The Role of Gis in Monitoring the Impact of Climate Fluctuations on The Decline of Surface Water Stored in The Mohamed V Dam on the Moulouya River (Eastern Region)

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Abstract. Water resources are not just a fundamental pillar of territorial development, but also a lifeline for all human economic and social activities. This necessity has led Moroccan officials to consider technical solutions to collect surface water, particularly in arid and semi-arid regions. Consequently, numerous dams have been constructed, forming significant infrastructure for water storage, with over 135 large and medium dams built by 2018. A new project was also initiated in early 2020 to construct more dams, underscoring the critical role of water resources in our daily lives. In recent years, the water reservoirs in arid and semi-arid regions, such as the lower Moulouya basin in northeastern Morocco, have been severely impacted by siltation. This is primarily due to the climatic characteristics of the region, marked by sudden and concentrated rainfall. The resulting water erosion, exacerbated by alternating periods of drought and continuous human pressure, has significantly reduced the storage capacity of the Mohamed V Dam from 730 million cubic meters at its inception to 327 million cubic meters. These observations, made using Geographic Information Systems (GIS), underscore the urgent need to address this issue.

Keywords: Geographic Information Systems, Water Resources, Climate Fluctuations, Mohamed V Dam, Eastern Morocco.

1 Introduction

Water resources play a pivotal role in driving economic and social sectors and are a key focus of Morocco's developmental policies. The country has formulated a robust strategy to sustainably preserve and manage this vital resource. However, these initiatives often need to address various factors that impede their implementation, be it natural elements (such as climate fluctuations across Moroccan regions) or human factors (such as the increasing pressure on water resources).

The Laayoune-Guenfouda corridor, facing the challenge of mobilizing the Mohamed V Dam, urgently requires a clear vision for the rational management of surface water resources. This

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 https://doi.org/10.1051/e3sconf/202560704003

is particularly crucial amidst current climatic conditions characterized by successive droughts since the 1980s and increasing overexploitation.

2 Methodology and Tools

2.1 Study Area Presentation

The study area, a part of the Taza-Oujda corridor, is an arid region with unique natural resources that set it apart from its surroundings. With a relatively low population density compared to the national average and recent human settlement, this area holds great potential for sustainable water resource management (Fig.1).

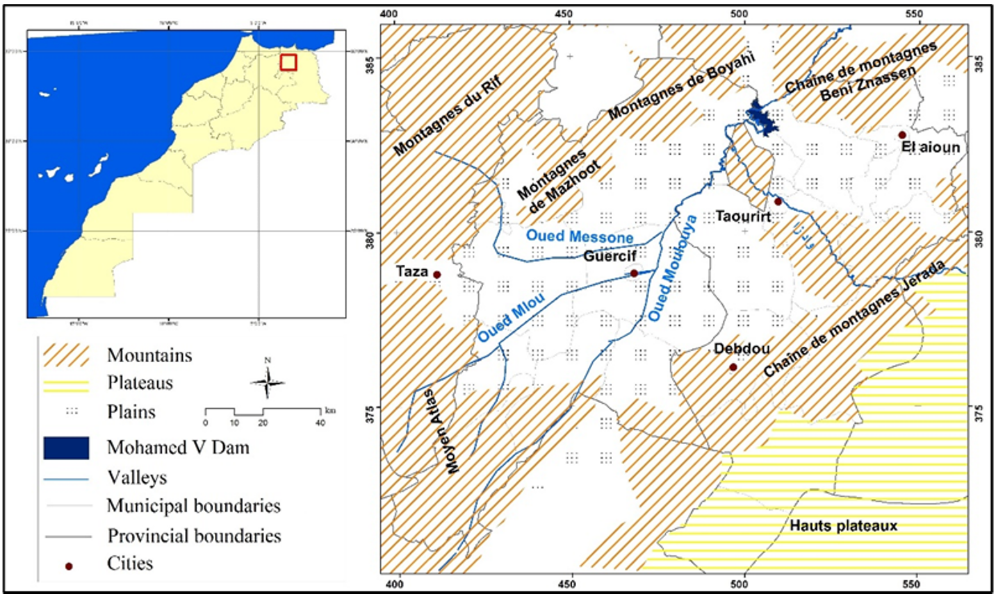

Fig. 1. Delineation of the Study Area

(Source: Administrative Division of 2015 + Topographic Maps 1:50,000)

The strategic location of the Mohamed V Dam, situated upstream of the Mechra Hammadi Dam and 70 km from the mouth of the Moulouya River, underscores its crucial role in regulating the river's flow and controlling flooding. Initially designed to handle a flow rate of approximately 10,000 cubic meters in 15 hours, with a storage capacity of 730 million cubic meters at its inception [1], the dam has since experienced a decline due to various factors, including climate fluctuations and human pressure on water resources in the region**.**

2.2 Statistical Processing

The index, as defined by Nicholson et al [2], $Ii = (Xi—Xm) / \sigma$, is a testament to the meticulous statistical processing methods employed in this research. This index, where Xi represents the rainfall height in mm (or flow rate in m3/s) of year i, Xm is the average rainfall height in mm (or flow rate in m3/s) over the study period, and σ is the standard deviation over the study period, ensures the highest level of accuracy in our analysis.

