IRAN'S DAM WATERBODIES: A 10-YEAR TREND ANALYSIS (2013–2023)

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ABSTRACT

Previous studies have shown instances where aquatic ecosystems in Iran have experienced water loss even in the absence of upstream dams, while other ecosystems with upstream dams did not show significant declines in water levels. Thus, attributing the drying of these ecosystems solely to climate change in the watershed is not definitive, especially when water levels behind dams have increased while wetlands' water volumes decreased due to water diversion. This complexity underscores the challenge of linking the decline of aquatic ecosystems exclusively to climate change, as reduced rainfall would naturally lead to decreased water levels behind dams as well. This study addresses this complex issue by analyzing 60 water bodies behind dams across various regions of Iran from 2013 to 2023, using Landsat 8 satellite images and the AWEIsh water index. We employed linear regression to detect surface change trends during this period. Our findings revealed statistically significant (P-value < 0.05) trends in 13 out of the 60 water bodies, with four showing an increasing trend in water levels, indicating diverse precipitation patterns across Iran rather than a uniform decline. Among these, nine dams with significant trends experienced decreased water levels, reflecting reduced upstream rainfall in their watersheds over the past decade. This supports existing research highlighting climate change's impact on Iran's water resources. Despite highlighting the impact of declining precipitation and increasing temperatures in certain regions, our study also reveals that certain areas in Iran have not faced such severe conditions. In fact, some regions have seen a notable increase in dam water levels over the past decade. This study emphasizes the importance of an impartial assessment of Iran's water reserves, free from preconceived notions from previous studies. Such an objective evaluation is crucial for effective management of Iran's water resources.

Keywords: Wetlands, aquatic ecosystems, rivers, dams, remote sensing.

INTRODUCTION

Recent studies in Iran suggest that various infrastructures, such as roads, railways, urban areas, industries, mines, and agricultural activities, significantly impact the country's territory (Karimi & Jones, 2020; Khosravi & Hemami, 2019; Rahimi & Dong, 2022; 2023). Additionally, climate change has been identified as a crucial factor affecting Iran's biodiversity, with predictions indicating that species are likely to experience a reduction in their future distribution ranges (Ashrafzadeh *et al*., 2022; Ashrafzadeh *et al*., 2019; Ebrahimi *et al*., 2021; Farashi & Shariati, 2017; Moghadam *et al*., 2021; Mohammadi *et al*., 2019; Rahimi *et al*., 2024; Yousefi *et al*., 2019). Furthermore, studies predict an increase in temperatures in Iran, with Vaghefi *et al*. (2019) employing an ensemble approach using five high-resolution climate models, indicating that Iran's southern regions are expected to face prolonged periods of extreme maximum temperatures during the 2025–2049 timeframe compared to the 1980–2004 period.

Wetlands are valuable ecosystems, covering 6 % of the Earth's surface (Mitsch *et al*., 2010), yet providing 40 % of the world's ecosystem services (Zedler & Kercher, 2005). Iran, with its arid and semi-arid climate, is located in southwest Asia and is home to over 250 wetlands spanning 2.5 million hectares (Sajedipour *et al*., 2017) including 25 wetlands covering 1,655,449 hectares listed under the Ramsar Convention (Halls, 1997). Environmental pressures on these wetlands primarily stem from human activities such as dam construction, agriculture, industrial and domestic wastewater discharge, wood harvesting, and vegetation removal for fuel (Ghazali, 2012; Malekmohammadi & Jahanishakib, 2017; Wang *et al*., 2020; Zedler & Kercher, 2005). The existence and size of wetland water bodies depend on the balance between water inputs from precipitation and groundwater and water losses due to evaporation (Salimi *et al*., 2021). Climate change poses a significant threat, causing alterations in the water bodies of wetlands(Erwin, 2009; Sanjerehei & Rundel, 2017).

