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Using Remote Sensing Methods for the Three Lakes' and Evaluating Their Water Surface and Their Fluctuations

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ABSTRACT

Iran faces numerous environmental issues such as drought, population growth, war, air pollution, climate change, industrial and agricultural output, sanctions, excessive water consumption, and lax enforcement of environmental regulations. Climate change is thought to be one of the crucial factors of impact on water resources in the world. The research is focused on the lakes of Urmia, Namak, and Hamun, using satellite images from Remote sensing to estimate water areas within 10 (2015-2024) years, follow the changes, and analyze the reasons for these changes. Lake Urmia experienced a downward trend in water levels, despite increased precipitation and water rights allocation. Namak Lake showed a greater correlation with temperature fluctuations and precipitation. Hamun Lakes' water volume was more dependent on water rights and temperature fluctuations significantly impacted lake water levels. So all the lakes, located in different areas of the country did not show the same correlation with climate change. As the recovery plan for Lake Urmia seems to include the impact assessment of agricultural water consumption, Hamun Lakes seems to be more dependent on Afghanistan's dams, only Namak Lake showed a good response to the precipitation values. The results of the work could be used by the authorities for the proper water management assessment.

INTRODUCTION

Iran faces numerous environmental challenges, including drought, population growth, conflict, air pollution, climate change, industrial and agricultural production, sanctions, wasteful water and resource use, and lack of enforcement of environmental standards (Tahbaz, 2016; Saatsaz, 2020; Pakmehr et al., 2020; Sharifi et al., 2021; Bagheri, 2024; Veicy, 2024; Panahi et al., 2024).

Climate change impacts the water sector, reducing farmer income and harvest, and exacerbating poverty (Bozorg-Haddad et al., 2020). Farmers can control climate change effects by adopting adaptation strategies. Sustainable urban water administration is crucial due to rapid urbanization. A study by Mirdashtvan et al., 2021) and colleagues found a negative correlation between drought severity and resilience in rural households during droughts, with factors such as financial, social, human, natural, and physical livelihood assets accounting for 84% of resilience variance. Desertification remains a significant environmental issue, with 228 mm of precipitation annually in 2017, 6% below the long-term average of 242 mm/year (FAO. (2017).

One of the main reasons lakes are considered delicate landscape elements is because they have always been impacted by climatic changes. One of the most vital resources for human needs and a major force behind environmental change is the lake ecosystem. Changes in geographical distribution of rainfall intensity, along with global warming, have led to variations in the physical, chemical, and biological properties of lakes. It is obvious that a variety of factors interact to either intensify or lessen the feedback effects of abrupt environmental change, and lakes can experience sudden changes in their environmental state. The shortage and crisis of water resources is one of the most pressing issues of our day, particularly in arid and semi-arid areas. Keeping an eye on water resources (rivers, dams, etc. lakes) is an essential instrument for managing water resources. Indeed, modeling and mapping surface water changes in lakes, rivers, and reservoirs are important issues for environmental management and observation (Emami & Zarei, 2021; Abbaszadeh Tehrani et al., 2022; Helali et al., 2022; Harati et al., 2021; Kharazmi et al., 2023; Zolfaghari et al., 2022; Sheikh et al., 2024).

The dryness of Lake Urmia, Hamun, and Namak is causing increased dust storms, causing socio-economic stress, public health implications, and negatively impacting agriculture. Health conditions deteriorate due to agricultural development, climate change, temperature variations, dam construction, groundwater extraction, aerosol pollution, and challenges in water resource use for agriculture. The desiccation of the Hamun Lakes in the Iran-Afghanistan border is causing socio-economic stress, public health issues, and potential livelihood shifts and migration. Climate change influences vegetation cover in the Namak Lake basin, and rural residents lack adaptation tools due to poverty. Sustainable development strategies for Urmia Lake Basin are needed to address challenges, social resistance, and increasing energy demand, releasing GHG. Monitoring the amount and volume of water in selected lakes is crucial for these issues (Akbari et al., 2021; Ehsani & Shakeryari, 2021; Harati et al., 2021; Nasrollahi et al., 2021; Schmidt et al., 2021; (Mir et al., 2022; Parsinejad et al., 2022; Afsharinia et al., 2023; Rahimabadi & Azarnivand, 2023; Sheikh et al., 2024).

