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Urmia Lake Salinity and Evaporation Management: Prioritizing Critical Areas

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Abstract

By examining the evapotranspiration rate of the northern and southern parts of Urmia Lake, an attempt has been made to find a better solution for sustainable management of the region based on prioritizing sensitive areas for further attention. By integrating Landsat-based evapotranspiration estimates into a GIS framework, we spatially identify and rank the most vulnerable zones, thereby guiding targeted management strategies. To calculate evapotranspiration, the SEBAL algorithm was used with the help of Landsat satellite data from 2002 to 2020. Due to its comparative nature, the evapotranspiration rate was calculated in a simplified manner and without considering meteorological parameters. First, by examining the rate of groundwater changes, we found that the rate of decrease in both regions was almost the same, and this data was obtained from the GRACE satellite. Using precipitation data and calculating the standard precipitation index (SPI), we concluded that when precipitation decreased in the southern part, evaporation was much higher than in the northern part with increasing temperature, while in different time intervals, they changed almost at a constant ratio in both regions, which indicates that water salinity has increased due to climate change, which has led to increased evaporation and ultimately a further decrease in lake water in the southern part, which requires attention to this area in regional management.

Keywords: SEBAL, Evapotranspiration, SPI, VHI, Google Earth Engine

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1. Introduction

The Lake Urmia watershed is the area where surface and groundwater flow into Lake Urmia (Jani et al., 2023), which is one of the key areas in the management of Iranian water resources, with a network of seasonal and permanent rivers, plays an important role in feeding and maintaining the saline Lake Urmia. This basin includes rivers, agricultural areas, urban areas, and other natural ecosystems, all of which directly or indirectly affect the lake's water level (Jani et al., 2023; Kazemi Garajeh, Akbari, et al., 2024). Due to its arid and semi-arid climate conditions, this region is always exposed to severe climate changes, increased water withdrawal for agricultural and industrial uses, and reduced rainfall. Factors that have caused the lake's water level to decrease, drought to increase, and environmental and economic problems to arise. On the other hand, the importance of this region, due to its direct impact on agriculture, biodiversity, and the sustainability of the region's ecosystems, has made careful monitoring of hydrological and climatic trends a scientific and management necessity. This basin is a vast area in the northwest of Iran that includes many sub-basins, each with its own hydrological characteristics (Jani et al., 2023). The main water sources of the basin are rainfall, surface runoff, and groundwater. Numerous rivers also originate from the mountains and flow into Lake Urmia or groundwater, which is important in supplying the lake with water (Jani et al., 2023). In two decades, due to the decrease in the level of Lake Urmia, the salinity of the lake has increased. The risk of increasing salt marshes and the spread of various diseases will be even greater than the size of this basin, which is a very vital issue in the region, and for this reason, focusing on sustainable management of the region and controlling water consumption is essential for this region.

The vital framework for the analysis and management of sustainable development in the Urmia Lake basin is formed by Geographic Information Systems (GIS) and Remote Sensing (RS). RS offers the opportunity to acquire high-resolution spatial and temporal data essential for the determination of key climatic indicators. Among the indicators is the measurement of surface evaporation and transpiration, the rate of which has a direct relationship with the temperature of the air and the water. Another indicator is the measurement of the rainfall rate, the increase or decrease of which over time can be a telltale sign of climate change. Yet another is the determination of the change in groundwater storage, the knowledge of which is essential for understanding the basin's hydrologic regime. These datasets are then integrated, processed, and analyzed in GIS environments using Google Earth Engine and ArcGIS Pro to produce spatiotemporal maps of the northern and southern basins. Through GIS-based spatial analysis, sensitive areas are prioritized based on the intensity of climatic and human impacts, which helps in targeted management strategies and enhances the efficiency of watershed restoration efforts.

The discussion that is being raised now is to improve the management of the region to have the greatest impact in the shortest time, and this requires that areas with a high level of risk are identified, the cause of their occurrence is determined, and the effects that this situation will have on the region are analyzed and examined.

In this article, from the perspective of sustainable management of the region, considering the factors of drought and assessing the intensity of evaporation, climate change and groundwater depletion, it has been examined and attempts to find the part of the lake with the greatest amount of changes and its reasons, and prioritize restoration in order to improve the quality of management.

