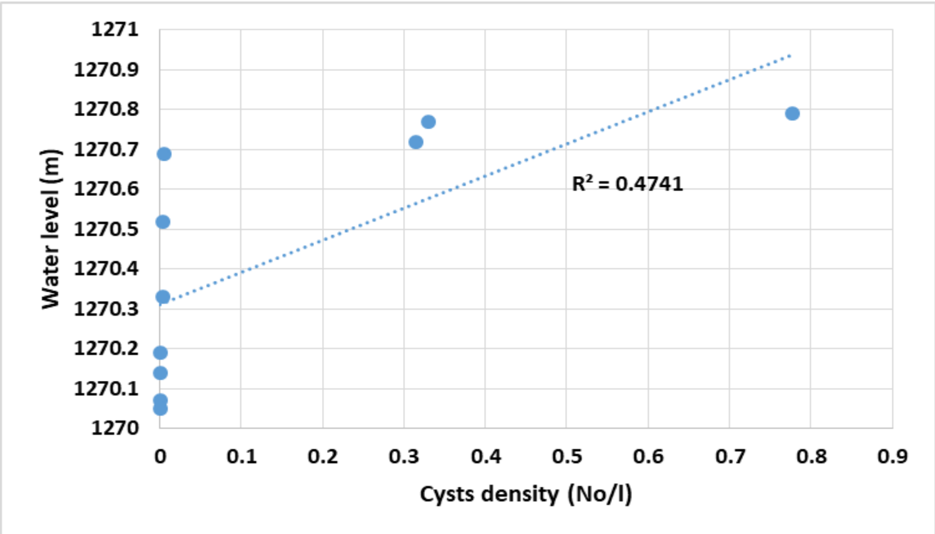

Figure 5. Correlation between Artemia cysts density and water level of Urmia Lake (Mars 2022- Feb 2023)

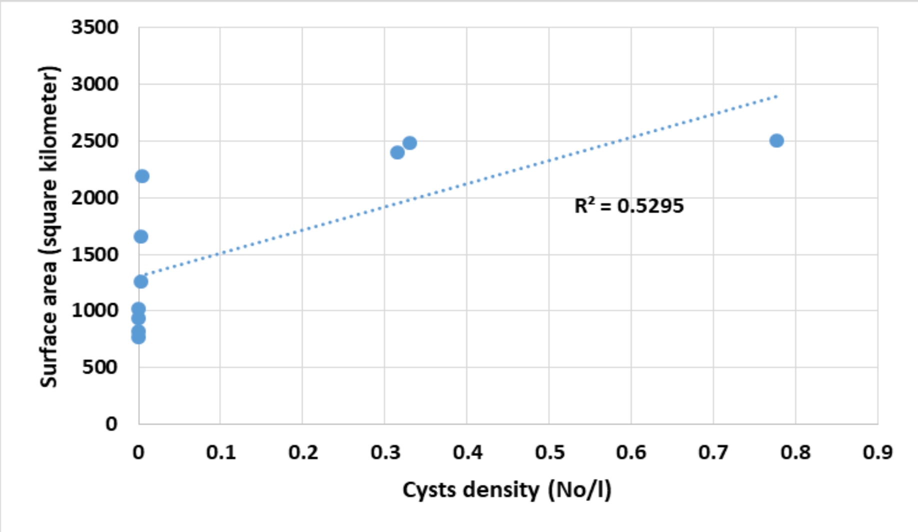

Figure 6. Correlation between Artemia cysts density and water surface area of Urmia Lake (Mars 2022- Feb 2023