The study area encompasses three major lakes: Urmia Lake, Namak Lake, and Hamun Lakes of Iran. Urmia Lake is Iran's largest inland lake, the lake is fed by various rivers and is primarily used by the agricultural sector, which accounts for 90% of the total water use in the basin. The rapid depletion of Lake Urmia is typically attributed to climate change, human-induced factors, and increased agricultural demand.

The growing population has led to increased demand for food and water, leading to dams, groundwater pumping stations, and water diversion pipelines. The declining trend has also impacted surrounding areas, leading to increased dust concentration and declining flora, increasing the incidence of DSI (dust storm index). The agriculture sector has also been affected by the drought, reducing food production over the past three decades (Parsinejad et al., 2022., Ghasempour et al., 2024). Additionally, Lake Urmia is exposed to aerosol pollution, affecting public health, nutrient cycling, climate, and visibility (Schmidt et al., 2021; Emami & Zarei, 2021; Harati et al., 2021; Feizizadeh et al., 2022; Parsinejad et al., 2022; Ghasempour et al., 2024).

Concerning agriculture: in recent decades the trend to increase the number of water-consuming crops increased: water-based farming increased from 350,000 to 500,000 ha from 1987–2014 (Akbar Rahimi and Jürgen Breuste, 2021). Also, the crops extensively change to many water-used crops, like beet sugar, and apple (Lake Urmia Restoration Program, 2014).

Shahid Kalantari causeway bridge: it was constructed by drying 85% of the boundary between the western eastern sides of the lake and caused the northern and southern halfs disconnected, providing the increase in salinity in the northern part from 166 (average) to 300 grams per liter (Merufinia et al, 2014). Construction of numerous dams (more than 49 + 40 are under study (Merufinia et al, 2014) affected the water flow to the lake: most of it never riches it and was used for agriculture purposes (according to some estimates 70% is losing due to mismanagement) (Merufinia et al, 2014).

Namak Lake (NL) in central Iran, a saltwater lake, is thought to face significant challenges due to climate change. The lake's bed is covered in salt sediments and minerals, posing a serious threat to the ecosystem and environment. The main river in the basin, the Qom-Rood River, is influenced by human activity, leading to dam construction projects like the Golpayegan and 15-Khordad Dams. Namak Lake is contaminated with heavy metals in its bed sediments, with higher metal concentrations in the southern part. A study on Iran's Namak Lake Basin found a diminishing trend in 72.2% of stations between 1970-2012, with varying patterns across the basin (Nodefarahani et al., 2020, Sheikh et al., 2020, Ebrahimivand et al., 2023; Rahimabadi & Azarnivand, 2023; Sheikh et al., 2024).

The Hamun Lake, consisting of four connected water bodies, was the greatest (>8500 km2) freshwater body in the Iran plateau. (Mahdi Akbari & Ali Torabi Haghighi, 2022). The Hamun Lakes Basin has experienced drought in recent decades, with surface water storage changes in 1998 and multiple wet periods following. An extended wet period between 2011 and 2017 further dried them, causing the lakes to lose 89% of their surface area in two years.

Despite this, increased agricultural activities in Afghanistan and Iran have led to increased irrigated areas. In 2013, the Hamun Lake was drained after 15 years, but environmental experts warn that the restoration of Lake Hamun is temporary and the danger of drying up still threatens this international wetland, which biodiversity is very important in arid and semi-arid regions and needs rehabilitation, protection, and water resource management for sustainable living conditions (Firoozi et al., 2020; Shirazian et al., 2021; Ehsani & Shakeryari, 2021; Rad et al., 2022a; Akbari et al., 2021; Zolfaghari et al., 2022; Mir et al., 2022; Kharazmi et al., 2023).