2. Literature Review

Due to climate change and human manipulation, this area is heading towards a decrease in water reserves and drought. Some studies show that human factors have played a more important role than climate change in the drying up of Lake Urmia. Human activities such as excessive water consumption in the agricultural sector and urbanization development put great pressure on the water resources of the basin. As a result, sustainable water resource management and changes in consumption patterns seem necessary. Furthermore, attention to adaptation strategies for water scarcity could mitigate the negative effects of this trend (Hooshyaripor et al., 2022; Sadeghfam et al., 2022; Shams Ghahfarokhi & Moradian, 2023).
The water resources of the Lake Urmia basin have been affected in various ways by climate change. These ways include our main focus of this comprehensive report: lake temperature, basin precipitation, basin evaporation, snowfall in the basin, drought conditions in the basin, groundwater resources in the basin, and river flow into the basin. Our main interest lies in understanding how the lake and its surrounding resources have been impacted by a changing climate. Why? Because an understanding is crucial for developing effective mitigation (reducing the intensity of impacts) and adaptation (making necessary changes to cope with the impacts) strategies. Further research into the specific magnitudes of these effects can better inform water management policies in the region (Hesami & Amini, 2016; Jani et al., 2023; Kazemi Garajeh, Haji, et al., 2024). In (Kazemi Garajeh, Haji, et al., 2024) the article examines the relationship between various variables such as temperature, precipitation, snow cover, groundwater salinity, and Lake water level. Changes in the Lake water level from 2000 to 2020 are also examined, showing that increasing temperature and evaporation of the water surface have caused the lake level to decrease, as well as groundwater salinity, which reduces arable land. The article (Jani et al., 2023) also examines climate change in the Lake Urmia basin. Some studies in this article have shown a trend of increasing temperature and decreasing rainfall. These findings underscore the complex interplay of climatic factors impacting the Lake Urmia ecosystem and the livelihoods dependent upon it. Further interdisciplinary research is essential to fully comprehend these dynamics and to devise sustainable solutions for the basin's future.
The article (Shams Ghahfarokhi & Moradian, 2023) addresses the causes of Lake Urmia's shrinking, focusing on climate change and human factors, and also points out that lack of precipitation and increased demand for water can lead to drought. A multivariate index for drought perception has been introduced that, in addition to precipitation, also considers water demand from the population. This innovative approach highlights the interconnectedness of environmental changes and societal pressures in exacerbating water scarcity. Such integrated

indices can provide a more holistic understanding of drought's impact and inform more effective water management strategies. The results show that drought perception is greater in densely populated areas and that population growth exacerbates the impact of drought (Hooshyaripor et al., 2022).
The article (Feizizadeh et al., 2023) examines the health effects of the drying up of saline lakes on the local population. This study examines the effects of the drying up of Lake Urmia on the health of residents of Shabestar County and shows that the health of residents of the region will be at risk with the trend towards drought. The article (Schulz et al., 2020) examines the factors that have caused the water level of Lake Urmia to decrease, and this article refers to the effect of evaporation on the decrease in the lake's water volume. These findings highlight the far-reaching consequences of the lake's desiccation, extending beyond environmental concerns to directly impact public health. Therefore, addressing the water crisis in Lake Urmia is not only an ecological imperative but also a crucial public health issue.

The article of (Jalilvand et al., 2021) examines the issue that the drying Lake Urmia has become a new source of dust of regional importance. The article (Alipour & Olya, 2015) presents a sustainable planning model for the restoration of Lake Urmia. This model emphasizes the development of an adaptive governance system, taking into account the capacity of the lake ecosystem. This article highlights the importance of stakeholder participation in water resources planning and management, which can reduce the risk of drought. These studies underscore the multifaceted challenges posed by the lake's decline, ranging from ecological and health impacts to the necessity of collaborative governance for effective restoration. The proposed sustainable planning model offers a crucial framework for addressing the crisis through inclusive and adaptive management strategies.

All the articles from different aspects of the discussion related to human and climatic reasons for the decrease in water reserves and the increase in the drought trend in the region have been examined, and the risks that may occur in the region if this trend continues have been concluded that proper management of water resources and restoration of the lake is a vital issue.

3. Methodology

3.1. Study area

Lake Urmia is a saltwater lake in northwestern Iran and the largest inland lake in the country. The lake is located between the provinces of West Azerbaijan and East Azerbaijan (figure 1). The lake's water level has decreased significantly in recent decades, with some sources such as Wikipedia stating that the decrease was about 95 percent. To accurately examine the process of evaporation and transpiration and their effects on the salinity of the lake water, in this study, two sample areas were selected within Lake Urmia, one above the lake and the other below, with the bridge in the middle of the lake as the dividing criterion.

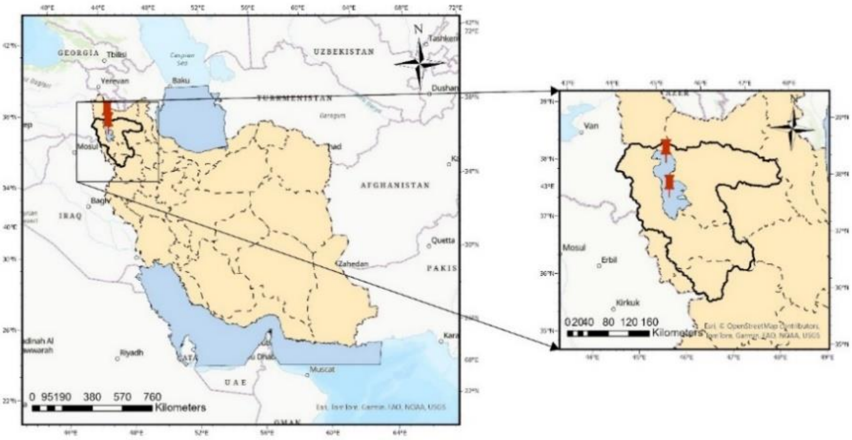

Figure 1. Urmia lake basin

The changes in these two areas have been different over time, which has caused different climatic changes in those areas. This division, in addition to showing regional differences, provides the basis for providing optimal solutions for managing water resources and dealing with the consequences of drought at the regional level.

