# Lake Urmia Water Evaporation Suppression Using Self-Assembled Coating: Case Study of Pools Near the Lake

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**Abstract:** Evaporation is the main outflow of many water bodies. In hypersaline Lake Urmia (LU), which has experienced significant shrinkage during the last 3 decades, evaporation is the only water outflow. The 15-year daily saline water evaporation pan data collected near the lake indicate that approximately 71% of the annual evaporation occurred from May to September, about 4.15 billion $m^3$/year. To reduce this water loss, three self-assembled layer coatings—fatty alcohols of stearyl and cetyl with stearic acid in hexane solvents, stearyl and cetyl alcohols with stearic acid powder, and stearyl and cetyl alcohols in ethanol solvents—were tested on pools and evaporation pans adjacent to LU in July, when the lake had the highest evaporation rate. Results of 60 h of experiments for each test showed that the coating composed of stearyl and cetyl alcohols with stearic acid in hexane had the best performance and could reduce evaporation by about 52%. This suggests that applying this coating to LU for 5 months/year could reduce the lake evaporation by about 1.5 billion $m^3$, which is more than the total annual supply of the main river flowing into the lake. A short-term study of *Artemia urmiana* indicated that the coatings did not have a significant effect on their length and weight. However, long-term side effects on human health and the environment need further investigation. **DOI: 10.1061/(ASCE)HE.1943-5584.0002162.** *© 2022 American Society of Civil Engineers.*

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## Introduction

Evaporation is the most significant outflow of many water bodies (Althoff et al. 2020; Arunkumar and Jothiprakash 2013). Hence, evaporation control plans could be of great economic significance as a possible solution for meeting water demand for domestic, agriculture, and industrial consumption. Evaporation reduction techniques are classified into biological, physical, and chemical methods. In biological methods, floating aquatic plants restrict the heat exchange between air and water (Sahoo et al. 2010). However, biological methods are not feasible in every water ecosystem. For example, some aquatic plants may change water quality (Waheeb Youssef and Khodzinskaya 2019). Physical methods of evaporation reduction are very diverse. In areas where wind is the dominant driving force for evaporation, using wind shelter would be a practical approach (Hashemi Monfared et al. 2019). In small water-storage tanks, shed balls and floating covers are useful (Li et al. 2021), but the implementation of these cover systems is not feasible and is very costly in large natural and artificial water bodies (Haghighi et al. 2018; Xi et al. 2010). For such conditions, the use of self-assembled molecular layers could be an elegant and cost-effective solution (Craig et al. 2005).

The self-assembled molecular layers are amphipathic molecular layers at the phase boundary of the air–water interface, which reduce evaporation by increasing the reflected solar radiation, damping the wind speed at the water surface, and limiting the escape of water molecules (Mozafari et al. 2019). Amphipathic molecules have hydrophilic properties at one end, and the other end repels the water (hydrophobic). Many organic compounds, such as surfactants, detergents, bile salts, and phospholipids, are amphipathic. When these materials spread over the water surface, they provide a self-assembled layer, i.e., their molecules stand on one end and provide proper coverage on the water surface (Lombardo et al. 2015; Waheeb Youssef and Khodzinskaya 2019).

Most water evaporation suppression studies have used a combination of cetyl alcohol or hexadecanol $[CH_3(CH_2)_{14}CH_2OH]$ and stearyl alcohol or octadecanol $[(CH_3(CH_2)_{16}CH_2OH]$, which resulted in water-savings of up to 43%, depending on climatic conditions (e.g., wind speed and air temperature), water body characteristics (e.g., area and fetch length), and the type of the chemical coating (ratios and additives) (McJannet et al. 2008). These compounds could self-spread on the water surface, and if the film breaks, the molecules will reform it by flowing toward the ruptured area. This chemical coating is biodegradable within 48–72 h, and it withstands waves and wind up to 16–24 km/h (McJannet et al. 2008; Waheeb Youssef and Khodzinskaya 2019). Nowadays, different types of water savers, which mainly comprise hydrated lime and cetyl or stearyl hydroxyl-alkanes, are introduced for use in freshwater. However, their performance in suppressing

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evaporation of saline waters may not be similar to their performance in freshwater. Therefore, we evaluated their efficiency on the endangered saline Lake Urmia (LU) water to determine (1) whether they can be effective on hypersaline water; and (2) if this can help to revive the lake, which is in a critical situation. LU suffers from 900 to 1,500 mm/year evaporation, which is the only outflow of the lake. This issue has not been addressed yet, so this study is first effort to present an evaporation reduction method for LU water.