MATERIALS AND METHODS

Resources

AQUASTAT Database. AQUASTAT Website., n.d.), (AQUASTAT, 2008. Country Fact Sheet: Iran. FAO's Global Information System on Water and Agriculture, n.d.), (Moridi, 2017; Savari et al., 2023; Darvishi Boloorani et al., 2023; Hamidifar, 2024).

Dynamic World dataset

The World Resources Institute and Google collaborated to create a dynamic record of the physical materials that make up Earth's surface. Deep learning was used to create Dynamic World, a free and publicly licensed global land use and cover dataset with a 10m resolution that is almost real-time. The goal of Dynamic World is to provide a data product that allows users to create derivative land cover maps by adding custom rules to assign final class values (8) Dynamic World, n.d.).

Dynamic World's primary innovations:

1. Near real-time data. More than 5,000 Dynamic World images are created daily, in contrast to the months or years that traditional methods of producing land cover data can take. Because of utilizing a cutting-edge deep learning methodology, based Dynamic World provides worldwide land cover updates every two to five days, depending on location, on Sentinel-2 Top of Atmosphere.
2. Per-pixel odds for each of the nine classifications of land cover. One of the main advantages of an AI-powered method is that the model analyzes an incoming Sentinel-2 satellite picture and calculates, for each pixel, the amount of tree cover, the level of urbanization in a specific region, and the amount of snow cover, if any, in the area after a recent blizzard.

Dynamic World is a Land Use/Land Cover (LULC) dataset that contains label information and class probabilities for nine classes, available from 2015-06-27 to the present. Sentinel-2 revisits every two to five days, depending on latitude. When CLOUDY_PIXEL_PERCENTAGE <= 35% is present in Sentinel-2 L1C pictures, Dynamic World forecasts are produced. Using a mix of S2 Cloud Probability, Cloud Displacement Index, and Directional Distance Transform, predictions are masked to exclude clouds and cloud shadows. Except for the "label" band, all probability bands add up to 1.

Value	Color	Description
0	#419bdf	water
1	#397d49	trees
2	#88b053	grass
3	#7a87c6	flooded_vegetation
4	#e49635	crops
5	#dfc35a	shrub_and_scrub
6	#c4281b	built
7	#a59b8f	bare
8	#b39fe1	snow_and_ice

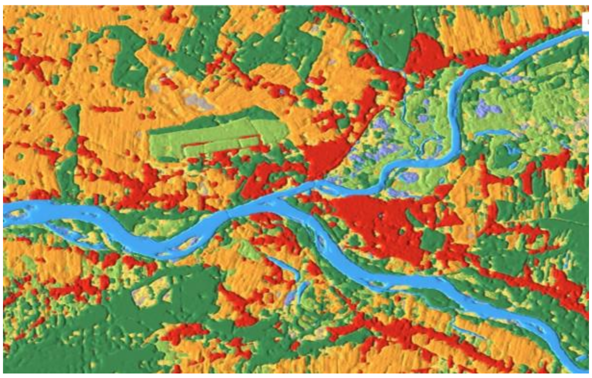


Figure 1. Example of the LULC dataset visualization

The Google Earth Engine

Google Earth Engine combines extensive analytical capabilities for the entire planet with a vast database containing numerous geospatial datasets and satellite imagery. Researchers, scientists, and software developers utilize Earth Engine to analyze trends, assess fluctuations, and discover transformations occurring across the Earth's surface. Thanks to its cloud-based infrastructure, this platform enables users to perform large-scale geospatial analyses and leverage Google's powerful computational resources to address pressing societal challenges, including food security, water resource management, deforestation, droughts, natural disasters, and environmental conservation. (Google Earth Engine, n.d.). https://developers.google.com/earth-engine/guides/getstarted https://geohackweek.github.io/GoogleEarthEngine/01-introduction/

Firstly, images were taken from the Dynamic Data Set satellite, images related to the years 2015 to 2024, then we masked the water section and then we counted the number of water pixels. The total area of each region was calculated based on square kilometers, then the graph of water fluctuations and two factors, temperature and precipitation, which affect the amount of water in the studied areas were studied, and finally, the reasons for water fluctuations were studied.