Rahimi *et al*. (2023) investigated changes in the water bodies of 24 international wetlands by comparing late summer data from 2000 and 2020 using Landsat images. The study also examined the water bodies of upstream dams and the long-term trends of precipitation and temperature changes around the wetlands. They found that eleven wetlands experienced a 1.0 % to 53.5 % decrease in water area by 2020. The findings suggest that climate change significantly impacts some wetlands. In contrast, certain wetlands showed increased precipitation from 2000 to 2020, complicating the link between water level decline and climate change. For seven wetlands, an increase in upstream dam water areas between 2000 and 2020 was observed, with no strong evidence of climate change effects. Thus, upstream dam construction may be the primary cause of drying in these wetlands, posing a greater threat than climate change.

Globally, the number of large dams has increased at least tenfold from 1950 to 2017. Currently, there are over 58,000 dams worldwide that are either higher than 15 meters or between 5 and 15 meters and impound more than 3 million cubic meters of water (Thieme *et al*., 2020). At least 1,249 large dams are located within protected areas (PAs), with two-thirds (907) constructed before the establishment of the PAs. Additionally, 14 % of planned geolocated hydropower dams (509 dams) are situated within PAs (Thieme *et al*., 2020). The new era of dam construction in Iran began in the mid-1950s with the involvement of international companies and has remained the primary strategy for water supply. However, this approach has significantly affected both the quantity and quality of water in watersheds, rivers, and other water bodies, leading to considerable destruction of natural habitats and species. Dams have flooded forests to create reservoirs, facilitated timber smuggling upstream, and reduced forest areas downstream, thereby accelerating desertification (Zafarnejad, 2009). Hence, the presence of dams has consistently been identified as a threat to wetlands and rivers (Nielsen *et al*., 2020), particularly in Iran (Adib *et al*., 2016; Heydari *et al*., 2013; Karami & Karami, 2020), some studies, however, highlight climate change as the most significant factor contributing to the drying of Iran's wetlands (Alborzi *et al*., 2018; Delju *et al*., 2013).

We believe there are contradictions regarding the role of dams in reducing water levels in rivers and wetlands. Previous studies have shown that some wetlands have experienced water loss without the presence of an upstream dam, while other wetlands, despite having upstream dams, have not seen significant reductions in water levels (Rahimi *et al*., 2023). Therefore, it cannot be conclusively stated that climate change in the basin has caused wetlands and rivers to dry up, especially when water levels behind the dams have increased but the wetlands' water volume has decreased due to water diversion. In such cases, it is difficult to attribute the drying of rivers and wetlands solely to climate change, as a lack of rainfall would have also resulted in reduced water levels behind the dams.

Therefore, the objective of this study is to assess changes in 60 dam water bodies across Iran between 2013 and 2023 to identify any significant trends in their water levels. Three possible outcomes are anticipated: (1) If there is no significant change in water levels over the decade, it suggests seasonal fluctuations rather than a clear trend, making it difficult to determine whether there has been an increase or decrease in rainfall during this period. (2) A significant decrease in water levels could indicate climate change, with reduced rainfall in the upstream watershed. Consequently, downstream wetland water bodies are expected to decrease due to both dam construction and climate change impacts. (3) If there is a significant increase in dam water body levels, the drying of downstream wetlands in downstream cannot be attributed to climate change but rather to upstream dam construction limiting water flow to the wetlands. This scenario implies that low rainfall would also result in decreased water levels in the dam reservoirs.

METHODS

Study area

Figure 1 illustrates the geographical distribution of 30 sub-basins and the locations of 60 dams under study. The map highlights that the central and eastern regions of Iran have fewer selected dams. These areas, characterized by arid and semi-arid climates, as well as challenging topographic conditions, have historically seen limited dam construction.

Landsat 8 data

To analyze the dynamics of 60 dam water bodies across Iran, the Landsat 8 dataset was utilized. A total of 366 scenes with specific Landsat path and row combinations were downloaded between 2013 and 2023. Figure 2 depicts the geographic location of Iran alongside the Landsat satellite's path and row configurations. Data acquisition was conducted via the website https://earthexplorer.usgs.gov/, where search criteria included a cloud cover percentage of zero percent, with preference given to images captured in August. August was chosen as the critical season for studying aquatic ecosystems because it typically has no rainfall, very high temperatures, and increased evapotranspiration, creating significant stress on water bodies and their habitats (Rahimi *et al*., 2023).