This study aimed to develop practical and safe nanomolecular layers for the case study of LU in the northwest of Iran, which is one of the world's largest permanent hypersaline lakes. The surface area of the lake was estimated to be about 5,725 $km^2$ in 1995; since then it has experienced a dramatic decline, and its surface area was 1,856 $km^2$ in 2015. LU's water level has been decreasing significantly during the last 3 decades due to the overuse of upstream rivers and continuing drought (AghaKouchak et al. 2015; Bateni et al. 2018; Pouladi et al. 2019; Razmara et al. 2016). The hydrological concern about LU's shrinkage has shifted to the widespread threat to human health, ecosystem sustainability, and regional economics. For example, salty windblown dust originating from the lake's dry area can endanger the health of 76 million people living within a 500-km radius of LU (Pengra et al. 2012). Moreover, land connections between LU islands and the nearby shorelines have been expanded by draining the water around them. Therefore, two rare mammal species, yellow Persian deer and Armenian mouflon, are threatened with extinction (Eimanifar and Mohebbi 2007). Shrinkage of LU has also increased salinity, from 169 g/L in 1995 to more than 350 g/L in 2004 (Pengra et al. 2012; Wurtsbaugh et al. 2017; Nikraftar et al. 2021), which has led to a rise in saline bacteria and other celiac diseases, and has created very adverse conditions for *Artemia urmiana* (AU), for which the optimal salinity range for growth, survival, and reproduction is 75–125 g/L (Agh et al. 2008). AU has a crucial role in producing an essential portion of live food in aquaculture, and LU is one of the most significant natural habitats of AU in the world (Razmara et al. 2016).

Because of these consequences and considering the strategic environmental situation of LU, the Iranian Department of Environment developed an Integrated Management Plan for Lake Urmia (IMPLU) in 2010, and the Iranian government established the Urmia Lake Restoration Program (ULRP) in 2013 to restore the lake. ULRP's mission is to stabilize the water level and restoration of LU (Nikraftar et al. 2021), and IMPLU emphasized that at least 3 billion $m^3$/year water is needed to maintain the LU water level at its minimum ecological water level of 1,274.1 m (Sima and Tajrishy 2013). LU is a closed saline lake with no outflow, and the evaporation loss is the major component of the lake's water balance. Therefore, simultaneously with the increase of water inflow to LU, reducing the amount of water evaporation loss can provide better conditions to reach this water volume needed in a shorter period. Combined with restoration programs to increase the inflow of the lake, water evaporation suppression will accelerate the rehabilitation of the lake.

The primary objective of this study was to extend the investigation of the effectiveness of chemical coatings in evaporation suppression from the laboratory scale using standard evaporation pans and LU water at Sharif University of Technology in Tehran to field study in the lake environment. Field experiments were carried out at Golmankhaneh port near LU using cetyl and stearyl alcohols with stearic acid in an optimal ratio determined in the laboratory-scale study. The experiments were performed in a field station containing four pools and two evaporation pans near LU to take into account the lake's climatic conditions, which have effects on the coatings. Moreover, we investigated the short-term effect of the coatings on AU's size because it is the only and last large aquatic organism in LU. The best chemical coating that could be used in LU was identified.

## Methods and Materials

### *Site Description and Field Experiments*

The Golmankhaneh meteorological station and Artemia Research Center at Golmankhaneh port were selected for the field study. Golmankhaneh port is located at the center of the western shoreline of LU (Fig. 1), and was assumed to be representative of weather conditions across the lake.

To identify the best period to conduct the study, we used the daily evaporation data collected near the lake. In this study, saline water evaporation data collected from 2000 to 2014 at the Golmankhaneh meteorological station using a Class A pan were obtained [Figs. 2(a and b)]. Average daily and monthly LU

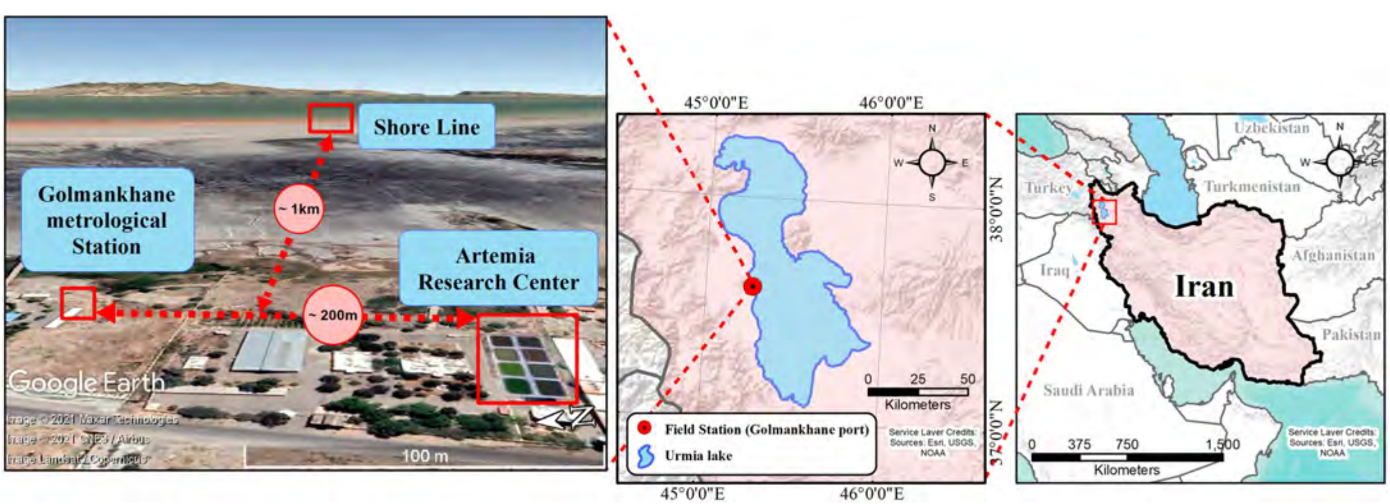


**Fig. 1.** Map of the study area showing the location of Golmankhaneh port and an aerial view of the field station. (Image © Google, Image © 2021 Maxar Technologies, Image © 2021 CNES/Airbus, Image Landsat/Copernicus; Sources: Esri, USGS, NOAA.)