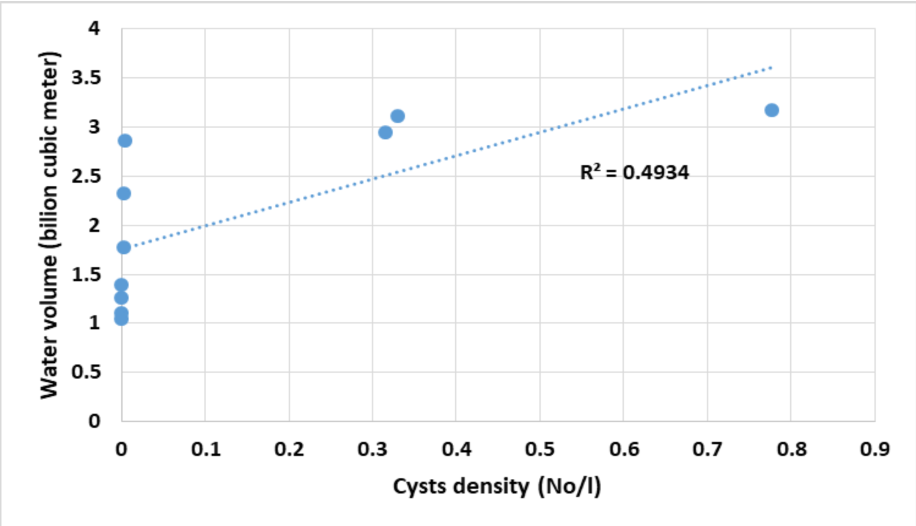

Figure 7. Correlation between Artemia cysts density and water volume of Urmia Lake (Mars 2022- Feb 2023)

At the Zanbil sampling site, cyst abundance varied from the lowest recorded at 0.002 cysts/l in June 2022 to the highest observed at 0.64 cysts/l in April 2022. In Agh Gonbad, the range of cyst density fluctuated between the lowest and highest values, occurring in July and May 2022, at 0.002 and 0.78 cysts/l, respectively. Similarly, Myan Gozar exhibited the lowest and highest cyst counts of 0.003 and 1.68 cysts/l in June and May, respectively. In Kazem Dashi, the cyst density ranged from 0.002 to 0.21 cysts/l in June and May 2022, respectively. The initial PCA analysis, based on cyst density and physico-chemical parameters, was conducted (see Figure 8). In this analysis, axes 1 and 2 explained 91.923% and 6.971% of the total variance (refer to Table 6). TDS, EC, and salinity emerged as the most significant factors on axis 1, with loadings of 0.648, 0.539, and 0.537, respectively. On axis 2, EC, TDS, and salinity had the highest effects, indicated by loadings of -0.830, 0.395, and 0.359, respectively. The distribution pattern of sampling sites on the PCA axis 1-2 highlights significant variations in environmental factors among them (see Figure 8).

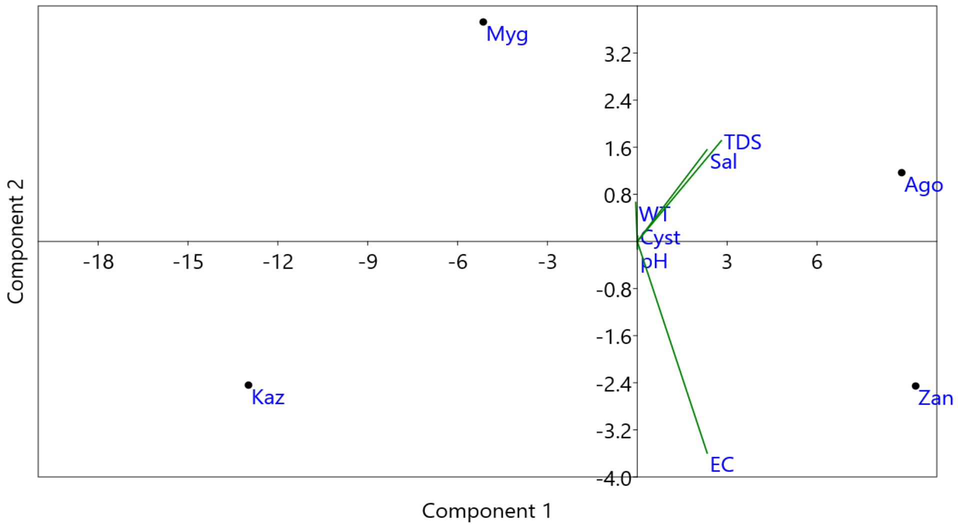

Figure 8. PCA of environmental parameters on the sampling sites of Urmia Lake

Table 6. Summary of variances explained by three first axes of PCA on environmental parameters of the sampling sites in Urmia Lake