The study focused on Landsat Collection 2 Level-2 data, specifically using the Landsat 8 satellite (OLI/TIRS). The Level-2 Surface Product (L2SP) includes atmospherically corrected Surface Reflectance (SR), Surface Temperature (ST), intermediate bands of ST, angle coefficients, and Quality Assessment (QA) Bands. These products are derived from Level-1 Systematic Terrain (Corrected) (L1GT) or Level-1 Precision Terrain (Corrected) (L1TP) images, with atmospheric corrections applied to enhance data accuracy (Landsat, 2020). For each Landsat path and row combination annually, a visual inspection was performed to verify the availability of images. While efforts were made to procure August images with zero cloud cover, some regions in northern Iran necessitated downloading images with cloud cover. In instances where August imagery was unavailable or obscured by clouds, images from July or alternative months were accessed as a backup solution.

Fig. 1. Location of Iran sub-basins and location of 60 understudy dams. Each sub-basin is represented by a numbered marker, while the dams are denoted by location signs.

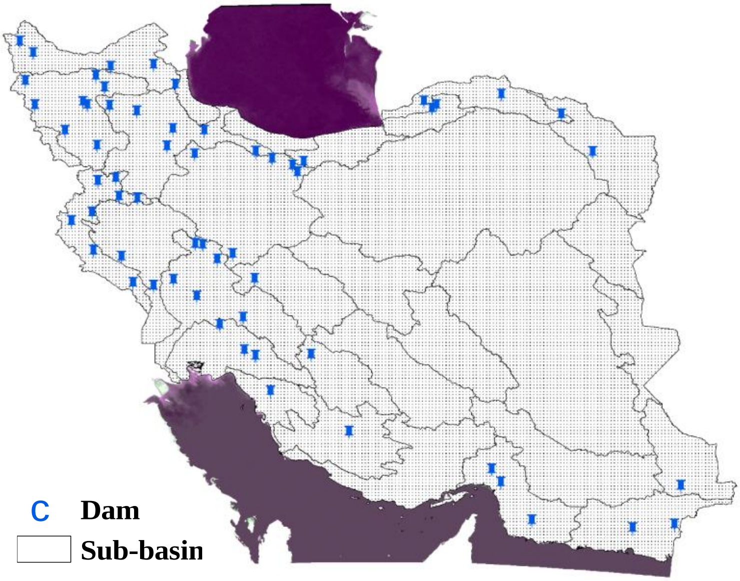
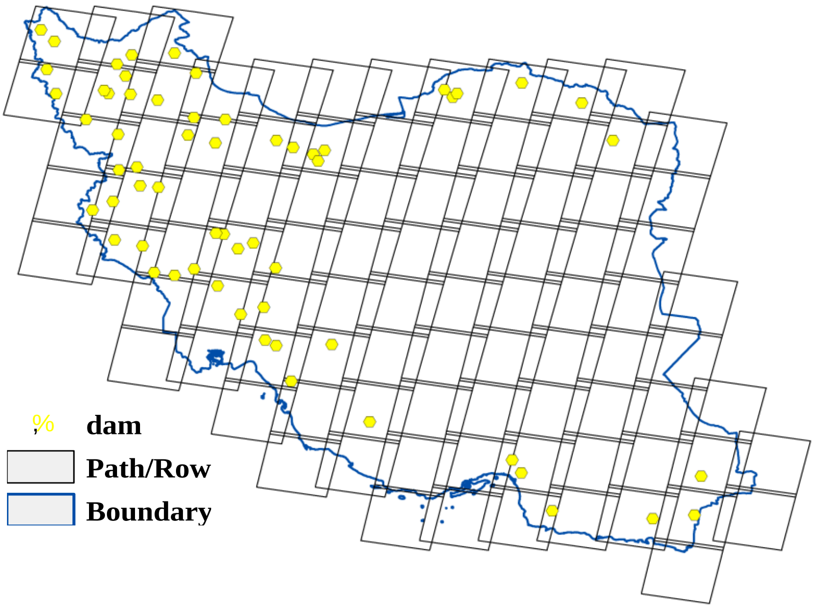


