The status of artificial wetland areas in light of climate change using Geospatial systems: Case study Ain Zada Lake (Algeria)

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ABSTRACT Climate patterns in North Africa, specifically the southern Mediterranean, have changed considerably due to global climate change. As a result, a major environmental problem has emerged: the deterioration of wetlands and associated ecosystems, which are protected under the Ramsar Convention. This study examines the state of an artificial wetland, notably the reservoir formed by the Ain Zada Dam in northeastern Algeria, from 2001 to 2021. RS, GIS, and GEE were used to analyse indices and satellite images. The study found that the reservoir's water storage decreased significantly, from 10.5 million m³ in 2001 to 2.4 million m³ in 2021. This finding is entirely consistent with the NDWI index, which was generated from an analysis of 151 satellite images. The drop in water storage has had an extensive effect on the reservoir's ecosystem. That decline is linked to changes in the region's environment over the last 40 years, which has been characterized by lower water levels and higher temperatures, providing additional evidence of global warming.

KEY WORDS artificial wetlands – semi-arid region – climate change – geospatial systems – Ain Zada Lake dam

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1. Introduction

Algeria has rich and diverse ecosystems, including wetlands, defined by the Ramsar Convention as any area of swamp, bog, peat land or water, whether natural or artificial, permanent or temporary, with water that is quiescent or flowing, fresh, brackish or salt water, including seawater, the depth of which does not exceed six meters at low tide (Ramsar Convention Secretariat 2016). Algeria joined the Ramsar Convention in 1984; with 50 wetlands covering a total area of 2,991,013 hectares and is one of the richest areas in terms of biodiversity and animals (Mouhoubi 2014).

Artificial wetlands (reservoirs) type of 42 species classified by the Ramsar Convention (Ramsar Convention Secretariat 2013), artificial wetlands (reservoirs) has great, various benefits and services such as irrigation, hydroelectric power, domestic and industrial water supply, flood control, drought mitigation, shipping, fish farming and recreation (Tortajada 2014). Ecological: its role in environmental balance and the preservation of biological heritage (animal and plant). Economic: In relation to both aquaculture and agriculture, so that reservoir contribute to the irrigation of neigh boring and remote agricultural areas, in addition to industrial use. Urban: by supplying the population with drinking water (water security; Reid et al. 2019).

On the other hand, we note that almost all recent studies confirm that climate change is accelerating globally (IPCC 2023; Turral et al. 2016; Trenberth 2011; Boudiaf, Şen, Boutaghane 2021) including the North Africa region (southern Mediterranean), which is one of the regions in the world most vulnerable to these climate fluctuations, and it considered as "hot spot" in the world (IPCC 2023; Fig. 1).

Based on many evidences, the temperature of the atmosphere and oceans has risen (Turral et al. 2016, Treberth 2011). Which lead to decrease in precipitation on many sites and an increase in evaporation rates (Boudiaf, Şen, Boutaghane 2021).

It is worth noting that many of the expected impacts in this region have already been observed, such as issues of water scarcity and desertification. Climate change is expected to exacerbate these environmental risks and their implications for water security.

Due to these climate changes, the levels and sizes of lakes are not constant, and have even begun to decline in recent years. However, even when water levels and quantities are monitored, information from strategic, political, commercial or national departments is rarely freely available (Busker et al. 2019).

Since lakes and reservoir datasets are not comprehensive, most estimates of water storage are static or do not provide long-term data. The monitoring of lakes and reservoirs using remote sensing has attracted a lot of attention in recent years (Rouibah, Belabbas 2022).

The present study aims to thoroughly evaluate the effects of climate change on the water volume of Ain Zada Dam Lake in Algeria, using advanced geomatic

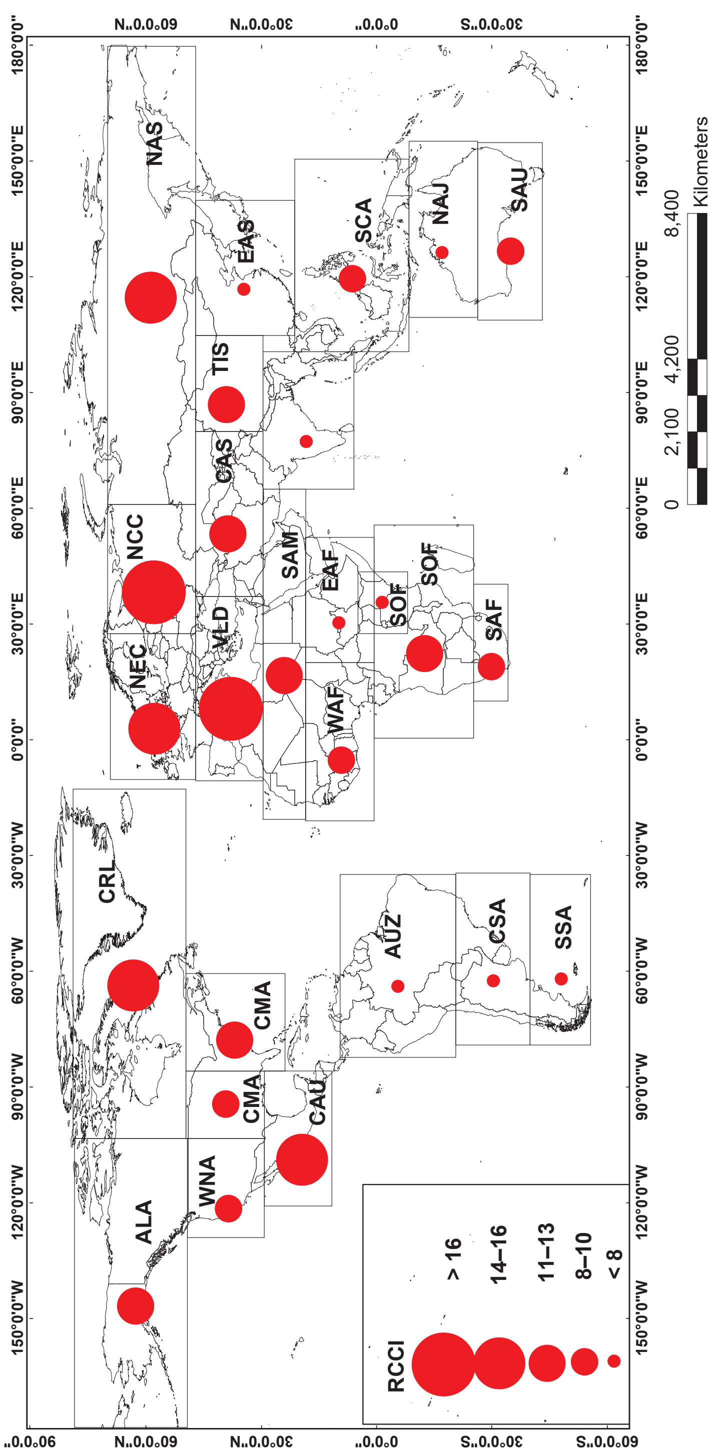


Fig. 1 – Regional Climate Change Index (RCCI) across 26 regions of the world calculated from 20 Global Climate Models coupling the Atmosphere and Ocean (AOGCM) from 3 emission scenarios (IPCC, 2000, 1998). According to Giorg (2006). Coordinate System: WGS 1984 World Equidistant Cylindrical, Projection: Equidistant Cylindrical Ellipsoidal, Datum: WGS 1984, False Easting: 0.0000, False Northing: 0.0000, Central Meridian: 0.0000, Standard Parallel 1: 0.0000, Units: Meter.

techniques, including Geographic Information Systems (GIS) and remote sensing, for assessment and monitoring. It analyzes long-term climatic data (1981–2022), such as temperature, precipitation, and evaporation, to understand how these variables influence water levels in the reservoir. By leveraging satellite remote sensing, particularly data from Landsat and Sentinel missions, the study captures and analyzes lake imagery regularly, allowing for precise measurement of changes in surface area and water volume over time. This approach enables the identification of significant trends and patterns in water volume changes and facilitates the correlation of these changes with climatic variables and other environmental factors. Furthermore, the study underscores the sensitivity of the Ain Zada region to climate change, emphasizing the critical need for continuous monitoring and advanced geomatics techniques to manage and mitigate its impacts. By providing data-driven insights and policy recommendations, the study aims to support effective water resource management and ensure the sustainability of the reservoir amidst evolving climatic conditions.

2. Literature review

Many international and local studies intersect with the issues discussed in this article, particularly regarding topics such as artificial wetlands, the patterns of climate change and its effects on water reservoirs in these regions, and the utilization of geomatics for monitoring climate change impacts. According to Abbass et al. (2022), existing literature on climate change up to 2022 includes approximately 95 articles identified through searches in databases like Web of Science, Google Scholar, Scopus Index Journals, Emerald, Elsevier Science Direct, Springer, and Sciverse. These studies primarily focused on analyzing and modeling global climate change impacts, adaptation strategies, and sustainable mitigation measures.