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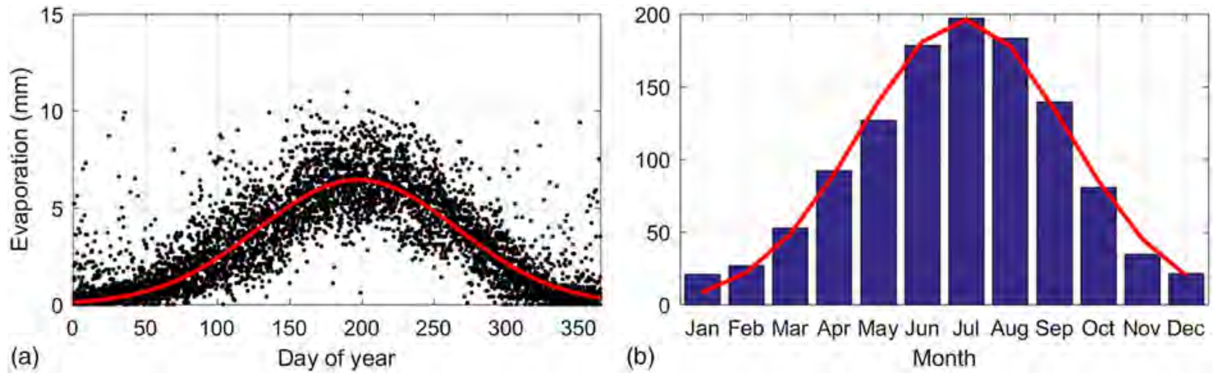


**Fig. 2.** Evaporation rates of saline water measured at Golmankhaneh meteorological station during 2000–2014: (a) daily; and (b) mean monthly. Lines are the fitting Gaussian functions.

**Table 1.** Parameters and statistics of fitting Gaussian functions determined to depict daily and mean monthly evaporation variations

| Time scale | $a$ | $b$ | $c$ | $R^2$ | RMSE (mm) | NRMSE | NS |
|---|---|---|---|---|---|---|---|
| Daily | 6.4 | 197.30 | 97.68 | 0.97 | 0.38 | 0.06 | 0.97 |
| Mean monthly | 196.1 | 6.95 | 3.34 | 0.99 | 6.8 | 0.04 | 0.99 |

water evaporation rates were identified based on these long-term measurements using a correction factor of 0.77 for the pan (Allen et al. 1998). Observations of daily and monthly evaporation rates with respect to time ($t$) can be described as a Gaussian function (Deo and Samui 2017; Shabani et al. 2020)

$$f(t) = a \exp\left[-\left(\frac{t-b}{c}\right)^2\right] \quad (1)$$

where $a$ = amplitude; $b$ = time at which maximum evaporation rate occurred; and $c$ = constant parameter related to temporal distribution of variations in evaporation. The parameters of Eq. (1) were calculated using the least-squares method to depict daily and monthly distributions of evaporation. Goodness of fit was assessed using $R$-squared ($R^2$), RMS error (RMSE), normalized RMS error (NRMSE), and the Nash–Sutcliffe coefficient (NS). The fitted Gaussian functions parameters are presented in Table 1. Statistics of the fitting curves indicated that the Gaussian functions were able to describe the temporal distributions of evaporation at both daily ($R^2 = 0.97$, RMSE $= 0.38$ mm, NRMSE $= 0.06$, and NS $= 0.97$) and long-term average scales ($R^2 = 0.99$, RMSE $= 6.8$ mm, NRMSE $= 0.04$, and NS $= 0.99$). Fig. 3 shows the observed and simulated average daily and monthly evaporation values. Different range of the parameters ($a$, $b$, and $c$) were used to calculate the error bars in Fig. 3. Based on this comparison, the Gaussian function is a reasonable function for the prediction values. The results show that the maximum evaporation occurred on day 197th of the year [parameter $b$ in Eq. (1)]. Therefore, the month of July, with the highest evaporation rate, was selected to perform our field experiments. The coating tests were conducted at two scales: (1) at a small scale in evaporation pans [Fig. 4(a)], and (2) at the scale of salt pools at the Iranian Artemia Research Center [Fig. 4(b)].

The pools of the Artemia Research Center were used to assess the performance of the coatings in suppressing evaporation. The Iranian Artemia Research Center in Urmia was established in 2000 and has been nominated as a reference *Artemia* research center in central and west Asia by the Food and Agriculture Organization (FAO) (Eimanifar and Mohebbi 2007). The Artemia Research Center has salt pools for *Artemia* cyst production. In this study, four similar salt pools were selected to assess the performance of chemical coatings on evaporation suppression. The pools had isosceles trapezoidal cross sections with an average depth of 1.1 m and a surface area of $15 \times 9$ m [Fig. 3(b)].