Fig. 2. Location of understudy dams and Landsat path/row



Water index calculation

Numerous spectral reflectance indices (SRIs) related to water have been created to identify liquid water presence. These SRIs are extensively applied in agricultural and ecological contexts, encompassing tasks such as characterizing surface water bodies, estimating vegetation water status, and monitoring wetlands like paddy rice fields (Debanshi & Pal, 2020; Ma *et al*., 2019). However, selecting appropriate SRIs for particular studies can be challenging due to the arbitrary choice of indices in various applications and the inconsistent naming of indices across different studies. As an illustration, different indices such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), and Enhanced Vegetation Index (EVI) are commonly employed to assess vegetation water status, often without thorough evaluation of their appropriateness for the specific application (Ma *et al*., 2019).

Utilizing methods such as single-band thresholding and two-band indices involves identifying an optimal threshold that maximizes accuracy, a task complicated by the variability in threshold values across different locations and times of image capture. Therefore, Feyisa *et al*. (2014) developed an index that consistently enhances the accuracy of water extraction amidst diverse environmental noise, while maintaining a stable threshold value. Thus, we introduced the Automated Water Extraction Index (AWEI), designed to improve classification accuracy even in areas with shadows and dark surfaces where conventional methods frequently struggle to classify correctly (Bijeesh & Narasimhamurthy, 2020; Feyisa *et al*., 2014). In this study, we utilized the AWEI that enhances the distinguishability between water and non-water pixels by leveraging band differencing, addition, and the application of specific coefficients (Feyisa *et al*., 2014; Fisher *et al*., 2016).

$$AWEI_{insh} = 4 \times (Green - SWIR1) - (0.25 \times NIR + 2.75 \times SWIR2)$$

For Landsat 8 equation details are: Band 3 (green), Band 5 (NIR). Band 6 (SWIR1) and Band 7 (SWIR2)

In AWEI we have positive values for water pixels and predominantly negative values for most non-water pixels. The equation assigns notably negative values to pixels covered by vegetation, soil, and bright built environments (Feyisa *et al*., 2014; Rad *et al*., 2021). In this study, we rescaled the index between 0 and 1, with 1 indicating water cells and 0 indicating non-water cells, to facilitate easier threshold determination.(Feyisa *et al*., 2014; Rad *et al*., 2021).

Binary classification

The majority of automated methods for extracting water body information from remote sensing data can be categorized into two main approaches: threshold segmentation and image classification (Li *et al*., 2022). Thresholding is a critical aspect in the application of water indices for extracting water bodies. Typically, indices like NDWI indicate water presence with values greater than 0 based on water's reflectance characteristics. Hence, a threshold value of 0 is commonly used to delineate water in index images. However, research suggests that adjusting the threshold value can often improve extraction accuracy. This becomes particularly challenging when applying thresholding to either a time series of images covering the same water body or a single image encompassing multiple water bodies, as manual adjustment for each image is impractical for automation (Bijeesh & Narasimhamurthy, 2020; Huang *et al*., 2018; Li *et al*., 2022). Utilizing methods such as single-band thresholding and two-band indices involves identifying an optimal threshold that maximizes accuracy, a task complicated by the variability in threshold values across different locations and times of image capture. Therefore, in this study, we first calculated the AWEI for 60 dams between 2013 and 2023 and applied a thresholding approach to differentiate water from non-water cover, a common methodology in this field (Eid *et al*., 2020; Feyisa *et al*., 2014; Rad *et al*., 2021; Teng *et al*., 2021; Yulianto *et al*., 2022).

In the next step, we rescaled the AWEI values to a range of 0-1. Using visual assessment in ArcGIS software, we checked the value range of water bodies in each dam. These ranges varied between 0.74 to 0.92 depending on the year and location of the dams. We classified all AWEI values into two classes based on these thresholds. For each year, we obtained 16 binary images showing water and non-water surfaces. To select the proper threshold for each year, we created 600 random points across the dams under study as ground truth points and calculated the Kappa coefficient and overall accuracy. Based on the highest values of these accuracy assessment coefficients, we selected the most suitable threshold for each dam per year.