Artificial wetlands have gained significant research interest globally due to their potential to provide ecosystem services and support biodiversity. Recent studies focus on their role in wastewater treatment and climate change mitigation, emphasizing the need to understand the conditions for their effective operation and environmental benefits (Busker et al. 2019; Thorslund et al. 2017; Giosa, Mammides, Zotos 2018; Sudarsan, Jain 2023). Research using GIS and remote sensing techniques highlights the importance of these tools in monitoring wetland conditions and human impacts. For instance, Cheng and Dang (2022) proposed an AI method for ecological data monitoring and wetland simulation using GIS remote sensing, noting reed swamp degradation due to development and the need for advanced monitoring to preserve ecosystems. Studies on the Harike wetland in India and tropical wetlands demonstrate the use of remote sensing and GIS for analyzing land use, land cover, and water quality changes, stressing the need for comprehensive assessments to address seasonal fluctuations and factors influencing wetland conditions (Singh et al. 2022).

Numerous studies emphasize the relevance of GIS and remote sensing in wetland inventory, mapping, and change analysis across various regions. For instance, Xu et al. (2018) proposes a knowledge-based raster-mapping framework using remote sensing images and point of interest (POI) data to assess wetland ecological conditions in Suzhou, China. Similarly, Abdelmajeed et al. (2023) highlight the importance of developing local capacity for wetland management in southern Africa through remote sensing. Advanced applications of these technologies, such as using high-resolution LiDAR data and aerial photographs for mapping prairie potholes and surface hydrologic flow pathways, demonstrate their potential in environmental monitoring and management. While these studies primarily focus on natural wetlands, their methodologies can be adapted for assessing artificial wetland (reservoir) water storage.

In Algeria, various studies have addressed the impact of artificial wetlands, reservoir siltation, dam breach scenarios, conservation of wetland ecosystems, and water quality assessment in dams. These studies underscore the significance of artificial wetlands, particularly in arid regions, and the need for sustainable management and conservation practices. For example, Ouamane (2009) discusses the progress and prospects of dam engineering in Algeria, emphasizing effective water resource management. Gaagai et al. (2022) model the risks associated with dam-break flooding in semi-arid mountain watersheds, using the Yabous Dam as a case study. Hammana et al. (2024) highlight the stakes for conserving biodiversity in the wetlands of Northeastern Algeria, while Marouf and Remini (2019) study the environmental and socio-economic impacts of the Beni-Haroun Dam. Additionally, Soltani et al. (2021) propose a novel methodology for assessing water quality in Algerian dams using data envelopment analysis, offering a comprehensive approach to water quality management.

However, there is a scarcity of studies linking climate change to artificial wetlands, both in Algeria and globally. Rouibah and Belabbas (2022) investigated the Ain Zada study area from 2015 to 2020 with a different methodology but did not adequately explain climatic changes due to its limited temporal scope. This highlights a significant gap in long-term data and comprehensive analysis connecting climate change impacts to artificial wetland dynamics in the region.

Based on a comprehensive review of prior research, this study addresses a problem with distinct characteristics. It focuses on artificial wetlands, which play significant ecological and socio-economic roles in a climate-affected region, and involves applying geomatics techniques to extract spatial and climate data. Consequently, this study serves as a foundational piece in geospatial research in North Africa.

3. Methodology

3.1. Study area

Ain Zada Dam Lake is lead in the upper basin of the Bou Sellam River (Fig. 2), approximately 35°45'57" and 36°20'50" N and 004°58'30" and 005°32'55" E (Mebarkia et al. 2017, Boulgueraguer et al. 2014).

The study area is situated within the Bordj Bou Arreridj province, approximately 40 kilometers to the east of Bordj Bou Arreridj and 25 kilometers to the west of Setif (Benlaharche 2019, Dahmane 2011). The area encompassed by the Ain Zada Lake basin is roughly estimated to be around 2080 km² (Dahmane 2011). It located along the Bou Sellam River, which joins the Malah River, the Kharoua stream, and the Ain Taghrout stream to the south of the reservoir (Dahmane 2011; Fig. 3, 4).

In 1979, the American design firm BECHTEL with the aid of HIDROTECHNIKA BELGRADE-YUGSLAVIE carried out the dam study (Belhaddad 2018, Boulgueraguer et al. 2014). While Sir M. Mac Donal of England and Office Atkins Hum-Phreys studies completed the follow-up works in 1981 and 1986 (Belhaddad 2018, Boulahbal 2007).

Originally, the dam was intended to irrigate the agricultural lands in the eastern upper plains (agricultural lands in Ain Taghrot and Ain Zada), but during its completion, the area experienced a period of drought that resulted in a major shortage of drinking water for residents of the major cities nearby (Boulahbal 2007). Therefore, this lake has a strategic geographical location and plays a pivotal role in irrigating neighbouring lands, as well as in providing drinking water to the population of major urban areas (the municipalities of Setif and Bordj Bou Arreridj).

3.2. Data selection

The research utilized two sets of data: satellite images (multi-spectral and SRTM images) and climate Data as shown in the Table 1 and Figure 6.

This study uses two categories of climatic data: (i) General Climatic Data: Regional temperature and precipitation data from various climatic stations (Nasa Power 2024). (ii) Specific Climatic Data: Daily evaporation data from the monitoring station at Ain Zada Dam, measured in Hm³, covering January 1, 1987, to December 31, 2020, excluding 1992, 2001, and 2002 due to missing records (Ain Zada Dam Directorate 2022).

Additionally, the Boumergad climate station (36.0675324 N, 4.7970209 E; 980 meters), located in Bordj Bou Arreridj province, approximately 34–40 km from the dam, serves as a monitoring station but is outside the dam's catchment