Pool 0 was selected as reference, and Pools 1–3, which had common sides with Pool 0, were chosen as test pools [Fig. 4(b)].

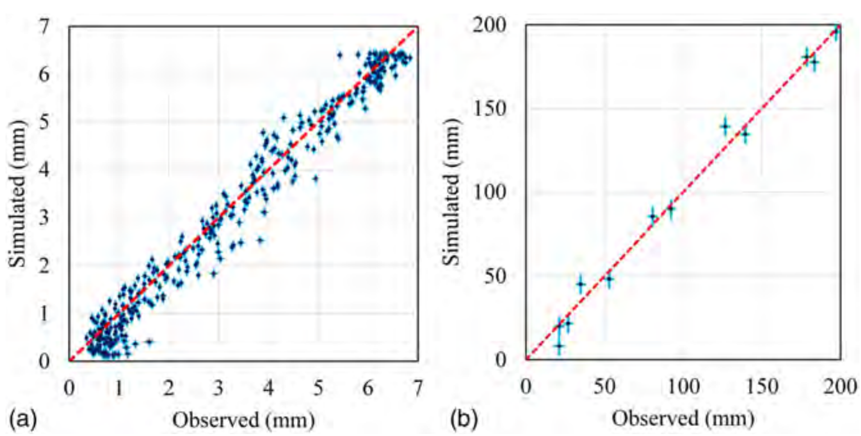


**Fig. 3.** Observed and simulated: (a) daily evaporation; and (b) monthly evaporation.

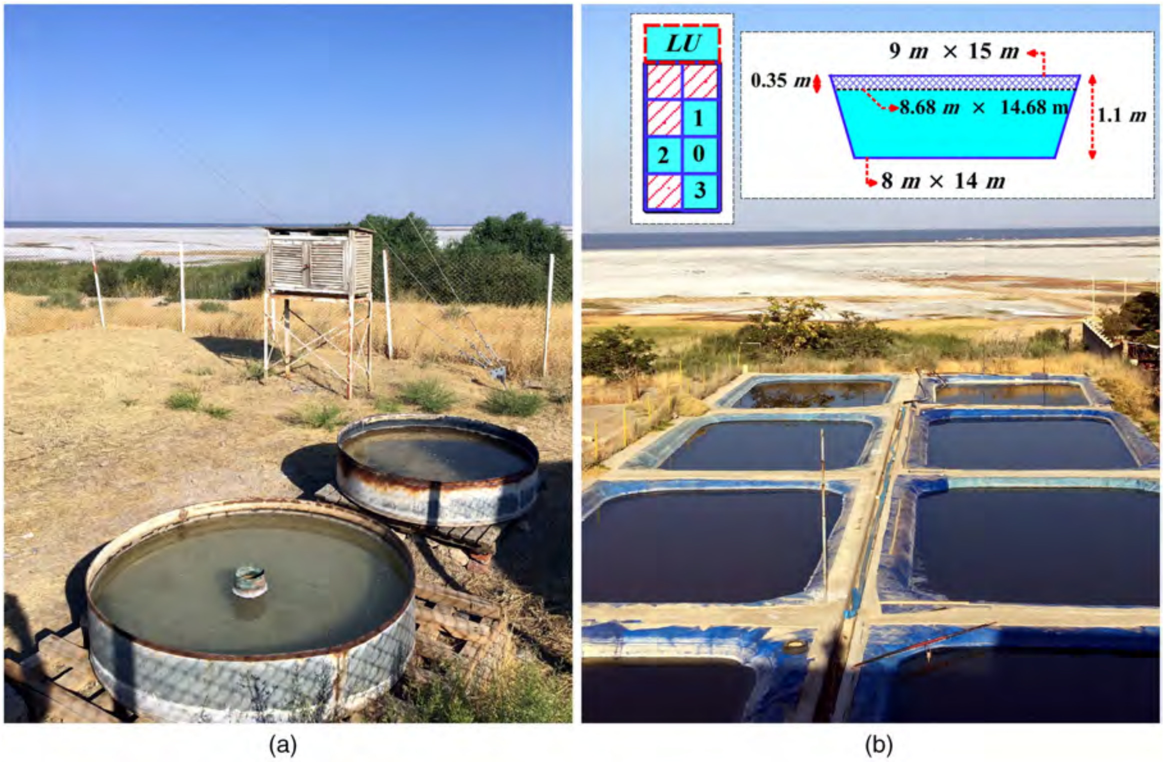


**Fig. 4.** (a) Two Class A evaporation pans at the Golmankhaneh meteorological station; and (b) images of the pools at the Artemia Research Center selected for the test, and schematic cross-section of a pool.