PC	special value	Variance (%)
1	119.73	91.923
2	9.080	6.971
3	1.439	1.105

To study the weights of environmental parameters on the seasons we recognized that total phytoplankton density (Tphy) explained the highest variation on the axis 1 (Figure 9, Table 7), while other parameters had little influences on the variation. On the component 2, surface area of the lake (S) influenced this axis very strongly (0.987) and EC, TDS and salinity partially affected the seasons distribution on the PCA.

Average	0.364083	0.002167	0	0.149583

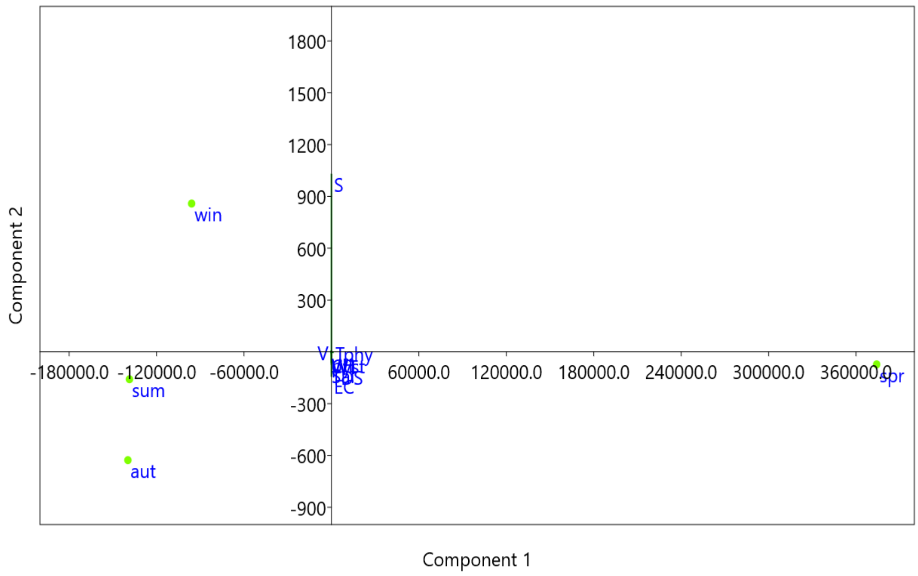

Figure 9. PCA of environmental factors affected seasons in the Urmia Lake (2022-23)

Table 7. Summary of variances explained by three first axes of PCA of environmental parameters (minus phytoplankton) on the seasons of Urmia Lake (2022-23)

PC	special value	Variance (%)
1	6.26×10^{10}	99.99
2	386887	0.00061767
3	1.32×10^{-6}	831.47

Another PCA was carried out to indicate environmental variables effects on the seasons (Figure 10). In this analysis axes 1 and 2 explained 67.85% and 31.85% of total variances (Table 8). The water volume, surface area and water temperature had the highest influences on the axis 1. On the other hand, water temperature, volume and surface area were the most significant factors on axis 2. As seen in Figure 10, spring, summer, autumn and winter were separated on the PCA axis that refer to dominance of different environmental conditions in these seasons on the Urmia Lake during Mars 2022 to Feb 2023.