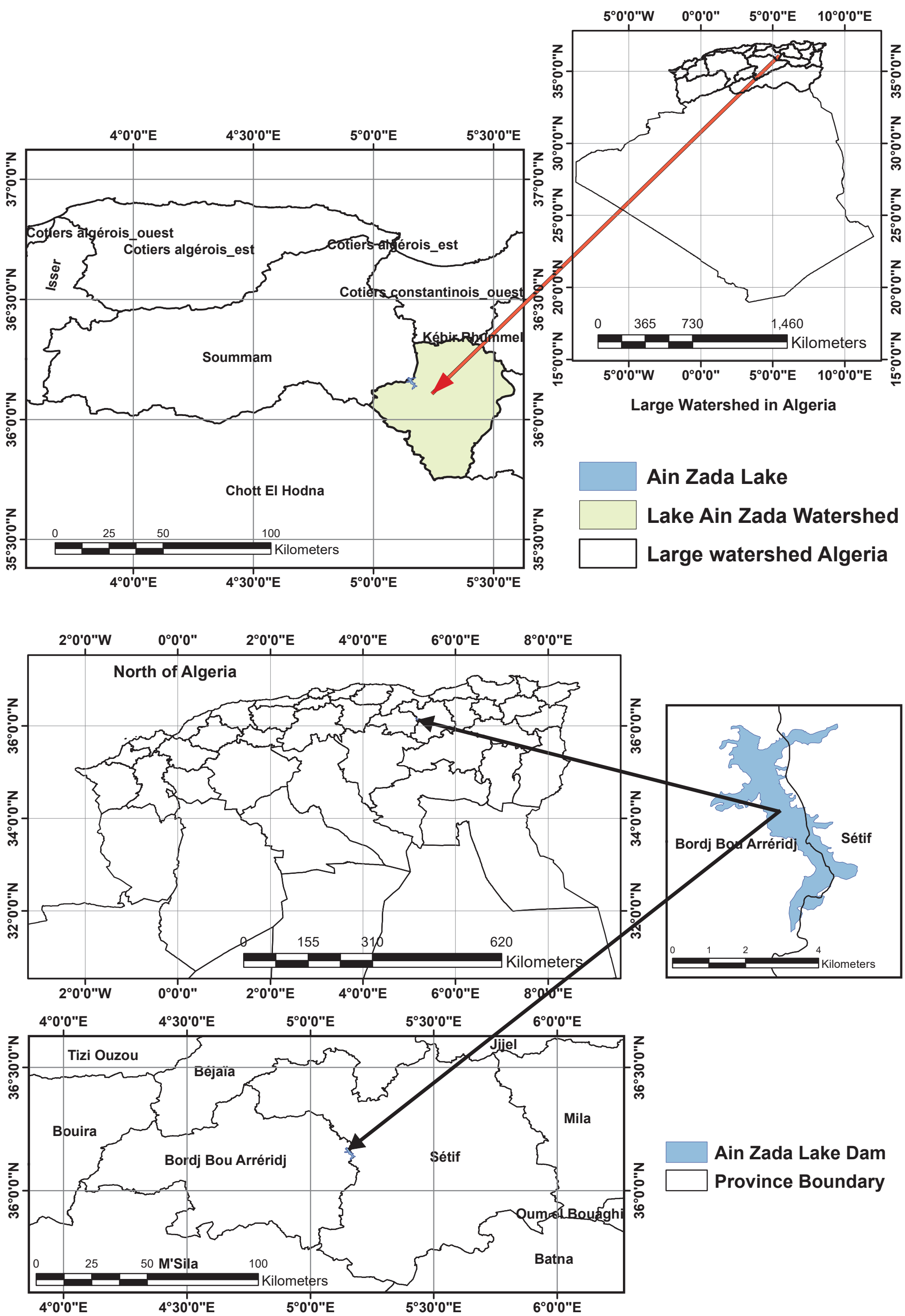


Fig. 2 – Study area location

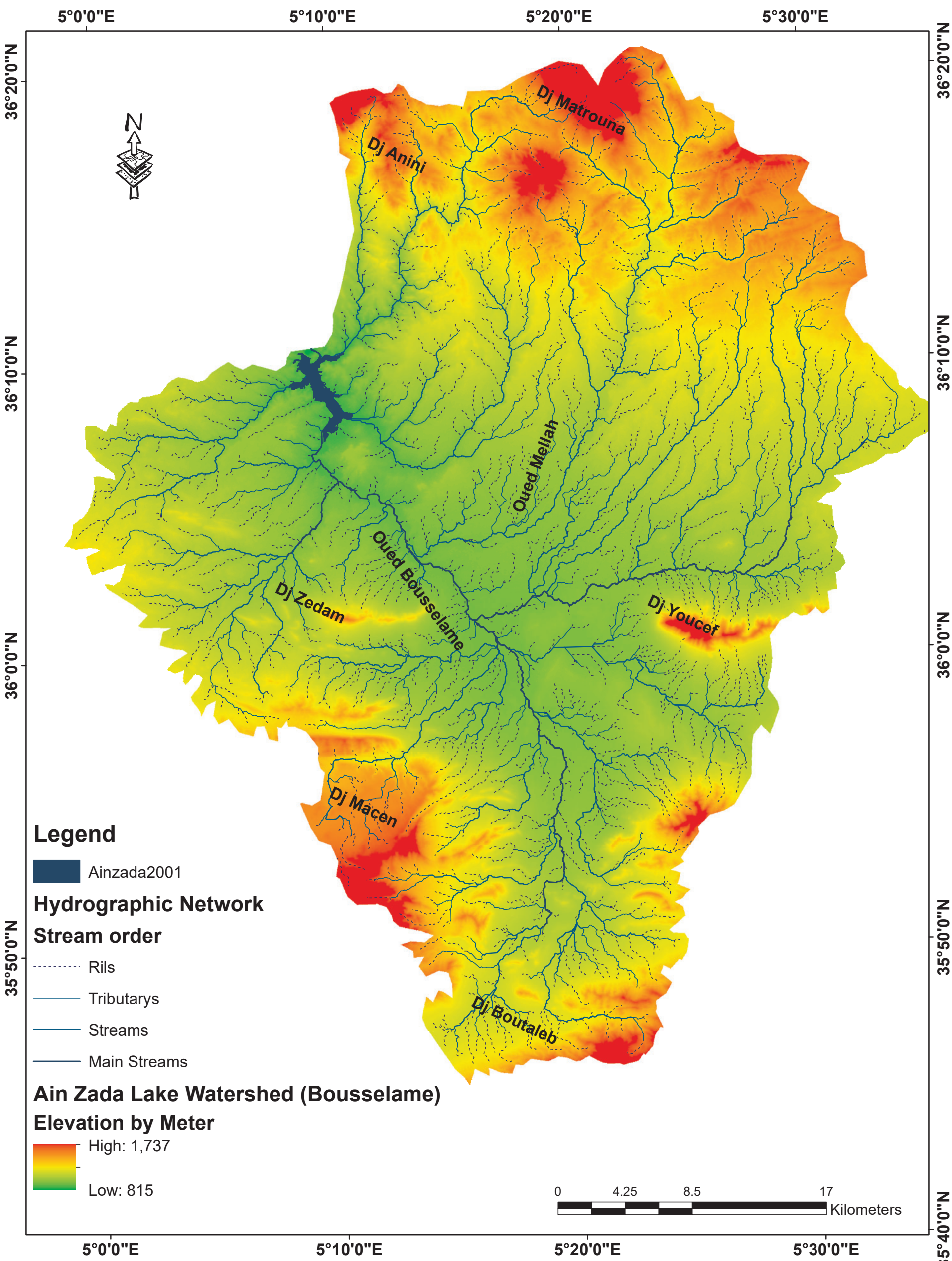


Fig. 3 – Watershed treated through SRTM imagery

Table 1 – Imagery Data

	Captured date	Resolution meters	coordinate system	Source
SRTM image	November 2013	0.00027777778	GCS_WGS_1984	(USGS earth explorer 2024)
Landsat 5 TM	January 2001	29.99. 29.99		
Landsat 8 ETM	January 2019	29.99. 29.99		
Sentinel A2	January 2021	20.20 meters		(ESA SENTINEL 2024)

Table 2 – Information about Weather Stations

Station References	Record duration (year)	Start of recording	End of recording
Station 01: 35.9364/5.3238	41	1981	2022
Station 02: 36.0908/5.0237	41	1981	2022
Station 03: 36.3401/5.2702	41	1981	2022
Station 04: 36.1274/5.5641	41	1981	2022
Station 05: 36.1685/5.1501	41	1981	2022

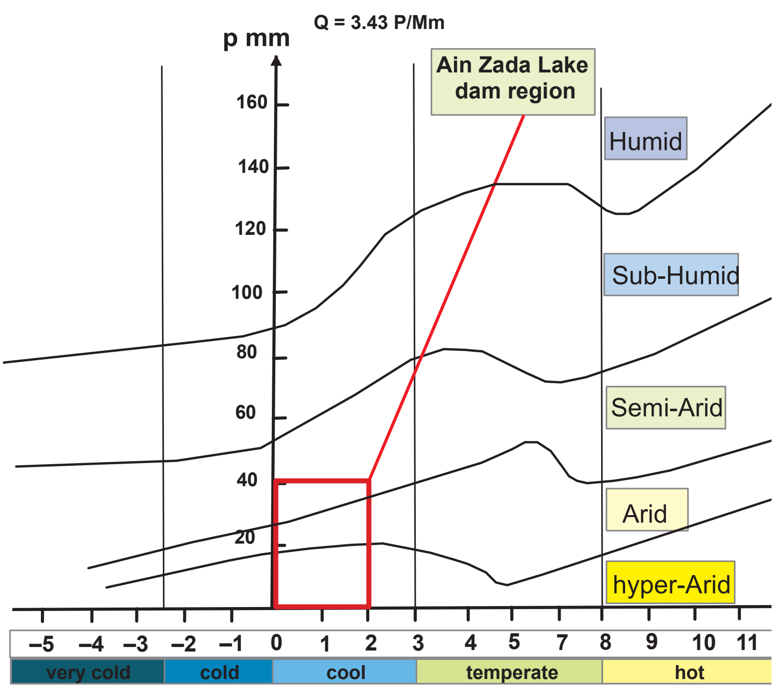


Fig. 4 – LA.Emberger climatogram (Mebarkia 2018, Côte 1999)