RESULTS AND DISCUSSION

The LULC dataset was used to extract data from the years from 2015-2024 – class 0 “water”, then the binary classification was applied: water = 1. The rest =0. The pixel’s quantity (10 m resolution) of water was calculated for each year for every lake. Temperature and precipitation were taken from meteorological archives for the nearest metro station.

Image 1. Water mask of the Lake of Urmia

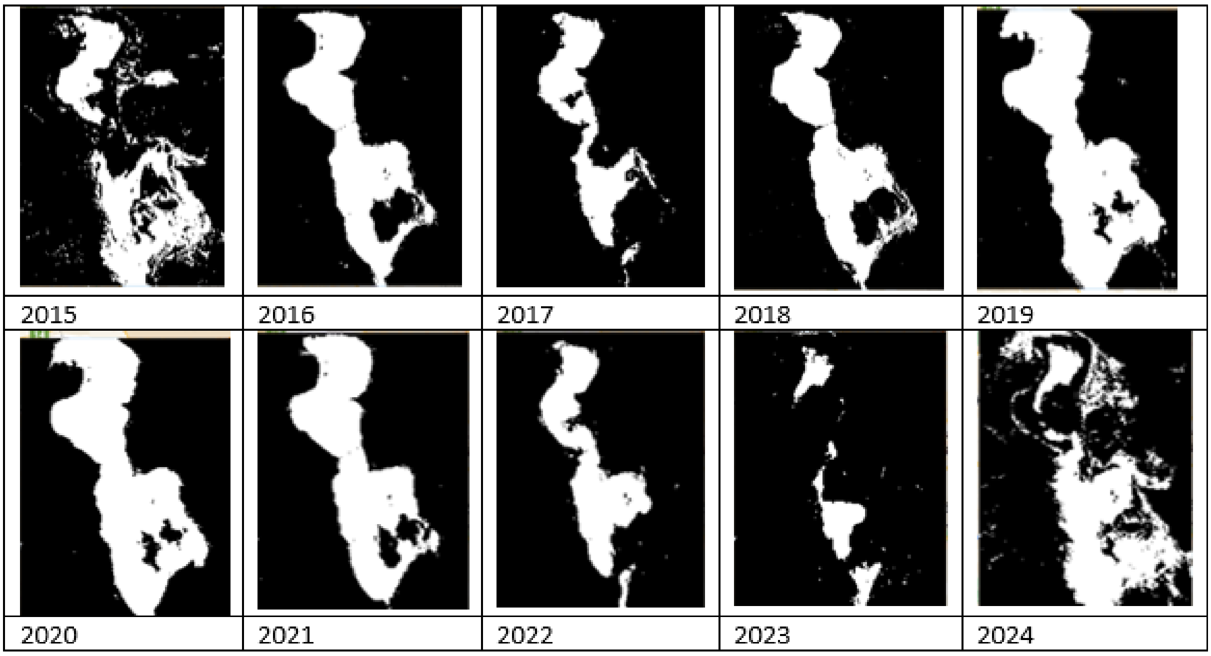


Image 2. Water mask of the Lake of Namak

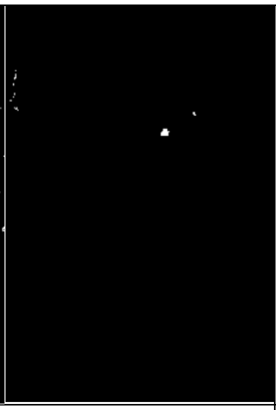
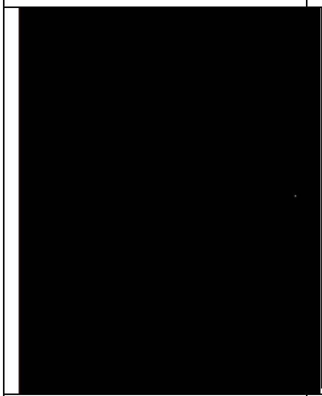
			
2017	2018	2019	2020
			
2021	2024		

Image 3 Water mask of the Lake of Hamun

			
2016	2017	2018	2019
			
2022			

The water area fluctuations of all the lakes were compared in a graphic form for the further analysis.