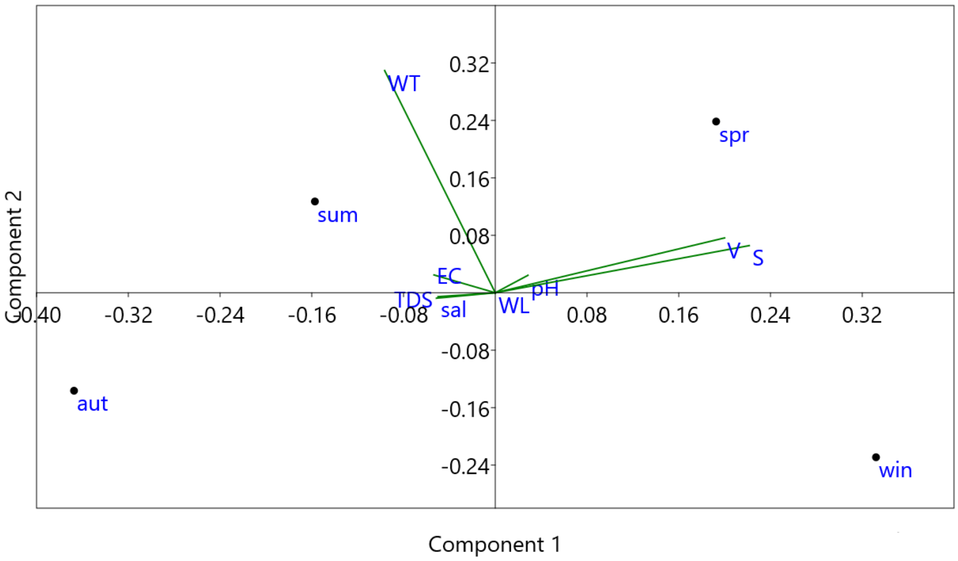

Figure 10. PCA of environmental parameters on the seasons of Urmia Lake

Table 8. Summary of variances explained by three first axes of PCA of environmental parameters on the seasons of Urmia Lake

PC	special value	Variance (%)
1	0.102	67.85
2	0.048	31.85
3	0.00045	0.298

Discussion

The brine shrimp *Artemia* is the dominant macro zooplankton in many highly saline environments (Wurtsbaugh and Gliwicz, 2001). This crustacean is often found in the food chain of very salty waters and its grazing activity controls water clarity (Wurtsbaugh, 1992; Lenz, 1987). The density and population structure of *Artemia* in highly saline lakes have rarely been studied. In fact, the population structure of its various biological forms depend on many factors and its investigation is relatively complicated. The growth and development season of *Artemia* biomass is relatively limited in temperate regions and it is observed in the warm season of the year (from May to early December). On the contrary, external factors, such as illegal harvesting and predation by birds, exert a notable influence on the *Artemia* population in Lake Urmia. Consequently, accurately pinpointing the physical and chemical factors affecting the *Artemia* population proves challenging, as also evidenced in this study. The disparity in the parameters used to quantify *Artemia* production and the diverse values reported in various sources affirm that conducting a quantitative assessment of *Artemia* in a saline water body (in terms of the number of individuals or biomass per unit of water) is intricate due to its highly heterogeneous distribution. *Artemia*, with its positive phototactic orientation, is exposed to water currents induced by wind, resulting in widely varying recorded densities (Persoone and Sorgeloos, 1980).

During this study, no forms of *Artemia* biomass (Nauplii, Meta-nauplii, young, and adult *Artemia*) were observed. Only *Artemia* cysts were noted and recorded as the sole form of *Artemia* in Lake Urmia from March 2021 to February 2022 (Mohebbi, 2021). This observation suggests unsuitable conditions for *Artemia* cyst spawning during this period. The observed cysts were, in fact, those situated at the bottom of the lake, nestled between salt crystals and sediments, and were washed away by rain and water, subsequently dissolving into the water, thus becoming visible in the samples. In 2017, due to excessively low water depth, no nauplii, meta-nauplii, young, and adult *Artemia* were observed in Lake Urmia. As the water level rose from the beginning of 2018, various biological forms of *Artemia* reappeared in the lake (Mohebbi, 2021). The density of *Artemia* cysts was also low in 2017, and with the rise of water in 2018, its density increased. A prior study (Mohebbi, 2021) revealed that the water level in Urmia Lake was lower than 1271 m in 2018, while it was higher than 1271m in 2019, inducing cysts to hatch, and *Artemia* biomass appeared in the lake. Over the last 25 years, the decrease in water level has led to a reduction in *Artemia* density in Lake Urmia. In 1898, when the water salinity was approximately 150 g per liter, 1200-1600 *Artemia* were counted per cubic meter of water (Günther, 1899). Additionally, Kelts and Shahrabi (1986) reported a density of 3000 *Artemia* per cubic meter of water in their study on Lake Urmia in 1977. As the water level decreased, the density of *Artemia* also rapidly declined, with no *Artemia* reported from the lake during the years 2010-2018. The high salinity of Lake Urmia, up to the saturation level (about 350 grams per liter), has caused the population density of *Artemia* to decrease to less than 1 number per cubic meter in recent years, compared to the density of 1 number per liter during high water (Mohebbi et al., 2022).