Accuracy Assessment

The accuracy assessment was conducted by generating random points within each dam area. Specifically, we created 100 random points per dam area per year, amounting to 6000 points across all dams annually. For each dam water body in each year, these points were classified into water and non-water categories, and used to calculate the Kappa and overall accuracy indexes. With a span of 11 years, we assigned a value of 0 or 1 to each point based on the presence of water in the dam under study for that particular year.

Trend analysis

For trend analysis of dam water bodies, we applied linear regression to model the relationship between the dependent (Y) and independent (X) variables, assuming a linear correlation. The slope indicates the rate of change, with a positive slope showing an increase and a negative slope showing a decrease in the dependent variable. The simple linear regression formula is:

$$Y=\beta 0+\beta 1X+\varepsilon$$

Y is the dependent variable,
X is the independent variable,
$\beta 0$ is the intercept,
$\beta 1$ is the slope,
ε is the error term, representing the difference between observed and predicted values of Y.

In this study, we treated the period from 2013 to 2023 as the independent variable, while water areas were used as the dependent variable. We then calculated the slopes for each dam between 2013 and 2023 to acquire increasing or decreasing trends. Additionally, the p-value (0.05) of the regression slope was considered to determine if the trend was statistically significant.

RESULTS

Accuracy assessment

Table 1 presents the results of accuracy assessments for binary classification conducted annually. Each row corresponds to a specific year, showing the threshold value that yielded the highest Kappa coefficient along with the corresponding Kappa score and overall accuracy. In 2013, a threshold of 0.77 achieved a Kappa coefficient of 0.95 and an overall accuracy of 0.98. Similarly, in 2014, a threshold of 0.87 resulted in a Kappa coefficient of 0.97 and an overall accuracy of 0.99. The years 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, and 2023 all saw high Kappa coefficients ranging from 0.95 to 0.96 and overall accuracies consistently near 0.98 to 0.99, with threshold values ranging from 0.83 to 0.89. These results indicate the effectiveness of the selected thresholds in accurately classifying water and non-water pixels within the dam areas across the evaluated years.

Table 1: Accuracy assessments of binary classification maps per year

Year	Threshold	Kappa	Overall accuracy
2013	0.77	0.95	0.98
2014	0.87	0.97	0.99
2015	0.87	0.96	0.98
2016	0.86	0.96	0.98
2017	0.83	0.95	0.98
2018	0.89	0.96	0.99
2019	0.89	0.96	0.98
2020	0.84	0.96	0.98
2021	0.86	0.95	0.98
2022	0.88	0.96	0.98
2023	0.89	0.96	0.98