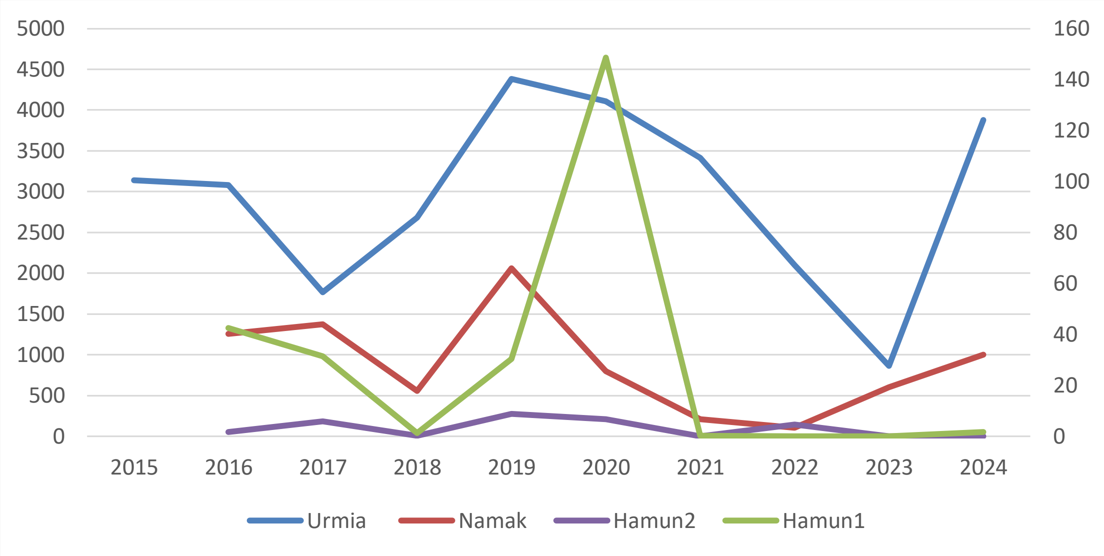


Chart No. 1 Fluctuation of water area for 3 lakes km2

From these curves, we can it can be seen, that there is no similarity in water volume fluctuations for all the lakes: for example, the year 2019 brought a maximum of water surface for all lakes, but not for Hamun Lake, which maximum was in 2020. The year 2017 was the minimum water surface for Urmia Lake despite the rest of the lakes.