The evaporation reduction was determined by comparing the evaporation rates of the test pools with those in the reference pool. The percentage of evaporation reduction ($ER$) was calculated as

$$ER = \frac{E_{\text{ref}} - E_i}{E_{\text{ref}}} \times 100 \tag{2}$$

where $E_{\text{ref}}$ = evaporation in reference pools; and $E_i$ = evaporation in the test pools (1, 2, and 3) after spreading the coatings, where $i = 1$, 2, and 3. Evaporation rates of the pools were measured for 6 days without coating, and the result showed that the daily evaporation rates of all pools were almost 8 mm. To calculate the evaporation, water level changes of the pools were measured using Hook gauges mounted on a stilling well with an accuracy of 0.01 mm. It was held up by supporting beams at the pools' corners. A stilling well provides support and diminishes water surface turbulence; hence, measurements of evaporation can be performed more accurately.

Temperature, net radiation, humidity, and wind were measured during the study. The temperature was measured with a digital thermometer with an accuracy of 0.1, and the net radiation was measured with an underwater quantum sensor LI-192 (LI-COR Corporate, Lincoln, Nebraska). Wind and humidity data were collected from the nearest meteorological station (Urmia meteorological station). The water pH and salinity of the pools were measured using a litmus and salinity tester to determine the effect of coatings on water quality indexes. The accuracy of the litmus was 1 unit of pH, and the salinity tester accuracy was 0.2 g/100 g NaCl.

In addition, we studied the effect of the coatings on *Artemia urmiana*, which is the only living creature in LU. To investigate short-term effects of the coatings on *Artemia*, random samples consisting of 50 AUs from each pool were taken and dried to measure their average weight and length before and after their exposure to the coatings (Fig. 5). Scales and a caliper with an accuracy of 0.0001 g and 0.02 mm were used to measure the weight and length of AU, respectively.

### Layer Formulation and Application

Cetyl alcohol, stearyl alcohol, and stearic acid are nontoxic (Johnson 1988; Laurie1987). These fatty alcohols are tasteless, odorless, and inflammable; are derived from either coconut or palm oil; and have been approved by the US Food and Drug Administration (FDA) for use in cosmetics, foods, and medicines. Their derivatives are biodegradable and innocuous to humans and animals (Fisk et al. 2009; Panjabi et al. 2016). The hydroxyl group of these alcohols is hydrophilic, and their carbon chains are hydrophobic. Since cetyl alcohol has a lower molecular mass than stearyl alcohol, it disperses more rapidly. On the other hand, stearyl alcohol provides a more robust coating than cetyl alcohol because of the longer carbon chains (Prime et al. 2012).

Stearic acid is an organic material, and was selected for blending with fatty alcohols. It waterproofs material, because of its chain length of 18 carbon atoms (Archer and La Mer 1955). The purpose of using stearic acid in coatings was to establish strong bonding between carboxylic stearic acid and other molecules such as water molecules, fatty hydroxyl groups, and salts in the LU water. Moreover, the boiling point of stearic acid and its molecular mass are higher than those of fatty alcohols, and it helps the final coating become more resistant to wind and evaporation. A lab-scale study of LU water in standard pans at Sharif University of Technology showed that the optimum amount of solid materials spread in volatile solvents, such as hexane and ethanol, should form a layer with an average thickness of about 6 monolayers (6 times the molecule's length) on the water surface. Table 2 lists the composition of the

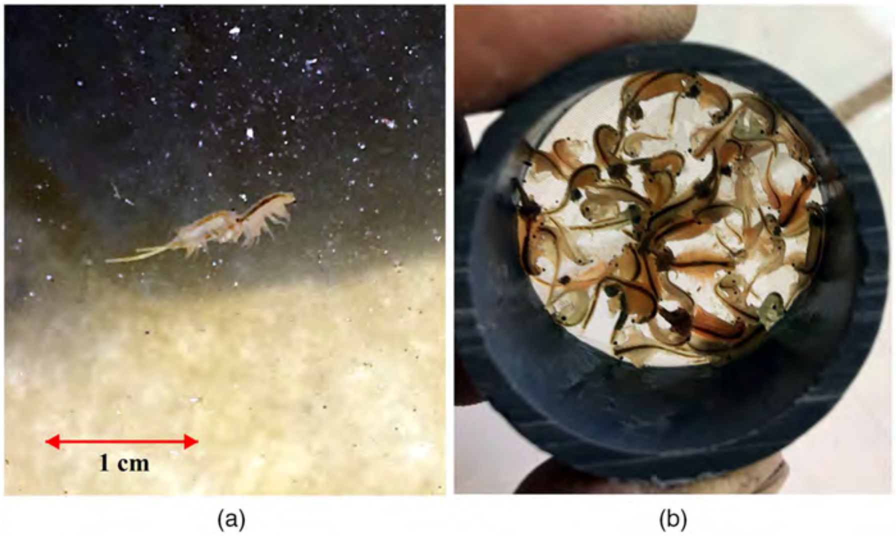


**Fig. 5.** (a) Two *Artemia urmiana*; and (b) a sample of 50 dried AUs.

**Table 2.** Information of coatings applied to test pools (Pools 1, 2 and 3) and evaporation pan

| Coating | Number of component parts: Stearyl alcohol | Cetyl alcohol | Stearic acid | Solvent coating | Pool |
|---|---|---|---|---|---|
| 1 | 3 | 1 | 2 | Hexane | 1 and evaporation pan |
| 2 | 3 | 1 | 2 | No solvent | 2 |
| 3 | 4.5 | 1.5 | 0 | Ethanol | 3 |