From April 2018 to February 2019, and also from December 2019 to February 2020, there was no *Artemia* biomass in Urmia Lake (Mohebbi, 2021). Overall, no life forms of *Artemia* were observed at water levels below 1271 m during this period. The highest water level in this period was 1270.79 m, recorded in April 2022. In 2018-2020, the average density of nauplii, juvenile, and adult *Artemia* was 1.15, 0.39, and 0.13 No/l, respectively (Mohebbi, 2021). Mohebbi et al. (2022) estimated *Artemia* cyst and biomass density at about 4.6 and 0.004 No/l, respectively, during April 2018 to February 2021. In the present study, *Artemia* biomass was not recorded at all, and cyst density was reported as 0.128 No/l. In fact, cyst density has dropped 36 times during two years. It is noteworthy that in a previous study (Mohebbi et al., 2022), a part of cysts was released by females that were present in the lake, whereas, in the present study, all cysts were washed out by precipitation and entering water, dislodging cysts stuck among salts and sediments. The correlation coefficient between salinity and cyst density was calculated as R= - 0.89. The high value of the coefficient infers the crucial role of salinity as the main parameter in cyst abundance changes. In this study, Kazem Dashi, located at the northernmost point of the lake (Figure 1), had the lowest cyst density. With no river or flowing water entering the lake at this station, cysts were not washed out. The high values of cyst density at Myan Gozar station are probably related to the dominant winds of the region (northwest-southeast) that accumulate the cysts at this site. Both Zanbil and Agh Gonbad, located at the southern arm, receive the most entering water into the lake.

The findings revealed that cyst abundance was low during the dry-warm season and high in the wet-cold season in Lake Urmia. In the summer and autumn (dry season), cyst density was 0.00216 and zero, respectively, while in the spring and winter (wet season), they were 0.364 and 0.149 No/l, respectively. Given the absence of *Artemia* biomass, these values indicate that the total cysts resulted from washing by precipitation water. The separation of sampling sites on the axis 1 and 2 of PCA was analyzed (Figure 8). In this analysis, components 1 and 2 shared 91.92% and 6.97% of variations, respectively. This PCA demonstrated significant variations in sampling sites from an environmental parameters perspective. The conspicuous separation of Kazim Dashi station indicates its unique position at the northernmost point of Lake Urmia. The lack of entering water or rivers into this station is likely another reason for this segregation. In this analysis, total dissolved solids (TDS), salinity, and electrical conductivity (EC) were the most important variables affecting the segregation of sampling sites.

The effects of environmental parameters on the separation of seasons were investigated through another PCA (Figure 9). The most noticeable characteristic of the seasonal arrangement in this analysis was the recession of spring from other seasons, lying at the end of axis 1 of PCA. This arrangement was shaped by fluctuations in phytoplankton (axis 1) and surface area (axis 2) in the lake during various seasons. On the other hand, summer and autumn showed more proximity than other seasons in this arrangement, suggesting relatively similar conditions in these two seasons. PCA was performed to analyze the effects of environmental parameters (excluding phytoplankton) on the variations among the seasons (Figure 10). In this analysis, every four seasons were properly segregated from each other, indicating that the studied parameters contained high variation ranges during different seasons. The most significant parameters explaining the seasonal arrangement in this analysis were the lake surface area and volume, water temperature, TDS, EC, and salinity on component 1, and water temperature, lake volume, and surface area on component 2, respectively. The lowest and highest TDS values in Lake Urmia were 394 and 576 g/l in March and October 2022, respectively. TDS is a variable that indicates the amount of total dissolved solids in water. The minimum and maximum values of electrical conductivity (EC) in March and October 2022 were recorded as 394 and 576 µm/cm, respectively.