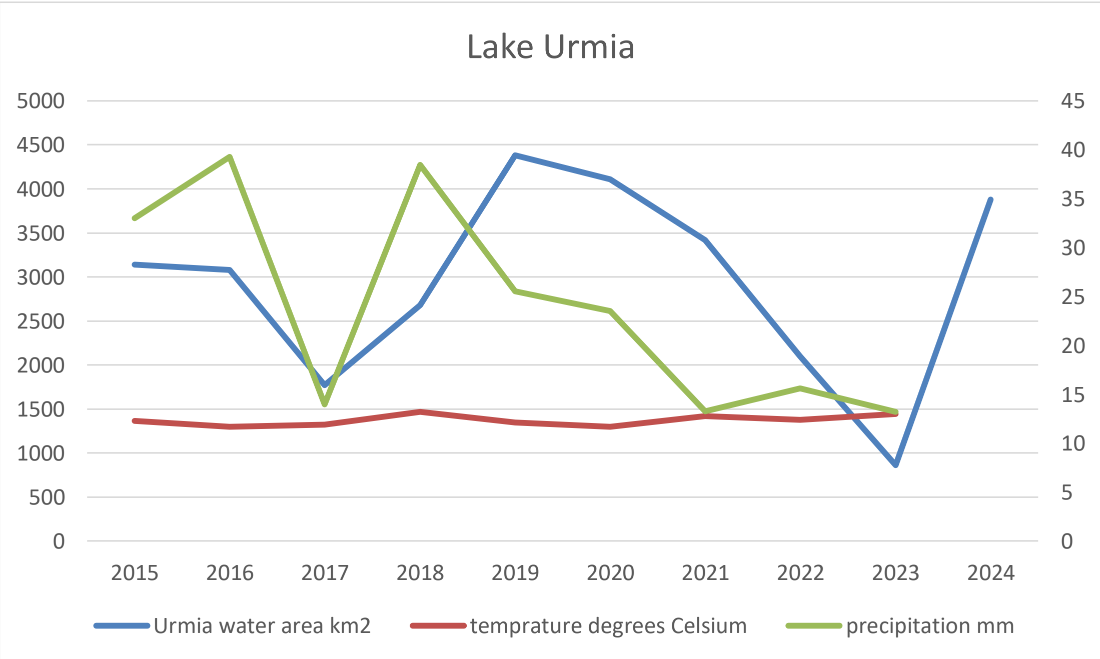


Chart No. 2 Average temperature (C0) and precipitation (mm) for Lake Urmia (2015-2024)

Traditionally the decrease in water level is explained by climate change influence. According to chart 2, it can be noted that the average temperature fluctuations were between 11.7 and 13.20 degrees while the water surface did not correlate with it. The years of 2017 and 2021 had minimum precipitation but only in 2017 lack of rains was accompanied with minimum water volume in the lake.

To compare this study reveals various trends in the lakes, with increasing and decreasing rates. It can be seen, that there is no similarity in water volume fluctuations for all the lakes: for example, the year 2019 brought a maximum of water surface for all lakes, but not for Hamun Lake, which maximum was in 2020. The year 2017 was the minimum water surface for Urmia Lake despite the rest of the lakes.

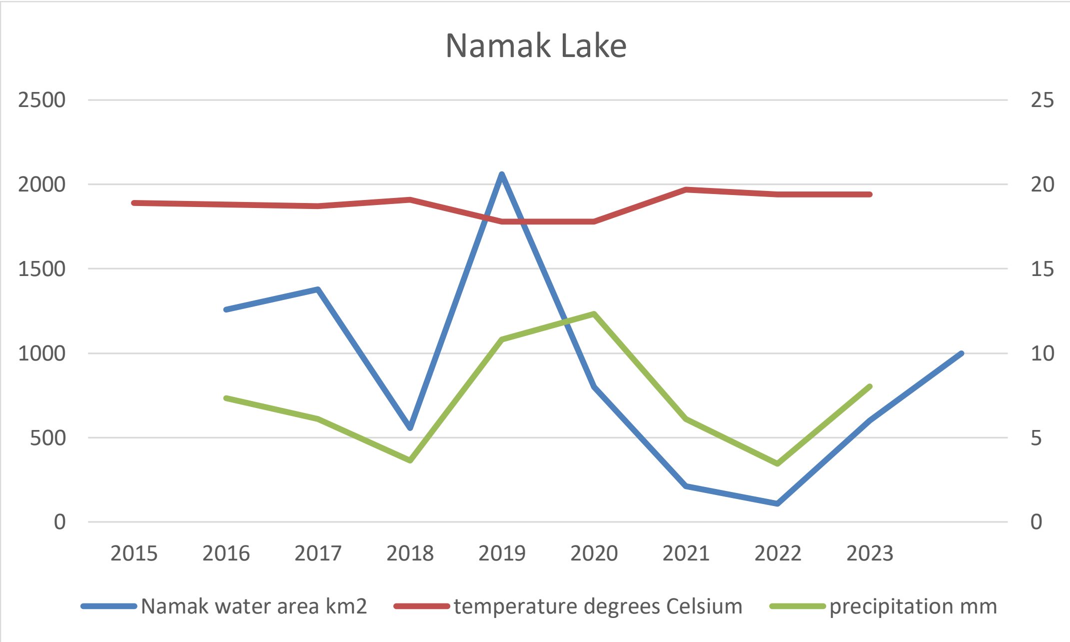


Chart No. 3 Average temperature (C0) and precipitation (mm) for Lake Namak (2015-2024)

The region of Namak Lake was characterized by more higher average temperature with a minimum in 2019-2020 (17.8°) and a maximum in 2021 (19.7°). For this lake, it can be seen that the water volume follows the precipitation volume with a maximum in 2019.