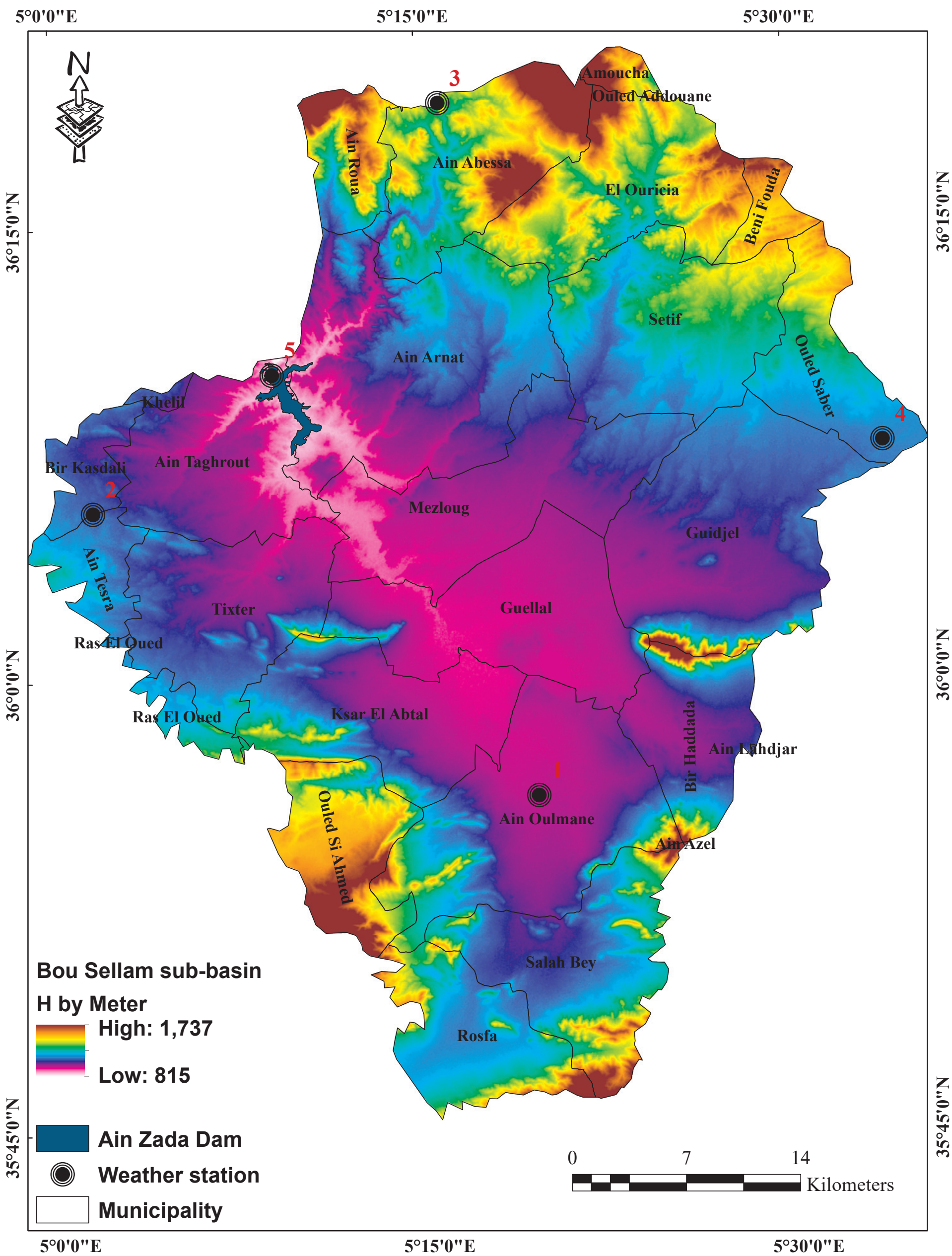


Fig. 5 – Meteorological station located in Bou Sellam watershed (personal treated)

basin. The Farmato station (36.2256686 N, 5.3985605 E; 1,096 meters) in Setif province is closer but lacks sufficient data for the Ain Zada Dam Lake catchment basin.

NASA's POWER Data Access Viewer project aids in obtaining meteorological information such as humidity, temperature, wind, and solar radiation (Pasha et al. 2021). The study utilizes climatic data from five stations across the Bou Sellam basin from 1981 to 2022 (Table 2, Fig. 5).

3.3. Method

The methodology of this research paper is based on two main components: The first involves the analysis of satellite images (both radar and multispectral) and the application of mathematical equations and spectral algorithms to extract essential information about the changes in the lake's water volume and area.

While the second axis revolves around the statistical analysis of climate data collected, whether from climate stations or by the Dam Directorate, for the purpose of knowing the paths of climate changes in the lake's catchment basin and the impact of that on the lake's water level (Fig. 6).

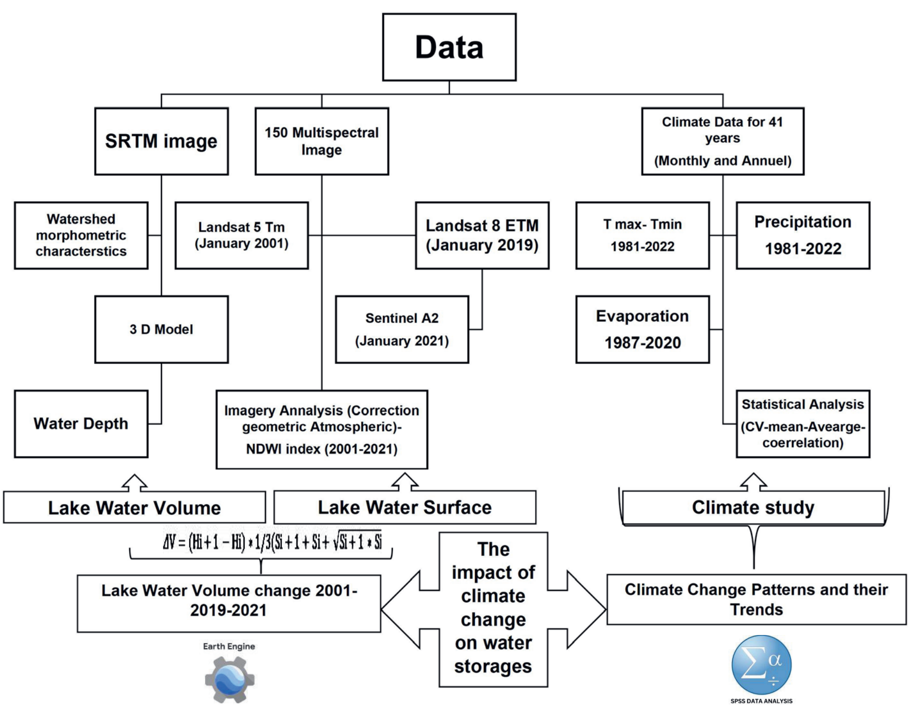


Fig. 6 – Data and methodology adopted

Table 3 – Equations for deriving indices to identify water bodies

Multiband Index	Equation
Normalized Difference Vegetation Index	NDVI = (NIR – Red) / (NIR + Red) (Wang et al. 2007)
Normalized Difference Water Index	NDWI = (Green – NIR) / (Green + NIR) (Singh et al. 2022)
Modified Normalized Difference Water Index	MNDWI1 = (Green – SWIR1) / (Green + SWIR1) (Hemalatha 2021) MNDWI2 = (Green- SWIR2) / (Green + SWIR2) (Minyan, Fiachra 2023)
Automated Water Extraction Index	AWEIsh = Blue + 2.5 × Green – 1.5 × (NIR + SWIR1) – 0.25 × SWIR2 (Minyan, Fiachra 2023) AWEInsh= 4 × (Green – SWIR1) – (0.25 × NIR + 2.75 × SWIR1) (Minyan, Fiachra 2023)

To accomplish the first task, we employed a variety of tools within Google Earth Engine (Google earth engine 2024) and GIS software for SRTM image analysis, utilizing features such as Fill, Flow Direction, Flow Accumulation, Watershed, contour tools and Tin (Fig. 6).

For the water bodies (lake) index-based classification, we followed three primary steps: computing water indices based on spectral reflectance, applying image classification algorithms for water identification, and assessing accuracy using ground truth data. Commonly used water indices, such as NDWI, MNDWI, and AWEI, are derived from spectral reflectance in the green, near-infrared, and shortwave infrared bands (Hemalatha 2021). Enhancements like MNDWI2 were introduced to improve performance (Table 3). Shadows from various sources can affect water body classification, leading to the development of AWEI with criteria for different scenarios (Minyan, Fiachra 2023).

In this study, we selected the NDWI indicator *NDWI* = [(*Green – NIR*) / (*Green + NIR*)] for its superior effectiveness in analyzing water bodies, compared to other indicators better suited for assessing humidity levels and water content in organisms. Custom algorithms outlined in Table 3 were applied to the satellite imagery analysis.

We utilized Google Earth Engine (Google earth engine 2024) to gather over 153 satellite images (Landsat 5, 7, and 8) with varying resolutions, covering the period from 2000 to 2022. Subsequently, we applied the aforementioned indicator equation to these images.

The second phase of this project, primarily reliant on satellite image analysis, aims to determine the volume of water held in the Ain Zada Dam Lake. This task utilizes data from NASA's Shuttle Radar Topography Mission (SRTM), covering the entire study area. To achieve this, additional data sources or algorithms are essential to estimate the height of the water surface for each pixel within the clipped Digital Elevation Model (DEM). This may involve employing thresholding techniques, such as leveraging information from preceding algorithms applied to water identification indicators (NDWI).

This equation effectively represents the process of calculating the volume of water in each pixel by multiplying the area of the pixel by the corresponding depth (Lin et al. 2020) The process involves subtracting the elevation of the lake bottom from the elevation of the water surface, effectively converting height values to depth. This is accomplished by calculating the area of each pixel and then multiplying it by the corresponding depth, resulting in the size of each pixel.

$Ew - Eb = D$, where

D – depth of the water at each pixel
Ew – elevation of the water surface
Eb – elevation of the lake bottom

{ extracted from 3 D Model through SRTM image }

The process can be represented by the equation:

$A \times D = V$, where

A – area of each pixel
D – depth of the water at each pixel
V – volume of water at each pixel

To calculate the change in volume *(ΔV)* of a water body, such as a lake, based on variations in surface elevation and surface area. Let's break down the components and the logic behind this formula:

$$\Delta V = (H_{i+1} - H_i) * 1/3 \left(S_{i+1} + S_i + \sqrt{S_{i+1} * S_i}\right)$$ (Pham-Ducet al. 2022)

$H_{i+1} - H_i$ = this represents the difference in elevation between two consecutive points $i + 1$ and i.

Here, H_i is the elevation at point i and H_{i+1} is the elevation at point $i + 1$.

$1/3 \left(S_{i+1} + S_i + \sqrt{S_{i+1} * S_i}\right)$

This part calculates an average area between the two elevations.

S_i – surface area at elevation H_i.