In summary, the results of this study demonstrate that the surface, volume, and level of the lake have been the most influential parameters on lake cyst density, with R = 0.728, R = 0.702, and R = 0.689, respectively. EC, salinity, and TDS of water have a moderate effect on the abundance of cysts in the lake, with R=-0.588, R=-0.543, and R=-0.463, respectively. Finally, pH and the density of phytoplankton are the least influential parameters on the density and composition of *Artemia* cysts, with correlation coefficients R=0.365 and R=0.2, respectively. In addition to the complete removal of biomass and the sharp reduction of *Artemia* cysts per unit of lake water volume, the decrease in the lake volume from about 30 billion cubic meters in the high-water years (1994) to about 1.2 billion cubic meters in the present study (2022-2023) caused a decrease of about 15 times the amount of cysts in it.The maximum harvestable cyst in Urmia Lake obtained about 150 kg (Table 9). With regard to harsh situation of the lake it would be so difficult to harvest this too little amount of the cyst. It should be noted that any harvesting of biomass reserves and *Artemia* cysts is dependent on obtaining the necessary permits from the country's environmental organization and relevant institutions, and any unauthorized harvesting has environmental consequences and can cause irreparable damage. During two decades, from 1990s to 2010s, the cyst density has reduced from 2500 No/l to 4.6 No/l and *Artemia* biomass from 1.5 to 0.004 No/l (Table 10). Water level reduction and simultaneous salinity increase is the most significant parameter in the *Artemia* population drop in the Urmia Lake. Food resources fall particularly *Dunaliella spp*. as the major alga of the lake is indirect effects of water fall down and incidence of harsh ecological conditions (Mohebbi et al., 2022).

Table 9. Estimation of existing and harvestable cysts in Urmia Lake (Mars 2022- Feb 2023)

season	spring	summer	autumn	winter	Annual average
Cysts density (No/l)	0.364	0.002	0	0.149	0.128
Lake volume (billion cubic meter)	3.05	1.83	1.13	2.95	2.24
Total cysts number (cysts × lake volume)	1.11×10^{12}	0.0036×10^{12}	0	0.43×10^{12}	0.368×10^{12}
Cysts weight* (kg)	5550	18	0	2100	1917
Cysts (kg) minus sampling and lab errors	4440	14.4	0	1680	1530
Harvestable cysts (kg) (10%)	444	1.44	0	168	153

*200000 cysts weigh about 1 gr

Table 10. Estimation of cyst and biomass of *Artemia* in Urmia Lake from 1899 to 2023

year	Cysts density (No/l)	Biomass density (No/l)	Water level (m)	Average salinity (g/l)	Reference
1899	-	1.2-1.6	1276	149	Günther (1899)
1978	-	(1)3*	1275.9	220	Kelts and Shahrabi (1986)
1994-95	2500	1.5	1278-79	165	Van Stappen et al., (2001)
2000-1	1	0.84	1273.7	253	Hafezieh (2016)
2003-4	17.5	0.52	1273.7	288	Ahmadi (2007)
2005-6	21.75	1.36	1273.4	310	Dahesht et al., (2013)
2019-2022	4.6	0.004	1271	343	Mohebbi (2022)
2022-23	0.128	0	1270.4	386	Mohebbi (under the publication)

**Artemia* density was considered as 1 per liter.

Conclusion

Integrated basin-scale management of Lake Urmia should be an urgent priority of local and national governors to prevent further damage to this endangered lake ecosystem. This is possible only by huge investments by government on the agriculture section which consumes more than 90% of water resources. This will preserve *Artemia* biomass and reduce of degradation of its cyst reserves in Lake Urmia. At the same time, this action will prevent further environmental consequences to the ecosystem and catchment area of Lake Urmia.

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