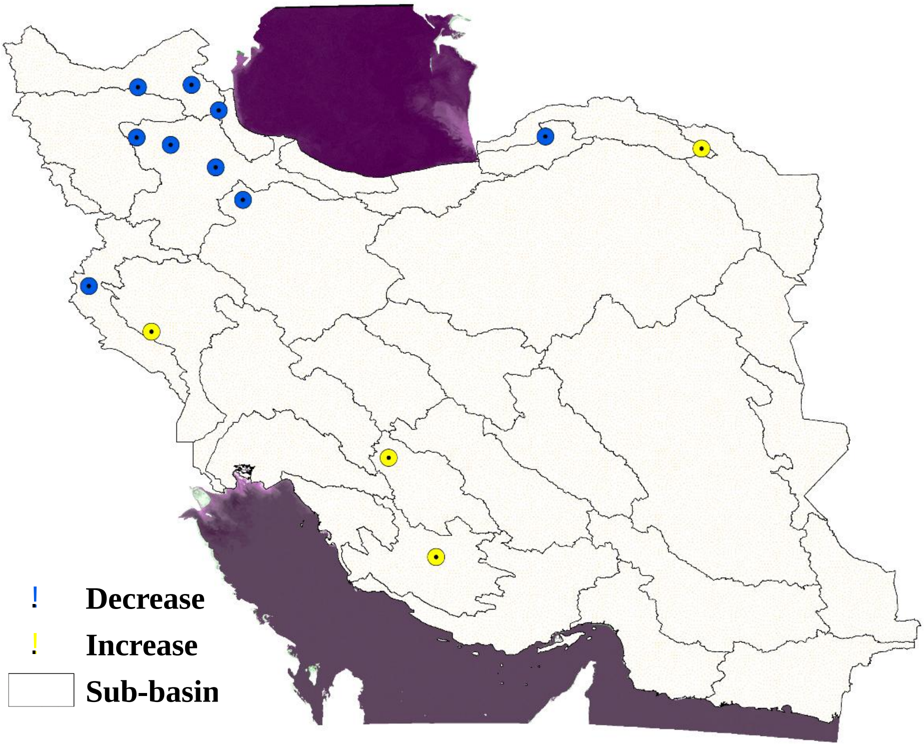
Trend analysis

Table 2 presents the outcomes of linear regression analyses conducted on 13 water dam sites that displayed statistically significant trends (P-value < 0.05). The table categorizes these trends based on the sign of the slope into positive and negative directions, offering a detailed overview of the observed changes in water body extents over the study period. Among the 13 dam sites analyzed, four demonstrate positive trends, indicating an increase in the number of cells over time. For example, Dam ID 5 exhibits a negative slope of -27.8, indicating a yearly reduction in the water body extent. Similarly, Dam ID 7 exhibits a pronounced positive trend with a slope of 1930.6, indicating a significant annual increase in water cells. Conversely, the remaining nine dam sites exhibit negative trends, signifying a decrease in the number of cells over time. For instance, Dam ID 1 displays a notable negative slope of -273.6, indicating an average annual reduction in water cells. Similarly, Dam ID 3 shows a steep negative trend with a slope of -365, reflecting a substantial annual decrease in water body extent. Figure 3 shows the locations of the 13 dams with statistically significant changes (P-value < 0.05). This sample illustrates that while the northwestern parts of Iran exhibit a significant decrease in dam water, dams with an increasing trend in water levels are scattered across different parts of the country.

Table 2: Linear regression equation for dams with significant trends (P-value < 0.05)

ID	Equation	Slope	P-value
1	555425.16 + (-273.6) * Years	-273.6	0.002
2	273279.33 + (-133.5)* Years	-133.5	0.003
3	742654.22 + (-365) * Years	-365	0.004
4	338256.87 + (-163.6) * Years	-163.6	0.005
5	-1895517.07 (+945.2) * Years	945.2	0.01
6	57072.82 + (-27.8) * Years	-27.8	0.01
7	-3866558.02 (+1930.6) * Years	1930.6	0.011
8	148545.25 + (-71.8)* Years	-71.8	0.015
9	595802.22 + (-293.9) * Years	-293.9	0.018
10	-255815.18 (+ 127.8) * Years	127.8	0.029
11	353318.45 + (-173.1) * Years	-173.1	0.03
12	205118.51 + (-100.5) * Years	-100.5	0.038
13	-1979294.76 (+992.5) * Years	992.5	0.047

Fig. 3: Locations of the 13 dams showing statistically significant changes.



DISCUSSION

In this study, we analyzed 60 water bodies located behind dams across various regions of Iran from 2013 to 2023 using Landsat 8 satellite images and the AWEIsh water index. Linear regression was applied to identify surface change trends during this period. The results revealed that 13 out of the 60 dams showed statistically significant trends (P-value < 0.05), with four dams exhibiting an increasing water level trend, while the remaining nine displayed decreasing trends. Importantly, the general trend across all 60 dams indicated that 35 dams showed a decreasing trend, while 25 showed an increasing trend. This suggests that, overall, many of Iran's dams experienced water level declines between 2013 and 2023.

The focus of our analysis was on the 13 dams with statistically significant trends. Despite the lack of significance for most dams, this does not imply the absence of water level trends. It is possible that the chosen time frame of 10 years was too short to capture the full extent of these trends. Studies on similar trends have shown that a longer time span is often required to identify consistent patterns (Rahimi *et al*., 2023). Therefore, the absence of significant trends in the remaining dams may be due to insufficient temporal data, not necessarily the absence of trends.