3.2. Dataset

This study uses a set of high-quality and reliable satellite data to analyze drought and water resource trends. Land cover data were extracted from Landsat 8 and Landsat 7 satellites; these images provide a suitable basis for calculating time series of surface water cover and thermal indices due to their high resolution (30 m for multispectral bands and 15 m for panchromatic bands) and advanced processing capabilities. Landsat 8, which was completed in 2013, is equipped with OLI and TIRS structures; while Landsat 7, which began its operations in 1999 and has suffered from gaps in images despite the SLC failure since 2003, continues to be used as a valuable source for analyzing environmental changes and vegetation cover. Both satellites, in an orbit with an altitude of about 705 km and a 16-day visit period, provide the possibility of providing up-to-date and accurate data for environmental and water resource studies. This time coverage allows researchers to monitor changes in the Earth's surface over time (Sreekanth et al., 2021). Landsat data is used in various fields such as agriculture, water resources management, urban studies, and environmental studies 2021; Yang et al., 2020). Landsat satellite thermal bands have been used to calculate land surface temperature (LST) and sea surface temperature (SST) (Wang et al., 2020). The normalized difference vegetation index (NDVI) is calculated by near-infrared and red bands and visible and infrared bands of Landsat have been used to calculate surface reflectance (Wang et al., 2020). Also, the green visible light (Green) and short-wave infrared (SWIR1) bands were used to calculate the normalized difference water index (NDWI) (Sreekanth et al., 2021).

To assess precipitation, TRMM satellite data was used, which is a joint mission of NASA and the Japan Meteorological Agency, launched in 1997, and provides accurate information on precipitation patterns in tropical and subtropical regions using precipitation radar and infrared sensors (Wu et al., 2024). TRMM data is a reliable source in climate studies, agriculture, and water resources management due to its wide geographical coverage and high accuracy in measuring precipitation (Wu et al., 2024).

GRACE satellite data has also been used to investigate changes in groundwater storage and analyze hydrological trends. GRACE, launched by NASA and the German Space Agency in 2002, provides information on changes in total terrestrial water storage, including groundwater, surface water, snow, and soil moisture, by accurately measuring changes in the Earth's gravitational field. In particular, the MASS_GRIDS_V04/LAND product, which records the equivalent water thickness (LWE Thickness), is an essential tool in groundwater storage monitoring and water resources management.

The satellites and the bands they use are shown in an integrated manner as shown in Table 1. This data was extracted through Google Earth Engine and then used in the ArcGIS Pro environment for further analysis.

Table 1. Dataset

Satellite	Bands	Start date	End date
Landsat 7	Blue, green, red, NIR, Thermal Infrared	2002	2019
Landsat 8	Blue, green, red, NIR, SWIR1, Thermal Infrared	2002	2019
TRMM	precipitation	2002	2019
GRACE	lwe_thickness_csr	2002	2019

3.3. Methods

According to the flowchart in Figure 2, first, the period when the intensity of the lake water level decrease was high is identified and selected, and this is done by examining Landsat satellite images of the region using the time series of surface water changes. After determining the time period, we divide the lake into two parts, the northern and southern, and select the deepest parts as a sample. Groundwater information is examined by the GRACE satellite in the selected areas to show the extent of its changes and its impact on the studies. Then, precipitation data is collected via the TRMM satellite and SPI is modeled. The albedo value is extracted from the Landsat satellite and used to model evapotranspiration using the simplified SEBAL algorithm. By analyzing the data obtained from the ET and SPI indices, the evaporation trend during the years 2002 to 2019 is examined and conclusions are drawn.