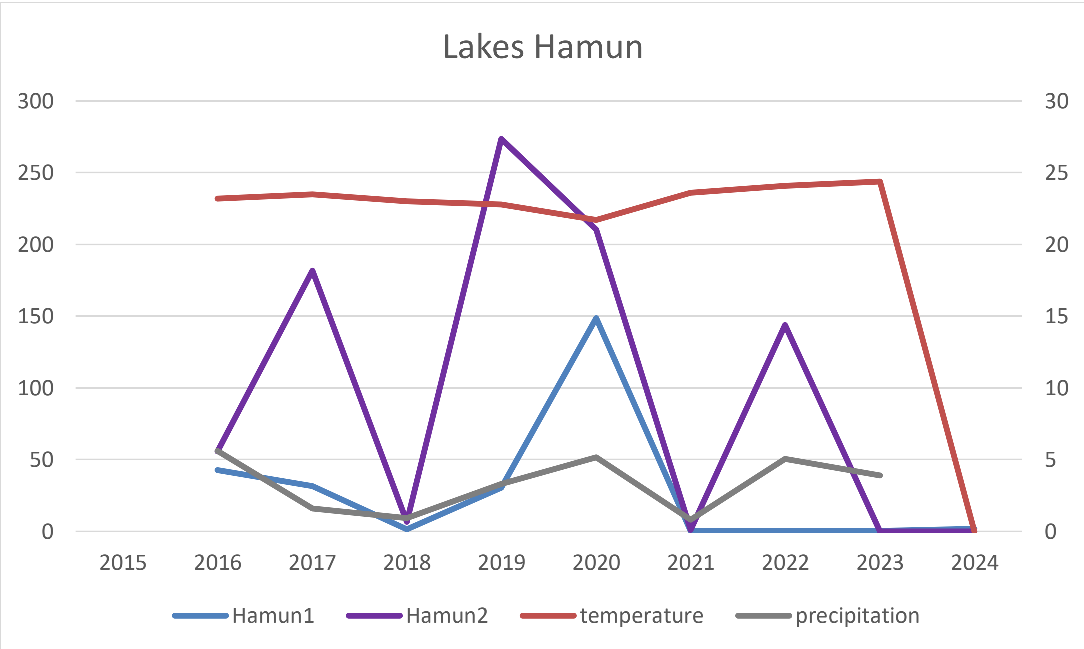


Chart No.4 Average temperature (C0) and precipitation (mm) for Lake Hamun (2015-2024)

The area of Hamun Lakes has an average temperature with a minimum in 2020 (21.7°) and a maximum in 2023 (24.4°). Lake Hamun 2 has a maximum and minimum every 2 years with no correlation with such climate factors as temperature and precipitation. Lake Hamun 1 has no connection too. As can be seen in the images of soil moisture dynamics, there is somehow a negative correlation with the water surface of the lakes.

The findings indicate that during the 10-year survey period (2015–2024), the Lake of Urmia showed a downward trend in water levels in 2015 and 2016, despite an upward trend in precipitation and the provision of the necessary water rights.

In 2018 and 2019, the amount of water in the lake reached its maximum level, due to the increase in precipitation and the allocation of water rights. In 2019, despite the decrease in precipitation due to the completion of water rights and policies, the amount of water in the lake reached its maximum. In the years 2020 to 2023, due to the decrease in precipitation and on the other hand, due to the non-allocation of the desired water rights, the amount of water in the lake has gone down and reached its lowest level in 2023. in that year, the relevant authorities released water rights (Salimi et al., 2019), (Pouladi et al., 2021). As a result, an increase in the amount of lake water was observed in 2024. There was no significant correlation between the amount of lake water and temperature fluctuations. Lake Urmia in Iran faces water loss due to natural and human factors, posing legal issues. To restore, the government and local communities should create buffer zones, support programs, and adapt to changing conditions (Faryadi, 2024).