S_{i+1} – surface area at elevation H_{i+1}

$\sqrt{S_{i+1} * S_i}$ The geometric mean of the surface areas at H_i and H_{i+1}, providing a more accurate average area.

Volume Calculation: The equation essentially computes the volume of a frustum (a truncated pyramid) between two levels of elevation.

Height Difference: The term $(H_{i+1} - H_i)$ represents the height (or thickness) of the frustum.

Average Area: The average surface area of the two levels calculated by taking the arithmetic mean.

$(S_{i+1} + S_i)$ and adding the geometric mean $\sqrt{S_{i+1} * S_i}$, the factor 1/3 ensures the average area calculation is weighted correctly for volume computation.

Applying this equation to the general framework of this paper, we obtain the following equation:

$\Delta 2001\text{–}2018 = (H2018 - H2001) * 1/3\ (S2018 + S2001 + \sqrt{2018 * 2001})$
$\Delta 2018\text{–}2021 = (H2021 - H2018) * 1/3\ (S2021 + S2018 + \sqrt{2021 * 2018})$

Sum the volume changes from the two intervals to get the total change in volume from January 2001 to January 2021:

$\Delta V\ total = \Delta V_{2001\text{–}2018} + \Delta V_{2018\text{–}2021}$

This study focuses on establishing a link between water levels in Lake Ain Zada and prevailing climatic conditions in North Africa, with a specific emphasis on Algeria. Long-term climate data is pivotal for comprehensive analysis and addressing broader climate-related issues. Climatic data spanning from 1981 to 2022 was gathered from five stations across the Bou Sellam basin.

The objective was to examine the relationship between temperature, precipitation, evaporation, and the volume of water in Ain Zada Dam, assessing evidence of climate change impacts on reservoir water levels.

Precipitation Analysis: Data spanning 41 years (1981–2022) from five weather stations within the Bou Sellam watershed was analyzed. This included records of maximum, minimum, and mean annual precipitation. Statistical methods like mean values, standard deviation, and coefficient of variation were employed to analyze precipitation distribution and variability. Trends over time were visualized graphically.

Temperature Analysis: Highest (T_{Max}) and lowest (T_{Min}) temperatures recorded over the same period were examined. Standard deviation and coefficient of variation were calculated to assess temperature variability and trends.

Correlation Analysis: The study investigated the correlation between temperature and evaporation rates using correlation coefficients and R-squared values. This analysis quantified how temperature variations influence evaporation and subsequently affect water storage in the dam.

Therefore, this comprehensive methodology combined statistical analysis of long-term climatic data with advanced remote sensing techniques. It provided a detailed assessment of climatic factors affecting water levels in Ain Zada Lake Dam, offering insights into the broader impacts of climate change on water resources in the region.

4. Results

4.1. Changes in the dam's water volume over 20 years (2001–2021)

We estimated, from satellite imagery, that the water volume of the dam was 10,462,168 m^3 out of 121.400 million m^3 at the first station in January 2001. Which the dam can fill if we calculate the area of the dam's muddy as the height of the water reached about 20.78 meters with an area of about 579 hectares (Fig. 7, 8; Table 4).

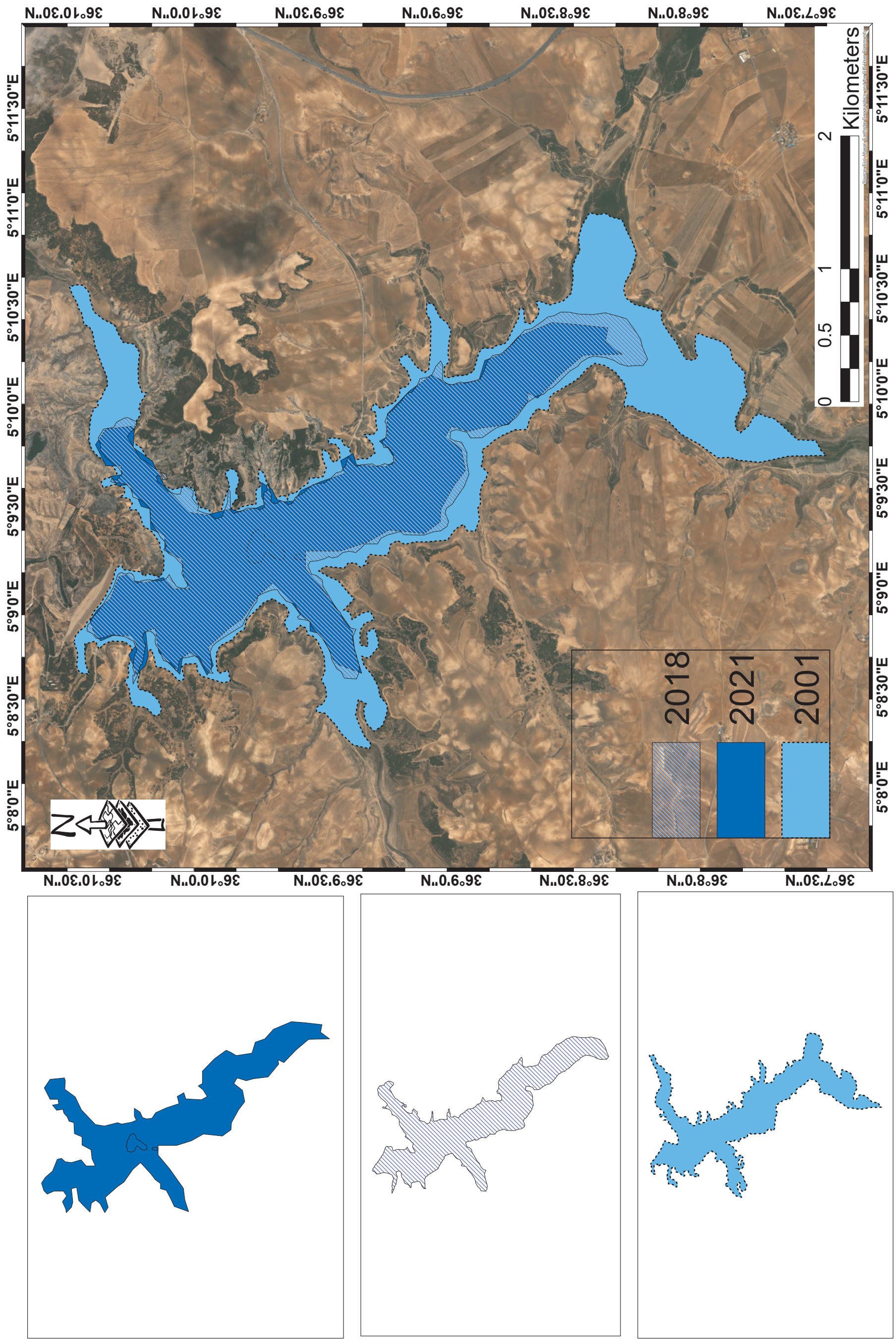
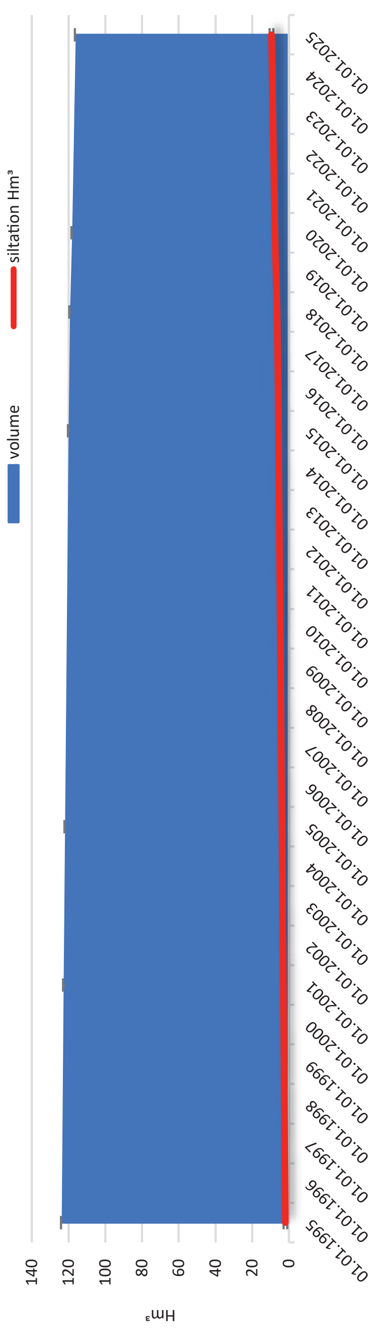


Fig. 7 – Water surface evolution. Source: Treated through satellite image (Landsat 5.8.9 and sentinel A2.



period	01.01.1995	01.01.2001	01.01.2005	01.01.2015	01.01.2018	01.01.2020	01.01.2025
volume	123.106	121.9696	121.212	119.318	118.5604	117.424	115.53
siltation Hm³	1.894	3.0304	3.788	5.682	6.4396	7.576	9.47