coatings and solvents in the pools and the pan. We used the amount of materials that theoretically could cover the water's surface. Given that the area cross sections of stearyl alcohol, cetyl alcohol, and stearic acid molecules are 23, 24, and 20 Å$^2$, respectively (Prime et al. 2012; Lendrum and McGrath 2009), the expected monolayer mass (g) was calculated as

$$\text{Monolayer mass}(g) = \frac{\text{Water surface}\,(\text{cm}^2)}{\text{Cross section area of molecule}\,(\frac{A^2}{\text{molecule}}) \times 10^{-16}} \times \frac{\text{Molecular weight}(\frac{g}{\text{mol}})}{6.023 \times 10^{23}\,(\frac{\text{molecule}}{\text{mol}})} \quad (3)$$

For example, to disperse a layer of stearyl alcohol, cetyl alcohols, and stearic acid on a Class A evaporation pan required 1.91, 2.23, and 2.70 mg of the respective molecules. To better disperse the layers on the water surface, they should be dissolved in a suitable volatile solvent such as ethanol and hexane. These coatings were spread many times over the evaporation pan and the test pools.

## Result and Discussions

### *Water Suppression Rate*

Time series of evaporation reductions in the evaporation pan and the pools are shown in Fig. 6. Coating 1 in both the pools and the pan performed better than the other coatings. Based on the obtained results, a maximum average suppression rate of 52% can be achieved within 60 h using Coating 1. This coating performed better than others because of the addition of (1) stearic acid; and (2) volatile solvent. The stearic acid made strong bonds with LU's water and caused better layer stability, whereas Coating 3, which had a long chain of fatty alcohols (stearyl alcohol and cetyl alcohol), did not reduce evaporation by more than 25.3% (Brzozowska et al. 2012). This is in agreement with other studies which used only fatty alcohols on freshwater, and showed that the fatty acids could not reduce evaporation more than 43% (Craig et al. 2007; McJannet et al. 2008). Adding a volatile solvent such as ethanol or hexane, which was not used in Coating 2, will help layers to spread over the water surface better and faster. We observed almost similar behavior for spreading time at 6 a.m. and 6 p.m., although daytime evaporation was greater than that at night. Since both $E_{\text{ref}}$ and $E_i$ values during the day were greater than those at night, $ER$ [Eq. (2)] was almost similar during the day and the night.

Higher average surface water temperature in evaporation pan (38°C at noon in a metallic container) than in the pools (35.5°C at noon with geomembrane walls) resulted in lower evaporation suppression and shorter life for the pan (Fig. 6). However, we expected greater evaporation suppression in the pan because it had a smaller surface area and experienced lower perturbation of the free surface (Mozafari et al. 2019). To cover the surface continuously, we applied the coatings at 60-h intervals, because their ingredients are degraded by photovoltaic activity and bacteria, and they need to be renewed at regular intervals (typically 1–3 days) (McJannet et al. 2008).

If Coating 1 was applied to the LU surface from May to September, the lake evaporation reduction would be about 1.5 billion m$^3$. This is more than the total annual supply of the Zarrineh-Rud River, which is the main river flowing into the lake and which provides more than 49% of the water stored in LU (Henareh Khalyani et al. 2014; Pouladi et al. 2020).

Table 3 lists the major atmospheric and pools condition during the study. Net radiation and temperature in air were higher than those at the surface of the pools by about 133 $\mu$mol/m$^2$s and 8.3°C, respectively, whereas they were almost similar at equal depths of the pools. Net radiation halved, and depth temperature decreased by 0.52°C/0.25 m.



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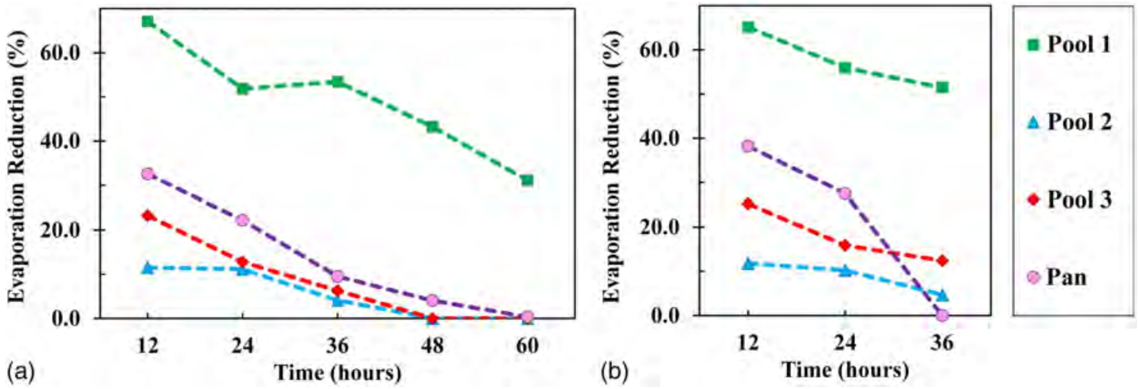


**Fig. 6.** Time series of evaporation reductions for the evaporation pan and salt pools with coatings applied at (a) 6 a.m.; and (b) 6 p.m.