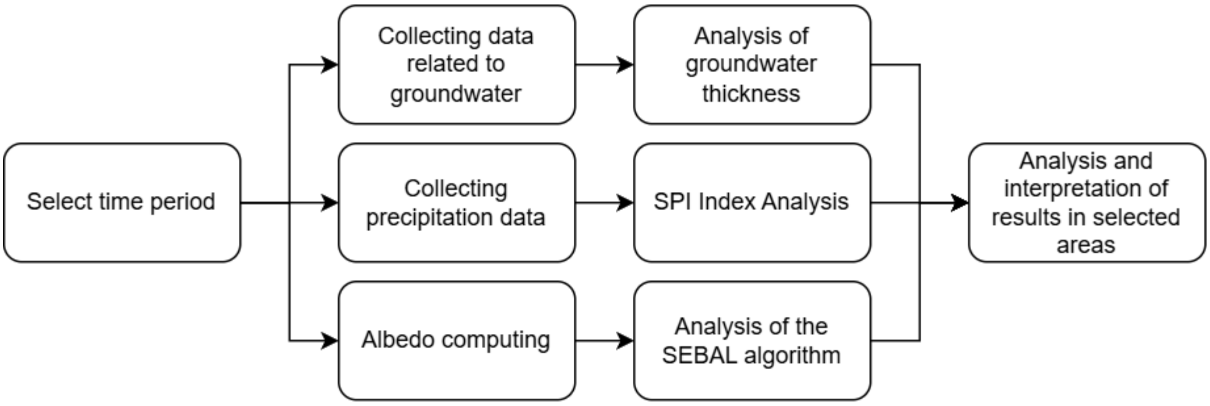

Figure 2. Research flowchart

The purpose of the study can play a role in choosing the right time frame. If our goal is to assess the effects of climate change, longer time frames are a better choice, but if our goal is to assess the effects of human activities, shorter and more precise time frames may be more appropriate (Ashraf et al., 2021) In some cases, periods are selected based on major changes in regional conditions, such as the construction of dams or land use changes (Jani et al., 2023; Tahmouresi et al., 2024). After considering the study objectives and regional variations, a period for which data is available should be selected. The desired period was determined by examining Landsat satellite images and examining the NDWI index (Shams Ghahfarokhi & Moradian, 2023). NDWI is used to measure the amount of water available in an area using remote sensing data. This index is calculated using a combination of the green and near-infrared bands of the electromagnetic spectrum. The green and near-infrared bands are used to calculate the NDWI index, and its equation is as follows (Shams Ghahfarokhi & Moradian, 2023):

$$NDWI = (Green - NIR) / (Green + NIR) \quad (1$$

High NDWI values indicate more water in the area, as water reflects more in the green spectrum and absorbs more in the near-infrared spectrum. Conversely, lower values indicate a lack of water or vegetation. Based on the trend of lake surface area changes, the period during which the rate of change is greater is determined (Shams Ghahfarokhi & Moradian, 2023) and this is important for determining the best time frame.

By measuring changes in the Earth's gravitational field, the GRACE satellite can determine changes in groundwater reserves. These changes are caused by the movement of water mass below the Earth's surface. Studies on Lake Urmia have used GRACE data to investigate the decline in groundwater reserves due to over-extraction and climate change (Ashraf et al., 2021). For this purpose, the lwe_thickness_csr band is used in the MASS_GRIDS_V04/LAND product.

The TRMM satellite has been used to extract precipitation data, which greatly helps us in ensuring the selection of the appropriate time frame for the study. TRMM data is available for a relatively long period of time (1998-2024). This allows for the analysis of precipitation trends and their impact on water resources. These data have been used as one of the key inputs for monitoring climate change and human impacts on water resources in the Lake Urmia basin (Kazemi Garajeh, Akbari, et al., 2024). SPI can be calculated using TRMM satellite data. It is one of the most widely used indices for drought assessment, introduced by McKee and colleagues in 1993. This index is calculated based on precipitation data at different time scales and quantifies the severity and duration of drought (Hooshyaripor et al., 2022; Sadeghfam et al., 2022). The SPI value is calculated based on the changes in total precipitation over a specified period of time from the climate average and is normalized using the standard deviation of precipitation over the same period (LALMUANZUALA et al., 2023). To create the index, we first extract the precipitation data for the desired period. Then, an appropriate probability distribution function (usually the gamma distribution) is fitted to the precipitation data. The gamma distribution fits the monthly precipitation data well. Based on the fitted probability distribution, the cumulative probability for each precipitation value is calculated. Finally, the cumulative probability value is converted to the equivalent value in the standard normal distribution. This value is the SPI value (Hooshyaripor et al., 2022; Shams Ghahfarokhi & Moradian, 2023). The SPI equation is as follows (Sadeghfam et al., 2022):

$$SPI = \emptyset^{-1}(\alpha(P)) \qquad (2$$

In this formula, $\emptyset^{-1}(\cdot)$ represents the inverse function of the standard normal distribution, and $\alpha(P)$ represents the gamma distribution fitted to the precipitation data (P). The SPI index is divided into 5 classes as described in Table 2:

Table 2. Classification of SPI

Class	SPI <= -2	-2 < SPI <= -1.5	-1.5 < SPI < -1	-1 < SPI < 1	1 <= SPI
Description	Very dry	Dry	Slightly dry	Normal	Full of water

Another important index to consider is the ET index based on the SEBAL algorithm. Many factors affect the accuracy of these calculations, but due to limited access to ground data, only the albedo portion of Landsat satellites was used in this study, and the simplified ET formula was used because both points are located on a lake and the time series of these two regions are comparable. The SEBAL algorithm is a method for calculating evapotranspiration at the land surface using remote sensing data. This algorithm works based on the principle of the land surface energy balance and uses satellite data and meteorological observations to estimate large-scale evapotranspiration rates (Wang et al., 2020). The main equation of the SEBAL algorithm is as follows (Wang et al., 2020):

$$LE = Rn - H - G \qquad (3$$

Latent heat flux (ET) Indicates the amount of energy consumed for evaporation and transpiration, surface net radiation (Rn) is the amount of net energy received from the sun minus reflected energy and surface thermal radiation, sensible heat flux (H) is The rate of heat transfer between the ground surface and the air and soil heat flux (G) is The rate of heat transfer into the soil.