Our findings indicate a predominant decrease in water levels across the study region. Specifically, 9 of the 13 dams with significant trends showed a reduction in water levels, which mirrors the broader trend observed across all dams. This decrease is likely related to reduced rainfall in the upstream watersheds of these dams, reinforcing the conclusions of other studies that suggest climate change has had a negative impact on water reserves in Iran (Moridi, 2017; Vaghefi *et al.*, 2019). Iran's water resources have been under pressure due to decreased precipitation, with the average annual rainfall dropping by 6 % between 1994 and 2014 (Ashraf *et al*., 2021). Additionally, the average volume of surface runoff has also decreased by 42 % over the same period, suggesting a systemic decline in the region's hydrological balance.

However, our results also show that 30-40 % of the dams exhibited increasing water levels, which points to spatial variability in rainfall patterns across Iran. While some regions, particularly the northwestern areas, have experienced water shortages (due to both dam construction and reduced precipitation), other regions have shown an increasing trend in water levels. This pattern is inconsistent with the overall narrative of widespread drought and suggests that localized hydrological conditions, such as increased rainfall or improved water management practices, may explain these increases in certain dams.

Dams showing a decrease in water levels, particularly in the northwestern regions of Iran, are likely experiencing reduced rainfall in their upstream areas, supporting the claim that declining precipitation is a key factor affecting water resources. On the other hand, the dams showing increasing water levels are more dispersed geographically, indicating that this trend is not regionally specific but may be linked to localized rainfall patterns or changes in watershed management. In contrast to the decreasing trend observed in the majority of the dams, the four dams with increasing water levels suggest that not all regions of Iran are uniformly affected by climate change. According to Yazdandoost (2016), Iran's climate is predominantly arid and semi-arid, with significant variability in precipitation distribution. Approximately 90 % of the country's precipitation falls in the cold and humid seasons, mainly in the northern and western regions, while the central, southern, and eastern regions receive less rainfall. This uneven distribution of rainfall is a key driver of the observed spatial variability in water levels. The northern and western regions, which typically experience higher rainfall, might be less affected by the decrease in precipitation observed in other parts of the country.

Furthermore, the temporal and spatial distribution of precipitation in Iran, as described by Yazdandoost (2016), may also play a critical role in shaping the observed trends in water levels behind the dams. The concentration of precipitation in the northern and western regions, coupled with the significant portion of the country experiencing water scarcity, further supports the idea that certain regions of Iran are more vulnerable to climate change than others. The continuing decrease in precipitation, especially in arid and semi-arid regions, is likely contributing to the long-term decrease in water levels, a trend observed in many of Iran's dams. In conclusion, the analysis of dam water levels between 2013 and 2023 reveals a complex relationship between climate change, dam construction, and hydrological conditions across Iran. While the majority of dams exhibited decreasing water levels, a few number also showed increases, suggesting regional differences in precipitation patterns and water management practices. Our findings support the growing body of research that links changes in water bodies to both climate change and anthropogenic influences, such as dam construction and water management (Hassanzadeh *et al*., 2012; Liang *et al*., 2021; Şen, 2021; Whitehead *et al*., 2009). Further studies with longer temporal data and regional analysis are necessary to better understand the full extent of these trends and their implications for water resource management in Iran.

CONCLUSION

Overall, Iran's water resources face considerable challenges, exacerbated by declining precipitation and increasing temperatures in certain regions. Recent studies underscore the worsening situation, with reduced rainfall and river flows observed over recent decades. Looking ahead, addressing these challenges requires a nuanced understanding of regional precipitation patterns and their implications for sustainable water resource management in Iran. Despite the findings highlighting the lack of rainfall and the impact of climate change in Iran, our study reveals that certain regions have not experienced such severe conditions. In fact, some areas have experienced a significant increase in dam water levels between 2013 and 2023. This study underscores the importance of an unbiased assessment of Iran's water reserves, independent of preconceived notions from other studies. Only through such an objective evaluation can Iran's water resources be effectively managed.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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