It is known that wind can the reduce effectiveness of the coatings (from 60% to 13%) (Mozafari et al. 2019) and can totally destroy monolayers at a critical wind speed above ~24 km/h. (McJannet et al. 2008). During our study, the wind speed was almost constant at about 10 km/h. Furthermore, historical wind time series at the Urmia meteorological station during May–September from 2011 to 2020 indicated that only for 4.5 days was the wind speed above 16 km/h. Since this is a threshold velocity to disrupt the coating film (Waheeb Youssef and Khodzinskaya 2019); wind is not an important parameter for stability of the coatings in our study area.

Water quality indexes of the pools are presented in Table 4. The average pH of the reference and test pools before and during the tests remained constant, i.e., 12 h. Before the tests, the average salinity of the reference and test pools was 49 and 49.7 g/100 g NaCl, respectively. The salinity of the reference pool increased more due to higher evaporation than in the test pools. Therefore, the lake's salinity experienced less variation while covered by the coatings.

## *Coating Effect on Artemia Urmiana*

The average weights of AUs before and after their exposure to the coating were 0.00642 and 0.00646 g, respectively. In a fully covered pool (Pool 1), it changed to 0.00638 g. Due to the small variation in AU weights, even in the reference pool (−0.00088 g), no significant positive or negative effects of the coating materials on AU growth were identified during the study period.

To find the effect of the coatings on AU length, half of the samples from each group were selected randomly and measured with a caliper. Then statistical hypothesis testing was conducted in which H0 (H1) was "AU length does not (does) change before and after their exposure to the coating," with an initial error of $a = 0.05$. Generally, in hypothesis testing, two kinds of errors can occur: false-positive or Type I error, in which H0 is rejected when it actually is true; and a false-negative or Type II error, in which H0 is accepted when it is not true.

*Artemia* length data had a normal distribution, like other natural phenomena, so we used Bartlett's test instead of Levine's test to investigate the homogeneity of variances. Bartlett's test is a prerequisite of $t$-test (Table 5). The results of this test indicated that the equal variances assumption was valid. Bartlett's test for statistical population before and after spreading the coating materials had the significance value greater than 0.05, so the assumptions of the equality of variance in statistical population was not rejected. The null hypothesis was not rejected, because the $t$-value and its probability in the $t$-test were more than 0.05. Moreover, the 95% confidence interval of the difference contained zero, which confirmed that the null hypothesis was not rejected. Therefore, we assumed that there was no change in AU length before and after their exposure to the coating. Bartlett's test and $t$-test significance values for Pool 1 were 0.369 and 0.42, respectively, which were in an acceptable range to declare that the coatings had no adverse effect on AU growth in the short timeframe of the study.

Wixson (1966) also showed that hydroxyl-alkane monolayer coatings had no harmful effects on fish species, such as *Gambusia affinis* and *Fundulus notatus*, but they reduced surface tension, causing filamentous algae to sink. In addition, studies if the impacts of monolayers on fish, ducks, and aquatic insects showed that these materials are not toxic (McJannet et al. 2008; Wiltzius 1967). No changes in the larva of Nilotic tilapia were detected after the 5-week exposure to the monolayers, but larval growth was delayed due to effects on the dissolved oxygen (Saggai 2013). Therefore, long-term effects of the coatings on AU should be investigated further.

## Conclusions

Since evaporation is the only outflow of saline Lake Urmia, reducing evaporation could help to maintain the lake level at the normal state. Based on the pan evaporation data using LU water at the meteorological station nearest to the lake, the time distribution of long-term mean monthly evaporation rates showed that 71% of total annual evaporation occurred in the 5 months of the year from May to September. Therefore, applying an effective evaporation suppression method during this period could facilitate the restoration of the lake. To address this, several types of fatty alcohols were investigated in volatile materials with potential as self-standing coatings in solvents or powder. These coatings were spread over three salty pools with surface areas of 127.5 $m^2$ and one Class A evaporation pan located next to LU. The coating with the best performance reduced evaporation of saline water by about 17% in the pan and 52% in the pools within 60 h. The short-term study of *Artemia* weight and length before and after their exposure to the coating indicated that these materials are not toxic, but further studies of the effect of the coating on aquatic species such as AU should be conducted. In addition, the safety of the coating technique to human health and to the environment needs to be investigated further. In general, this method, along with other water resources management techniques, could be of great help to LU and any other large surface water bodies due to rather economical and accessible materials and simple implementation.