Fig. 8 – The evolution of the capacity and siltation in the Ain Zada Dam from 1995 to 2025 (Dahmane 2011, Ain Zada Dam Directorate 2022)

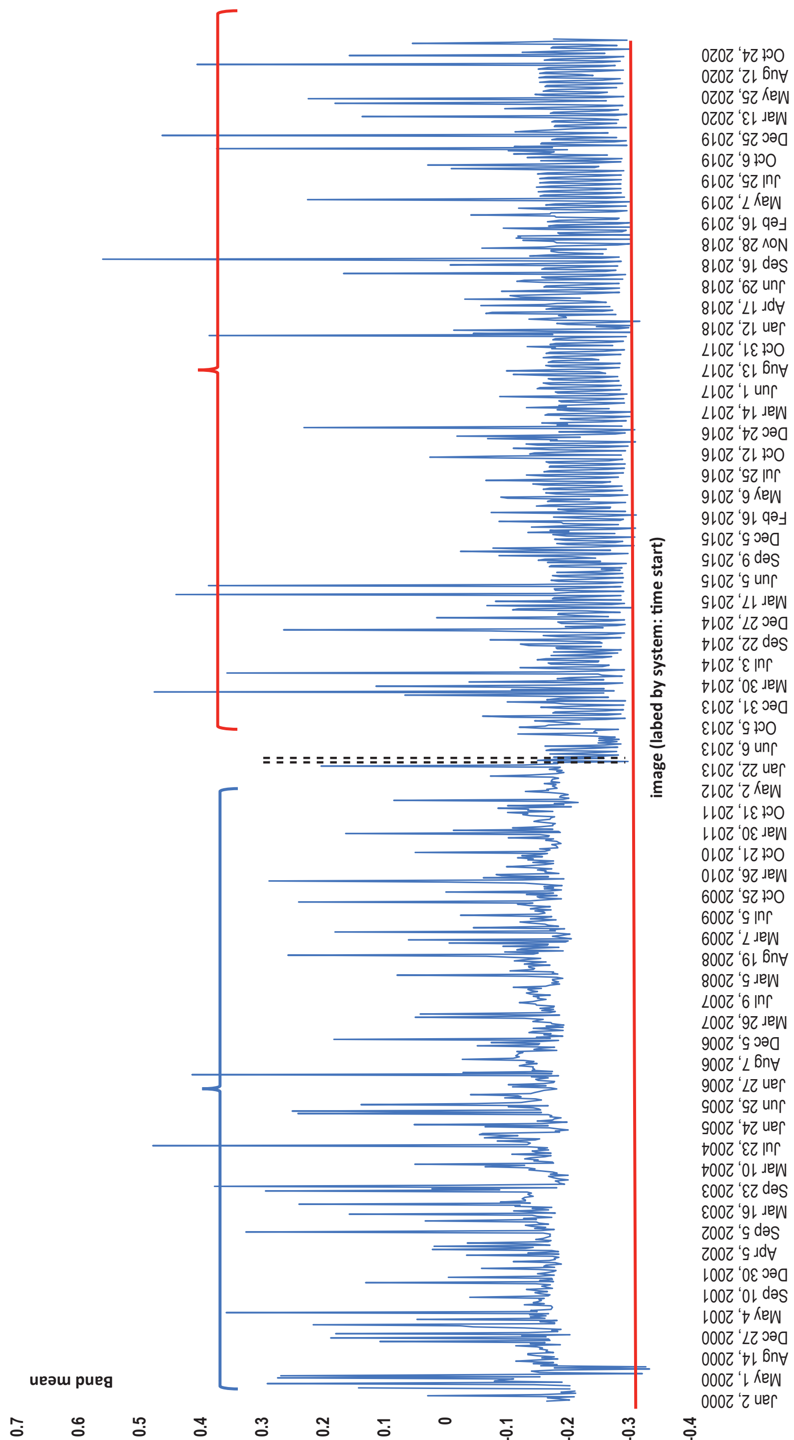


Fig. 9 – NDWI from 2000 to 2020 (personal analysis through 153 Landsat satellite image through GEE environment)

Table 4 – Results satellite image analysis

Years	Raising of the water level (m)	Water level (m)	Area 2D (m²)	Volume 3D (m³)
2001	848.9	20.78	5797313.5881523	10462167.649164
2018	847.3	19.18	3163654.54023	2996124.817937
2021	847.1	19	2830723.800855	2396735.633777

Source: Personal analysis of satellite images Landsat 5.8.9, Sentinel A2, and SRTM

At the second station, January 2018, the water level in the dam decreased to 2,996,125 m³ and the water level to 19 m, with an estimated area of 317 hectares. Water levels continued to drop in January 2021, reaching less than 19 meters and a volume estimated at 2,396,735 m³, covering 283 hectares, or 25% of the dam basin's total area.

In comparison to daily lifting levels managed by the dam management, these satellite measurements were very close, as shown in Table 4.

Regarding the results for the change in volume (ΔV) of the Ain Zada Dam Lake water body, based on the previous equations, we observe the following:

Period 2001–2018: Δ2001–2018 = −4,780,254.99 m³

This negative value indicates a decrease in water level from 2001 to 2019. The large magnitude of this decrease is due to the large difference in areas (S 2001 and S 2019) as well as the relatively long period with climatic fluctuations in the catchment basin of the lake.

Period 2018–2021: Δ2018–2021 = −399,759.89 m³

This negative value indicates a continued decline in water levels from 2019 to 2021. The smaller size, compared to the first period, indicates a less severe decline in this shorter and more recent period.

In a parallel analysis, examining roughly 153 satellite images spanning from 2000 to 2020, as illustrated in Figure 9, indicates corresponding alterations in the Ain Zada Dam lake area. These changes align with previous observations regarding the dam's water levels, offering compelling support for the previously posited hypothesis. This consistency effectively addresses the underlying issue.

Moreover, the graph 03 below portrays the progression of NDWI in the Ain Zada dam region over a 22 years span, from 2000 to 2020. This graphical representation delineates two distinct stages: the initial phase extends from 2000 to the conclusion of 2012, while the subsequent stage spans from 2013 to 2022 (Fig. 9).

During the first stage, the NDWI consistently demonstrates diminished values, commencing at −0.2, particularly evident during the summer months. However, excluding the summer of 2012, these values further decline, plummeting below −0.3. Conversely, the second stage illustrates a consistent decline in NDWI values over time, typically falling below −0.2 and occasionally dipping below −0.3.

Nevertheless, during winter months, NDWI values surge, reaching higher thresholds ranging between 0.4 to 0.5 (Fig. 9).

Therefore, the graph reveals two clear phases, signalling ongoing shifts and fluctuations in the region's climate. Initially, there is an upward trend in the index, followed by a notable downturn in the subsequent phase throughout the year.

4.3. Trend of climate changes on water volume Ain Zada lake dam

4.3.1. Precipitation variable

Understanding the correlation between precipitation and dam storage is crucial for comprehending how climate factors influence water levels in wetlands. The variability in precipitation introduces uncertainties in determining rainfall intensity at a catchment scale, essential for dam design. Changes in precipitation patterns, along with rising surface temperatures, can significantly alter the frequency and intensity of floods and droughts, affecting dam storage (Ehsani et al. 2017).

Stream flow, or the volume of water entering dams, is closely linked to rainfall. A decrease in rainfall can lead to reduced stream flow, thereby diminishing the storage capacity of water reservoirs (Water Corporation 2024). Thus, understanding precipitation patterns and their impact on dam storage is vital for effective water resource management in the context of evolving climate conditions.

The table provided (Table 5) show that the average yearly precipitation over a 41-year period is close to 554 mm. The highest recorded precipitation reaches around 870 mm, whereas the lowest stands at 187 mm.

Table 5 – Precipitation data of Bou Sellam watershed climatic stations

Station name	Record duration (year)	Start of recording	End of recording	Missing value	Max value	Min Value	Mean	Standard deviation	Coefficient of variation
Station 01: 35.9364/5.3238	41	1981	2022	0	822.66	179.3	514.694	130.406	0.2534
Station 02: 36.0908/5.0237	41	1981	2022	0	785.74	184.57	528.98	121.37	0.229
Station 03: 36.3401/5.2702	41	1981	2022	0	822.66	179.3	522.67	105.36	0.202
Station 04: 36.1274/5.5641	41	1981	2022	0	785.74	184.57	518.88	116.95	0.229
Station 05: 36.1685/5.1501	41	1981	2022	0	1,128.52	210.94	684.21	197.33	0.289
Average	41	1981	2022	0	869.064	187.736	553.8868	134.2832	0.24048

Source: Treated from Water Corporation 2024 Data

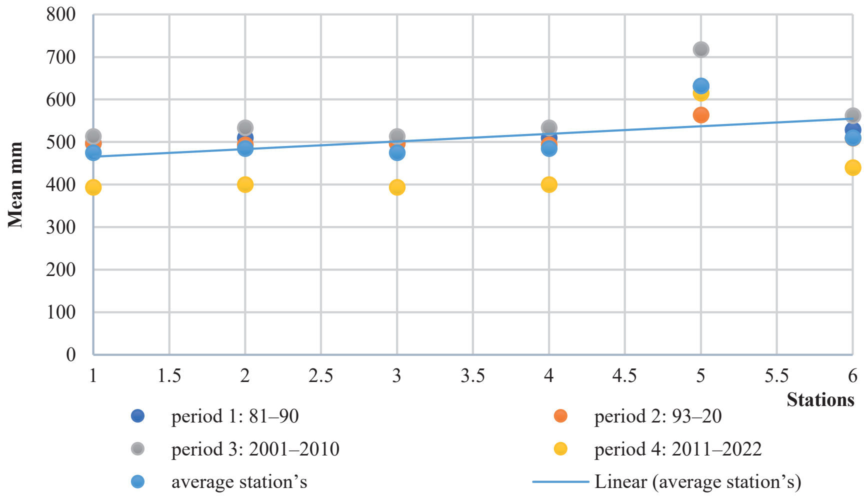


Fig. 10 – Precipitation Average in study area from 1981 to 2022. Personal analysis of data sourced from: NASA Power 2024.