To calculate the value of Rn we need the albedo value. The albedo value from Landsat satellites is obtained using a simple approximation with the following equation (De Razza et al., 2024):

$$\text{Surface albedo (SA)} = bBLUE * \rho BLUE + bGREEN * \rho GREEN + bRED * \rho RED + bNIR * \rho NIR + bSWIR1 * \rho SWIR1 + bSWIR2 * \rho SWIR2 + b0 \quad (4)$$

ρ is all two-way surface reflections and b is the corresponding conversion factors(De Razza et al., 2024).

After obtaining the albedo, the net surface radiation is obtained with the following simplified equation:

$$Rn = SA * 0.77 \quad (5$$

We approximately consider the value of G as 5% of the value of Rn and H as 30% of the value of Rn-G, so the simplified equation of evaporation and transpiration is calculated as follows:

$$ET = Rn * 0.665 \quad (6$$

Here, evapotranspiration ET is equivalent to latent heat flux LE.

The analyses obtained from the SPI and ET indices explain the status of the regions and the reasons for it.

4. Results

After examining images from different years, images from 2002 and 2017 were obtained from Landsat 7 and Landsat 8 satellites, respectively, and we obtained a time series of surface water changes. According to Figure 3, the rate of lake surface water changes in this period is very high and is suitable for studying evapotranspiration in the target areas. During this period, due to human manipulations such as the uncontrolled construction of dams and changes in land use (Ahmady-Birgani et al., 2018; Kazemi Garajeh, Akbari, et al., 2024), as well as climate change (Kazemi Garajeh, Akbari, et al., 2024), The rate of change in the lake has been very high, causing great concern about the future of the region.

Figure 3. From left to right, images from 2002 and 2017, and a time series of changes in Lake Urmia's level

Using GRACE satellite images for the areas specified in Figure 1, the amount of groundwater changes was obtained in the period from 2002 to 2017. According to Figure 1, which is the result of extracting the aforementioned satellite data in the specified areas, it is observed that there was a decrease of approximately 0.224 units in the entire period, which indicates water stress and drought. Long periods of rainfall deficiency (Figure 4) reduce the recharge of groundwater aquifers and, as a result, reduce their thickness (LALMUANZUALA et al., 2023). Reduced precipitation and increased evaporation and transpiration from plants cause a decrease in soil moisture and, as a result, a decrease in groundwater recharge (Kukunuri et al., 2022). Other reasons for the decline in groundwater depth include land use changes. Land use changes can reduce soil permeability and disrupt groundwater recharge, and the lack of sustainable water resource management can lead to rapid declines in water levels and aquifer thickness (Shahfahad et al., 2022). By examining Figure 4, we can conclude that the rate of groundwater changes in both regions is almost the same.

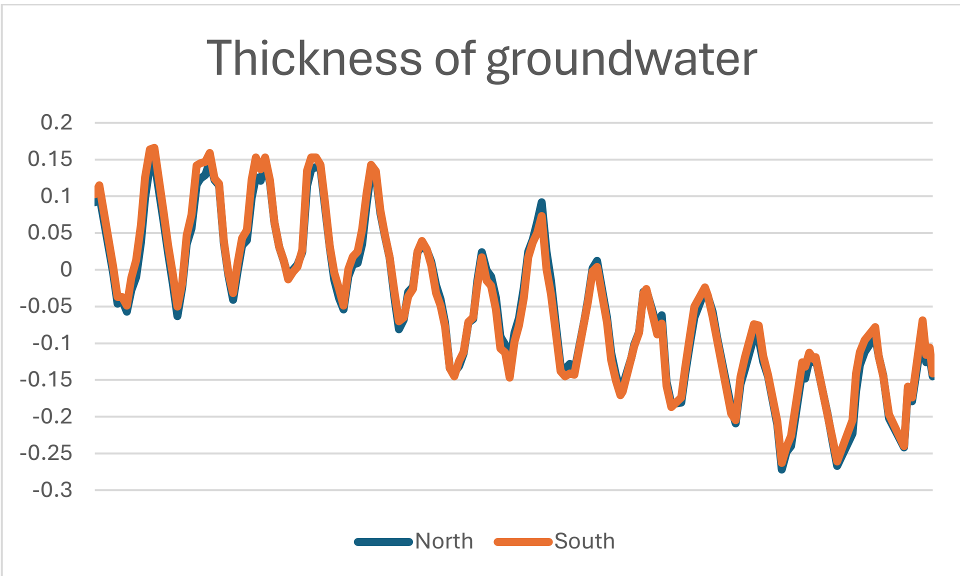

Figure 4. The thickness of groundwater between 2002 and 2017

The classified images related to SPI, according to Figure 4, show a very large decrease in the amount of precipitation compared to the average of the entire period in the Urmia Lake basin.