The Namak Lake, which is located in the central areas of the Iranian plateau, shows a greater connection and correlation with the temperature fluctuations and the amount of precipitation than the Urmia Lake. However, in 2017 and 2021, the required water rights of this lake were provided. But in 2021, due to the decrease in precipitation and increase in temperature, the water level of the lake has started to decrease. Therefore, it can be concluded that in this lake, temperature fluctuations and precipitation have more effects on the amount of water than the allocation of water rights. Rising water demand due to irresponsible usage necessitates water-saving measures in semi-arid locations. Solutions should focus on minimizing depletion and evaluating techniques in basins under water stress (Shadkam et al., 2020).

Hamun Lakes, the amount of water in Hamun Lakes has a relatively consistent relationship with the amount of precipitation, but it emphasizes the allocation of the relevant water rights from the Afghan side, for example, in 2017, despite the decrease in precipitation, the amount of water in the lakes has increased. It is due to the provision of the desired water rights. Although in the years 2021 to 2023, with the increase in precipitation, the volume of water in Lake No. 1 has not changed. This case shows the importance of dependence on the provision of water rights. In general, the water volume of Lake No. 1 is more dependent on water rights than Lake No. 2. Likewise, the amount of water in the lake has almost a significant relationship with temperature fluctuations. In the years with lower temperatures, the amount of the lake is more and in the warmer years, the amount of the lake is less. The Hamun Lakes, located in Afghanistan, experienced a significant decrease in surface area from 3809 km2 in 1999 to 410 km2 in 2001, losing 89% of its area in less than two years. The desiccation took 22 months over a period of 1984 to 2019. Despite sporadic droughts in the Helmand River Basin, the length and intensity of these droughts have not increased in the last decade. The increase in agricultural activity in Afghanistan and water diversion in Iran has also impeded the desiccation of the lakes (Rad et al., 2022b). Research in Afghanistan's Helmand Basin reveals increased agricultural water use and croplands since 2002, affecting downstream water bodies like Hamun Lake. Human activities like damming cause decreased flow and desiccation, requiring bilateral talks between Iran and Afghanistan(Akbari et al., 2021).

CONCLUSION

Based on the results obtained, it can be concluded that Urmia Lake has a better situation in terms of volume of water than the other two lakes studied because of the importance of the catchment area. This means that there is more hope for restoration and stable conditions for this lake and its surrounding residents. Simultaneously, the likelihood of the lake receiving more water will rise with the adoption of government policies and the allocation of additional water rights. Because the lakes have appeared and disappeared in different years, the Lake of Namak and Hamun has the greatest fluctuations in water levels. But there's greater hope for Namak Lake's rebirth compared to Hamun Lake. The water level of Namak Lake has increased recently because of heavy rainfall and the implementation of appropriate policies. It is important to remember that any decrease in the lake's water area would negatively impact the health of residents of Iran's two largest cities, Tehran and Isfahan, in an irreversible way. As a result, protecting and developing an appropriate policy for the appropriation of water rights is crucial. Beyond its arid environment, highest temperature, and least amount of rainfall when compared to the other two lakes, Hamun Lakes faces political and legal challenges in defending its water rights from Afghanistan. Consequently, it is imperative to establish a fair process to get the Afghan government to grant you water rights. These lakes have been restored (2017) if water rights are protected and released from the Afghan side, as seen in the picture. Additionally, from the Iranian side, plans for improved water circulation, such as dredging and well construction, are required. Ultimately, it appears that the implementation of water rights and appropriate agricultural use laws are essential to the sustainability of the Urmia and Hamun basins. While seasonal rains and floods have a greater role in the rehabilitation and survival of Namak Lake.

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