**Table 3.** Atmospheric and pool conditions before and during test

| Time | Atmospheric | | | | Depth (m) | Pool 0 | | Pool 1 | | Pool 2 | | Pool 3 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temperature (°C) | Net radiation ($\mu$mol/m$^2$ s) | Humidity (%) | Wind (km/h) | | Net radiation ($\mu$mol/m$^2$ s) | Temperature (°C) | Net radiation ($\mu$mol/m$^2$ s) | Temperature (°C) | Net radiation ($\mu$mol/m$^2$ s) | Temperature (°C) | Net radiation ($\mu$mol/m$^2$ s) | Temperature (°C) |
| 12 p.m. (without coating) | 38.4 | 1,730 | 32.9 | 9.9 | 0 | 1,435 | 30.6 | 1,497 | 30.2 | 1,340 | 30.6 | 1,445 | 30.3 |
| | | | | | 0.25 | 662.5 | 29.8 | 769 | 29.8 | 466.7 | 29.6 | 713 | 30.2 |
| | | | | | 0.5 | 351 | 29.1 | 449.2 | 28.6 | 284.7 | 29.2 | 363.1 | 28.9 |
| | | | | | 0.75 | 209.7 | 28.6 | 232 | 28.3 | 174.2 | 26.2 | 294.4 | 28.8 |
| 6 a.m. (without coating) | 33 | 381.6 | 32.8 | 11.3 | 0 | 316.5 | 26.6 | 295.73 | 25.9 | 446.3 | 26.4 | 337.5 | 26.3 |
| | | | | | 0.25 | 131.39 | 26.19 | 112.1 | 25.9 | 141.2 | 26.4 | 132.65 | 26.3 |
| | | | | | 0.5 | 71.19 | 26.1 | 53.75 | 25.9 | 58.12 | 26.1 | 59.55 | 26.3 |
| | | | | | 0.75 | 40.37 | 26.1 | 26.84 | 25.9 | 27.66 | 26.1 | 46.64 | 26.3 |
| 12 p.m. (6 h after coating) | 37.4 | 1,652 | 44.2 | 9.9 | 0 | 1,545 | 29.1 | 1,417 | 28.8 | 1,660 | 33.2 | 1,428 | 32.6 |
| | | | | | 0.25 | 742.1 | 28.9 | 743.4 | 27.9 | 824.6 | 32 | 752.3 | 32.4 |
| | | | | | 0.5 | 493.6 | 28.6 | 429.1 | 27 | 379.4 | 31.8 | 370.3 | 32.1 |
| | | | | | 0.75 | 251.7 | 28.1 | 207.6 | 26.9 | 375.3 | 30.3 | 257.8 | 31.8 |
| 6 p.m. (12 h after coating) | 37.8 | 1,127 | 27.3 | 12.6 | 0 | 1,115 | 29.6 | 1,029 | 30.4 | 1,144 | 30.6 | 928 | 29.6 |
| | | | | | 0.25 | 491.5 | 29.5 | 501.5 | 30.3 | 477.9 | 30 | 433.4 | 29.6 |
| | | | | | 0.5 | 340.9 | 29.4 | 258.8 | 29.6 | 236 | 29.8 | 178.2 | 29.5 |
| | | | | | 0.75 | 175.4 | 29.3 | 104.1 | 28.1 | 107.1 | 27.8 | 123.8 | 29.5 |
| 12 p.m. (30 h after coating) | 43.2 | 1,766 | 40 | 8.1 | 0 | 1,689 | 30.2 | 1,632 | 30.8 | 1,647 | 31.5 | 1,625 | 30.8 |
| | | | | | 0.25 | 921.1 | 28.9 | 856.1 | 29.3 | 800.1 | 30.9 | 840.3 | 30.8 |
| | | | | | 0.5 | 526.8 | 27.6 | 467.6 | 27.2 | 402.6 | 30.3 | 418.6 | 30.7 |
| | | | | | 0.75 | 311.8 | 27.3 | 265.6 | 26.9 | 206.6 | 30.1 | 266.5 | 30.6 |

**Table 4.** Water quality indexes of pools before and during test

| | Pool 0 | | Pool 1 | | Pool 2 | | Pool 3 | |
|---|---|---|---|---|---|---|---|---|
| Time | pH average | Salinity (g/100 g NaCl) | pH average | Salinity (g/100 g NaCl) | pH average | Salinity (g/100 g NaCl) | pH average | Salinity (g/100 g NaCl) |
| Without coating | 8 | 49 | 8 | 49 | 8 | 50 | 8 | 50 |
| 12 h after coating | 8 | 52 | 8 | 51 | 8 | 52 | 8 | 51 |
| 30 h after coating | 8 | 53 | 8 | 50 | 8 | 51 | 8 | 50 |
| 48 h after coating | 8 | 54 | 8 | 50 | 8 | 51 | 8 | 52 |

**Table 5.** AU length hypothesis testing before and after coating for all coated pools (population = 75)

| Bartlett's test for homogeneity of variances | *t*-test for equality of means | | | | | 95% confidence interval of difference | |
|---|---|---|---|---|---|---|---|
| Significance | *t* | Degrees of freedom | Significance (2-tailed) | Mean difference | Standard error difference | Lower | Upper |
| 0.164 | 0.102 | 48 | 0.919 | 0.00320 | 0.03145 | −0.06003 | 0.06643 |
| 0.164 | 0.102 | 47.752 | 0.919 | 0.00320 | 0.03145 | −0.06004 | 0.06644 |

## Data Availability Statement

All data, models, or code generated or used during the study are available from the corresponding author upon request.

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