This image shows that in 2002, the amount of precipitation was such that the region was above the average of the precipitation in the entire period and was at a high and medium level, but in 2017, this amount faced a very sharp drop. The quantitative SPI index for the period 2002 to 2017 has been calculated according to Figure 2 and shows that the SPI in 2002 was 0.866, which indicates that the entire region is at an average level in terms of water content, and this value was at a high water level in 2006, but after that it faced a sharp decline until 2008, so that the region was at a dry level or drought, and finally in 2017, with a value of -1.3, it was also at a dry level, but after that the region has adopted a better routine.

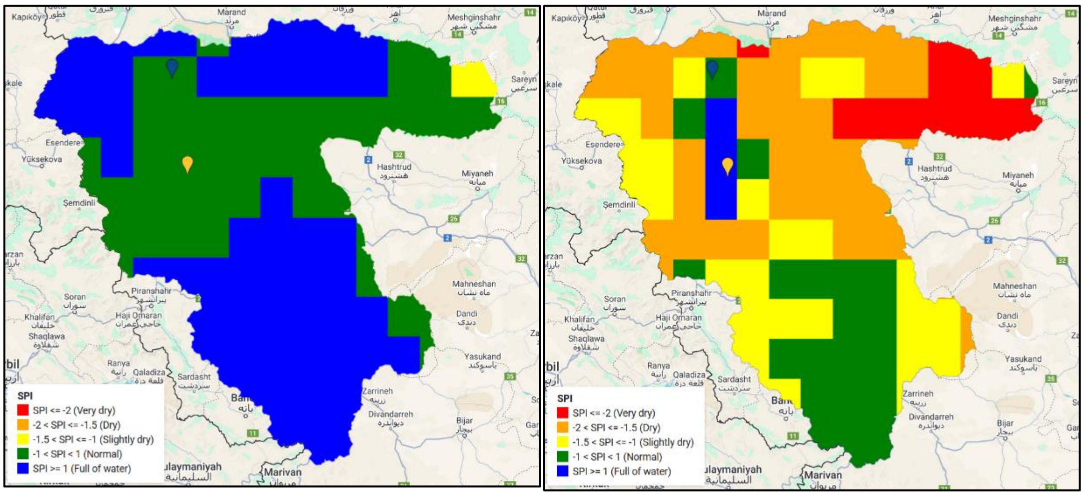

Figure 5. SPI image in 2002 and 2017

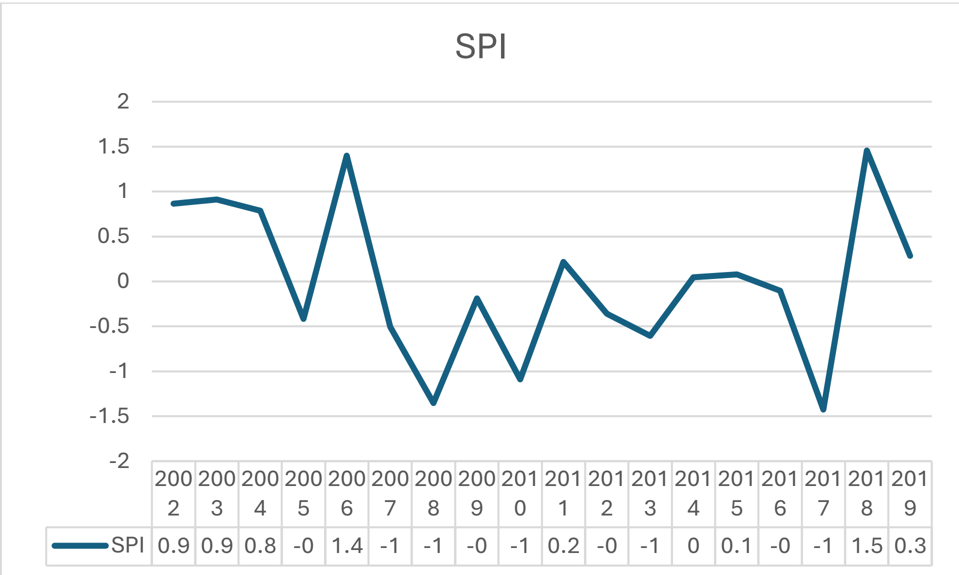

Figure 6. SPI of the Urmia Lake basin

These data show that one of the reasons for the decrease in groundwater is climate change and the decrease in average annual rainfall (Srinivas et al., 2022). The SPI index was calculated for both designated regions, and the result is shown in Figure 3. According to Figure 6, the rainfall in the northern region was slightly higher than the southern region until 2004, but after that, the rainfall in the southern region was somewhat higher than the northern region until 2010. But in general, both regions had a similar trend in rainfall compared to the average rainfall of the entire region from 2002 to 2010. After 2010, the rate of change in the two regions has been different, so that in the northern region from 2011 to 2016, the rainfall was higher than in the southern region, and the difference in these changes between the two regions in 2014 and 2015 was very large, and in 2016, this relationship was reversed and the situation in the southern region was better than the northern region. This situation is reversed again in 2019, according to the chart. This situation shows that after 2010, the rate of climate change in the region was very severe. This chart shows that the precipitation patterns in these two regions differ over time and may be influenced by different climatic factors, as the inversion of the SPI graph between the two regions indicates that different climatic patterns prevail in these regions. (LALMUANZUALA et al., 2023). This can be due to factors such as differences in weather systems, geographical location, and topographic effects (Eicker et al., 2024; Qi et al., 2024).