These figures imply variability in precipitation around the Ain Zada Lake area. This variability supported by a standard deviation of 134 and a coefficient of variation of 24 percent.

Overall, we observed minimal variation among different climatic stations, with the exception of station number 05, which situated in close proximity to the lake. At this station, the maximum precipitation recorded was 1,128.52 mm; the minimum was 210.94 mm, with an average of 684.21 mm.

Based on graph (Fig. 10) and the statistical data collected on precipitation from 1981 to 2020 across five climate stations, a notable decrease in precipitation rates observed at each station. Specifically, the period spanning from 1981 to 2010 showed a relative consistency in precipitation, averaging around 500 mm. However, in the subsequent phase from 2011 to 2022, there was a significant decline in precipitation rates, with most climatic stations experiencing levels below 400 mm.

The findings obtained earlier, including the NDWI index, which categorizes climatic periods into two stages: before 2013 and after, are largely accurate. Additionally, measurements of water storage volume derived from satellite images indicate substantial changes. In 2001, the volume was approximately 10,462,167 cubic meters. By 2018, it had decreased to about 2,996,124 cubic meters and further declined to approximately 2,396,735 cubic meters by 2021.The rain forecasts for the Ain Zada Dam basin over a 41-year period validate the conclusions drawn in this research paper. The findings affirm that the region is undergoing significant climate fluctuations, profoundly affecting the reservoir levels of the lake. This situation poses a serious concern for the ecosystem of the entire region (Sahnoune et al. 2013, Chourghal et al. 2016).

4.3.2. Temperature variable

Changes in air temperature caused by climate change can have lasting effects on water storage in dams or lakes by increasing evaporation rates and affecting water availability. Warmer air can hold more water vapour than cooler air, with air at 20 °C (68 °F) able to hold twice the amount of water vapour as air at 10 °C (50 °F) (Environmental Resilience Institute 2024). Higher air temperatures can accelerate evaporation rates from dams or lakes and influence the release of water vapour by plants during transpiration (USGS Water Science School 2024). Understanding these temperature-related mechanisms is crucial for managing water storage and availability in the face of climate change.

The graph (Fig. 11) illustrate depicts noticeable fluctuations in both T_{Max} and T_{Min}, particularly highlighting a significant rise in these temperatures over the last ten years, spanning from 2015 to 2022, where they consistently remained between 39 and 40 °C. In contrast, prior to this period, temperatures were predominantly within the range of 35 to 38 °C, with rare instances approaching 39 °C.

Generally, the data suggests a temperature increase of about 1 °C. From 1981 to 1990, the average T_{Max} was approximately 37.32 °C, and then it decreased slightly to 37.19 °C from 1991 to 2000. Subsequently, there was a modest rise to an average of nearly 37.71 °C from 2001 to 2010. Lastly, between 2011 and 2022, T_{Max} saw a significant rise, with an average temperature of 38.65 °C.

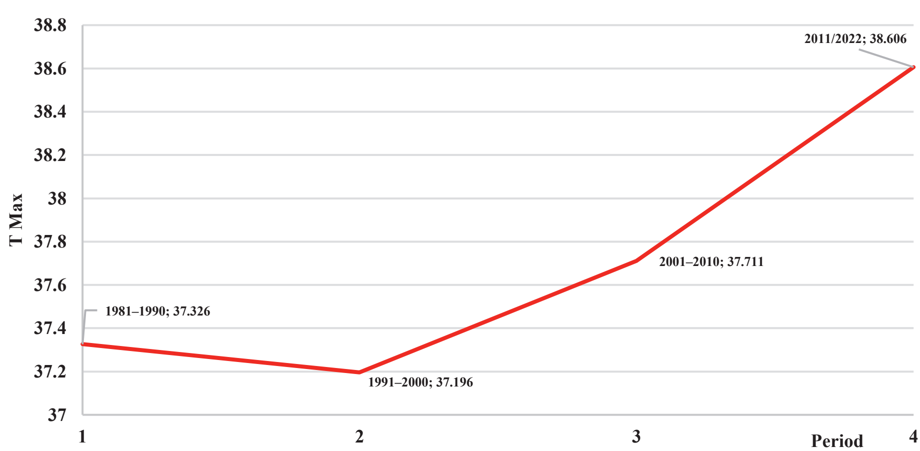


Fig. 11 – T_{Max} temperature Values from 1981-2022. Personal analysis of data sourced from: NASA Power 2024.

Based on to standard deviation (SD), T_{Max} values deviate by roughly 1.58 °C from the mean, while T_{Min} deviates by about 2.01 °C (with a mean deviation of 1.75 °C). As for the Coefficient of Variation, it is 4.04 for T_{Max} and for T_{Min}.

This measure offers a relative assessment of variability, comparing the standard deviation to the mean. A higher coefficient of variation indicates a greater relative variability in both T_{Max} and T_{Min} compared to their respective means.

In the present study, the standard deviation and coefficient of variation for the T values indicate that our region has undergone periods of warmth throughout the study period sample, particularly intensifying from the second phase (1993 to 2000) and further increasing between 2000 and 2020. This trend is continuing to rise, as depicted in the graph. These findings suggest a notable change in temperature values within the region (Fig. 11).

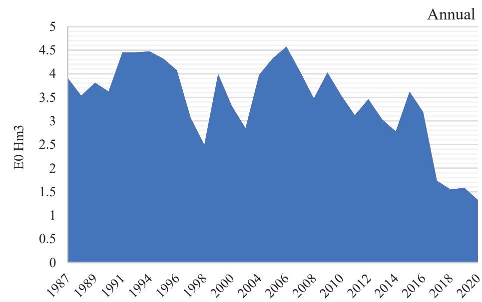
Changes in air temperature caused by climate change can have lasting effects on water storage in dams or lakes by increasing evaporation rates and affecting water availability. Warmer air can hold more water vapor than cooler air, with air at 20 °C (68 °F) able to hold twice the amount of water vapor as air at 10 °C (50 °F; Environmental Resilience Institute 2024). Higher air temperatures can accelerate evaporation rates from dams or lakes and influence the release of water vapor by plants during transpiration (USGS Water Science School 2024).

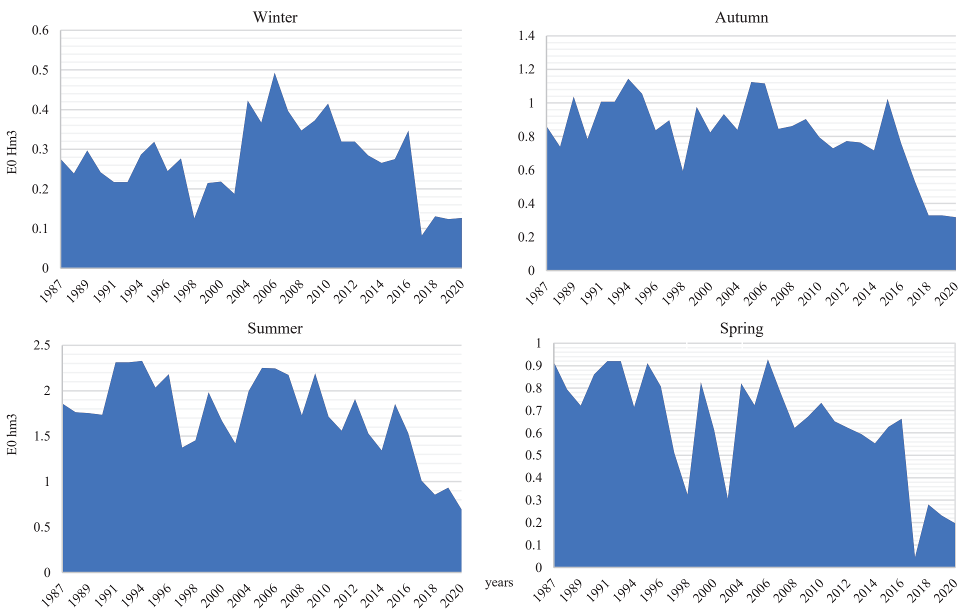
However, the correlation between air temperature and water storage is complex and influenced by various factors, such as precipitation patterns, inflow rates, and dam management practices (Li et al. 2021). Moreover, the specific impacts of climate change on water storage can vary depending on regional factors and local conditions (Degu et al. 2011). In this case study, we collected evaporation data of Ain Zada Dam Lake from 1985 to 2020 and found that the annual, seasonal, and monthly rates show a continuous decrease in humidity around the lake, with clear seasonal differences due to variations in temperature and precipitation. Understanding these interconnected factors is crucial for effective water resource management in the face of climate change (SERC Carleton 2024; Fig. 12).