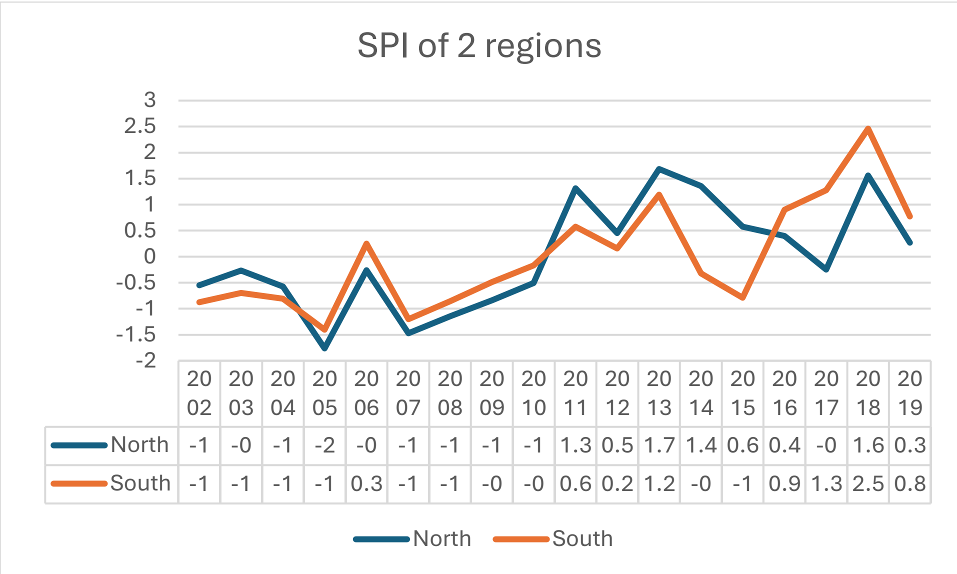

Figure 7. SPI of two regions

The evapotranspiration rate was simply calculated using Landsat satellite data for the region in March as a representative of the warm season and is shown in Figure 8. According to the chart, the evapotranspiration rate decreased by approximately 0.002 until 2004 compared to 2002. Due to the decrease in precipitation in 2005, the evaporation rate in the entire region increased, and between 2006 and 2007, it decreased again. But after 2007, it increased to the same level as in 2002. The highest evapotranspiration rate was in 2015, and after that, it decreased until 2020 and was at the average evapotranspiration rate for the entire period. This situation indicates that a decrease in the chart indicates a decrease in temperature or a decrease in precipitation, and an increase in evapotranspiration rate indicates an increase in temperature in the region and a decrease in precipitation over the entire period (Bozorg-Haddad et al., 2022; Jani et al., 2023; Schulz et al., 2020).

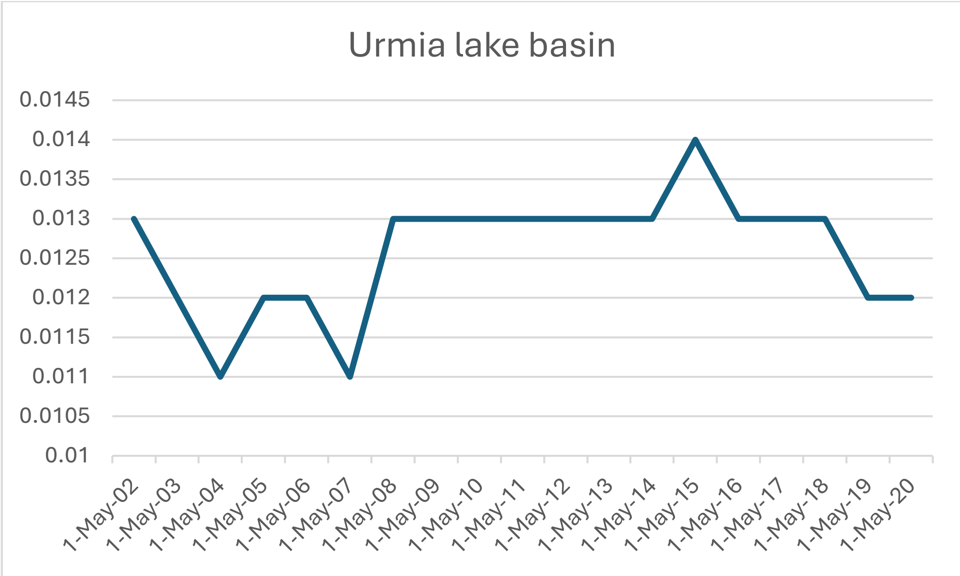

Figure 8. Urmia Lake basin evapotranspiration

After examining the rate of evapotranspiration in the entire region, we will continue to examine the rate of evapotranspiration in two selected regions. The calculated values are given in Figure 9. According to the data obtained in this chart, which is from two regions on the lake, it can be examined and concluded that the rate of evapotranspiration in the north and south of the lake increased very slightly between 2002 and 2013, and both regions are similar to each other. However, these values increased sharply in the southern part between 2014 and 2015 and returned to their previous state in 2016. According to Figure 3, it can be seen that the precipitation in 2015 in the southern part was much lower than in the northern part.

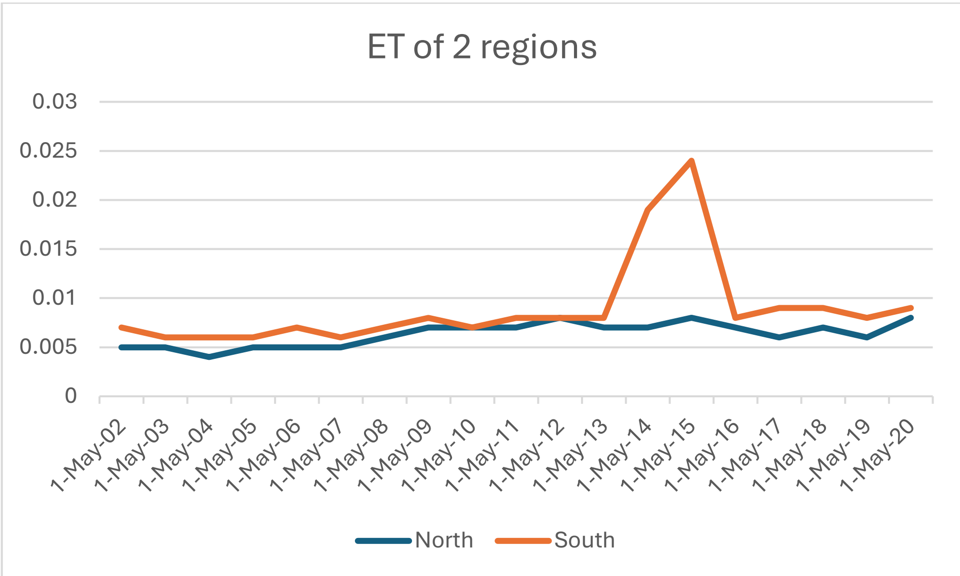

Figure 9. Evapotranspiration of two selected regions

The results of the analysis show that due to the construction of a bridge in the middle of the lake, which prevents the circulation of water in its northern and southern parts, and the construction of numerous dams that have reduced the amount of water in the lake, the water in Lake Urmia has not only decreased, but also increased the salinity of the water in the southern part compared to the northern part. Since the region is affected by different climatic conditions, the rate of evaporation and dryness is different in the northern and southern parts. The paper (Alipour & Olya, 2015)refers to a sustainable adaptive governance model, and the paper (Shams Ghahfarokhi & Moradian, 2023) deals with resilience-based water resources management, which develops scenarios for lake restoration with the help of integrated water resources management (IWRM). It should be noted that any change in the water supply to the lake or changes in the entire region that cause harmful climate change and reduce precipitation on the lake surface (Bozorg-Haddad et al., 2022) can increase water salinity, which will result in increased evaporation and transpiration of the Lake Surface and further decrease in the lake water level (Schulz et al., 2020). Therefore, before making any changes, climatic conditions and lake water salinity must be considered to prevent the lake's water from decreasing and its causes.

5. Conclusion

In this study, it was examined that Lake Urmia, due to its unique climatic conditions and high-water salinity, is very sensitive to volume and surface changes; because any reduction in the lake's volume and area can lead to an increase in salt concentration and intensify the evaporation and transpiration processes. Additionally, the existence of a bridge connecting the northern and southern parts of the lake has disrupted the natural water circulation and distorted the uniform distribution of salinity across the water surface; so that the southern part, due to the accumulation of higher salinity water, experiences a higher rate of evaporation and transpiration. Meanwhile, the region's climatic changes—including reduced annual rainfall and increased air temperature—play a significant role in lowering water levels and increasing salinity, accelerating the gradual drying process. Considering the obtained results, prioritizing management of the southern part of Urmia Lake seems essential. Controlling salt concentration through the injection of quality water and the intelligent management of dam reservoirs can significantly prevent excessive evaporation and stop the southern areas from turning into saline wetlands. Additionally, designing and constructing water circulation pathways between the northern and southern sections to achieve hydrological balance and prevent salinity concentration are considered necessary and practical measures. These approaches, when implemented and supplemented by an ongoing, real-time monitoring program that tracks changes in salinity and water volume, will create optimal conditions for the lake's ecosystem. The local communities adjacent to the lake can expect to derive continued social and economic benefits from this ecosystem restoration effort. But recent climate and human impacts that have driven the lake's decline are not going away. The ongoing use of modern remote sensing tools and GIS will ensure that at least the impacts of these tools will be felt in more rigorous and effective management planning. This framework will also ensure that any plans made in this management framework will be sustainable.

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