Although there has been a significant increase in temperature, the Figure 13 indicates a weak connection between the maximum temperature *(T_{Max})* and evaporation *(E_o)* in this region, with a correlation rate of 0.530. The R-Squared value of 0.2126 suggests that only approximately 21.26% of the variation in evaporation can be explained by the independent variable in the regression model.

Another factor that influences the decrease in evaporation *(E_o)* is the ongoing decrease in the size of the Ain Zada Lake dam, as shown in the map. The dam size has decreased from 5,797,313.58 m² in 2001 to 3,163,654.54 m² in 2018 and further down to 2,830,723.80 m² in 2021 (Table 4).

Fig. 12 – Evaporation Average in study area from 1987 to 2022. Personal analysis through Ain Zada Dam Directorate Data 2022.





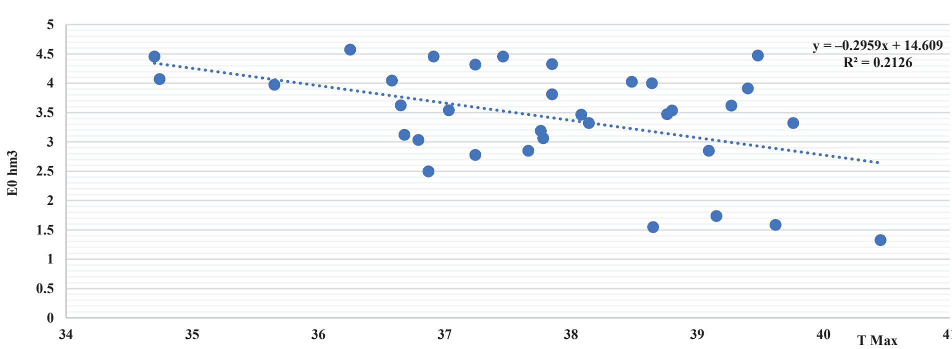


Fig. 13 – Correlation evaporation with T_{Max}. Personal analysis through Ain Zada Dam Directorate Data 2022, analysis NASA Power 2024.

5. Discussion

The study on water storage assessment in artificial wetlands, particularly Ain Zada Dam Lake, offers valuable insights into the impact of climate change on water resources especially in semi-arid regions, the application of remote sensing and GIS techniques, implications for water resources management, and future research directions.

Analysis of satellite imagery and hydrological data using the NDWI index revealed a notable decline in Ain Zadeh Dam Lake's water levels, from approximately 10.5 million cubic meters in 2001 to 2.4 million cubic meters in 2021 driven by regional climate fluctuations and their trends (Sahnoune et al. 2013, Chourghal et al. 2016).These findings are consistent with studies by Rouibah and Belabbas (2022) and corroborate data from the Ain Zada Dam Directorate (2022) and the Algerian Water Management Company for Bordj Bou Arreridj (2022), which highlighted concerns about potable water shortages from the reservoir. Similar studies in semi-arid regions confirm significant fluctuations in lake water levels, supporting the hypothesis that water levels in natural lakes are declining and their ecosystems are being affected (Ekpete et al. 2023)

The findings from this study's climate data analysis confirm significant climate changes that have visibly affected the environment and water levels in wetland areas, strongly validating the hypothesis of climate change. These results demonstrate a clear correlation between climate variations and notable declines in water levels and annual fluctuations. Earlier research supports these conclusions, highlighting a direct link between climate shifts and long-term changes in lake dynamics influenced by hydro-climatic factors (Matoušková, Fraindová 2023; Jiaxian et al. 2023). To assess the impact of these factors on lake dynamics, the study examined trends in climate indicators such as decreasing precipitation from 1981 to 2022 over 41 years, alongside increases in global and local temperatures (Boudiaf, Şen, Boutaghane 2021; Rouibah, Belabbas 2022; Chourghal et al. 2016). Comparative studies in similar semi-arid regions illustrate significant reductions in water levels due to climate change and human activities, underscoring the widespread challenge of water scarcity and emphasizing the urgent necessity for adaptive water management strategies (Wang et al. 2020; Liu, Shen 2018).

The accuracy of this study's results supports the scientific methods employed and the validity of data extracted using remote sensing technology. Analysis of Landsat and Sentinel satellite images, along with GIS tools and Google Earth Engine cloud algorithms, facilitated precise monitoring of changes in Ain Zada Dam Lake water levels. By integrating NDWI, modified water abstraction indicators, and advanced machine learning techniques, the research effectively mapped variations in lake surface area and volume (hydrodynamics) over time. This methodological rigor is consistent with global studies, such as those on Lake Victoria and the Murray-Darling Basin, demonstrating the effectiveness of remote sensing in monitoring water bodies and assessing hydrological changes (George, Ireland, Brian 2015; Leblanc et al. 2012; Li et al. 2021; Lin et al. 2020).

These studies highlight the versatility of remote sensing techniques in providing precise spatial data for informed water resource management. Based on the significant results of this study and considering the economic, environmental, and spatial impacts, there are major implications for water resource management strategies in Algeria's semi-arid regions. Originally designed for agricultural irrigation and drinking water supply, these artificial wetlands now require adaptive strategies to ensure sustainable water use. Lessons from global studies emphasize challenges and innovative solutions for managing water resources amid climate change (García-Ruiz et al. 2015; Tramblay et al. 2020; Matoušková, Fraindová 2023).

One such solution to address increasing water scarcity in Ain Zada Dam Lake is the implementation of water diversion projects, transferring water from northern regions like Bejaia, which is also developing seawater desalination projects to supply inland areas. Future research should focus on improving predictive models that integrate climate forecasts with hydrological data for accurate water availability predictions. Long-term monitoring using advanced satellite technologies will be crucial to maintaining comprehensive datasets for informed decision-making and adaptive management strategies. This approach aligns with ongoing global research on the Great Lakes and the Yangtze River Basin, emphasizing interdisciplinary approaches to address water quality and quantity challenges (Wang et al. 2020, Scavia et al. 2014).

6. Conclusion

The present research aimed to evaluate the water quantity in Ain Zada Lake Dam and its watershed using satellite images from SRTM and multispectral images (151 images Landsat and sentinel). The study assessed water storage in the lake over different periods, specifically 2001, 2019, and 2021. The Normalized Difference Water Index (NDWI 2001–2021) was chosen as an effective indicator for water mass analysis, while NASA's POWER Data Access Viewer project was utilized to analyse the correlation between variables such as temperature, precipitation, evaporation, and water volume at the Ain Zada Dam.

The study's findings indicate a significant decline in the water level of Ain Zada Dam over the past twenty years (from 2001–2019 by −4,780,254.99 m^3 and from 2019 to 2021 about −399,759.89 m^3), primarily due to fluctuations in precipitation and rising temperatures. Notable temperature variations were observed between 2015 and 2022, with an increase of approximately 1 °C. The research also highlights the complex relationship between air temperature and water storage in dams and lakes, noting that rising temperatures can increase evaporation rates, thus influencing water availability and storage.

Based on the research results, it can be confirmed that the decrease in water levels in Ain Zada reservoir is affected by fluctuations in rainfall and the noticeable increase in temperatures. The study indicates that there is a significant relationship between these climatic factors and the decrease in the dam's water level, which indicates their possible impact on water storage.

The decrease in water levels in the Ain Zada Dam Lake is likely linked to climate changes, especially changes in rainfall patterns and rising temperatures. The observed decrease in rainfall in arid areas, as shown in the study results, may have contributed to the decrease in flow to the dam. In addition, rising temperatures, linked to climate change, could intensify evaporation rates, further affecting water storage in the reservoir.

This hypothesis is consistent with the broader understanding of the impact of climate change on water resources, where changes in rainfall and temperature patterns can significantly affect water availability and storage. The results underscore the need to further investigate the specific climate drivers behind the observed decline in dam water levels, as well as to develop adaptation strategies to mitigate potential impacts on water storage in arid regions.

The results of this research are crucial for implementing proactive measures and making informed decisions regarding sustainable water management. Political decision-makers and stakeholders in the region, facing the risk of water scarcity, can utilize these findings to develop strategies for sustainable water management and address the challenges posed by the decline in water levels at Ain Zada Dam. The study's emphasis on the impact of climatic factors on water storage in dams and lakes underscores the importance of considering these variables in water resource management. It highlights the need for proactive measures to address potential risks associated with water scarcity in the region.

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