There are several statistical methods for detecting breaks in time series. These include the non-parametric Pettit test [3], Buishand's statistic, the Bayesian procedure of Lee and Heghinian, and Hubert et al.'s segmentation [4]. Each method has its own advantages and limitations, and the choice of method depends on the specific characteristics of the data being analyzed. In this study, the analysis was conducted using the Khronostat software, which is capable of implementing these methods and providing reliable results.

Our research leaves no stone unturned, as we have utilized a comprehensive set of satellite images from the LANDSAT satellite. These images, spanning from generation 2 for the years 1975 and 1980, generation 5 for the years 1985, 1990, 1995, 2000, 2005, and 2010, generation 8 for the years 2015 and 2020, and generation 9 for the year 2023, provide a detailed and thorough observation of the geographic reduction in the area of the Mohamed V Dam.

3 Results

Climatic studies are essential for understanding surface water characteristics and are critical factors influencing the current dynamics of the area, responsible for the deterioration of local resources [5]. The decline of the Mohamed V Dam significantly impacts the annual water yield of the dam, where stored water fluctuates yearly depending on the rainfall pattern, characterized by irregularity in time and space. This negatively affects the permanent surface water resources (Moulouya River) and stored resources (Mohamed V Dam), leading to a potential water crisis in the region (Fig.2).

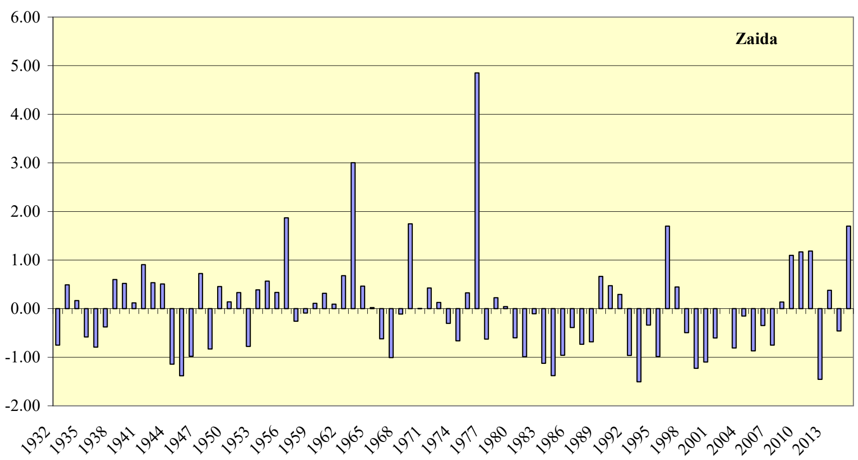

Fig. 2. Annual Evolution of Rainfall by the Reduced Nicholson Rainfall Height Index.

Our research has revealed two distinct periods: dry periods (1944-1948; 1970-1999 and 2010-2020) and wet periods (1920s and 1930s; 1950s-60s-early 1970s and 1990s-2000s). Notably, the Zaida Station (Upper Moulouya) and Ain Beni Mathar Station (Oued Za Basin) exhibit different behaviours, as illustrated in Fig.2. This underscores the need for further investigation into these variations, presenting a promising avenue for future research.

This research methodology is robust, employing rigorous statistical tests such as the Buishand and the Bayesian test by Lee and Heghinian. These tests, which are designed to determine the random or non-random nature of the rainfall series, have confirmed significant breaks in the series, as shown in Table 1. This further validates the robustness of our research and instills confidence in our findings.

Table 1. Detected Breaks in Rainfall Series by the Applied Tests.

Station /Tests	Range	Null Hypothesis Buishand	Null Hypothesis Pettitt	Null Hypothesis Lee and Heghinian	Hubert
Zaida	Accepted at 90-95% and 99%	(no break)	Accepted at 99-95% and 90%	(no break)	Accepted at 99-95% and 90%
Mohamed V Dam	(random chronological series)	Rejected at 99-95% and 90%	Rejected	Rejected; 1985, 2005, 1985; 2008; 2010; 2011; 2013	

The rainfall/discharge connection depicted in Figure 3 illustrates the changes in the hydroclimatic behavior of the Moulouya river, emphasizing the impacts of climate disturbances and human activities such as dams.

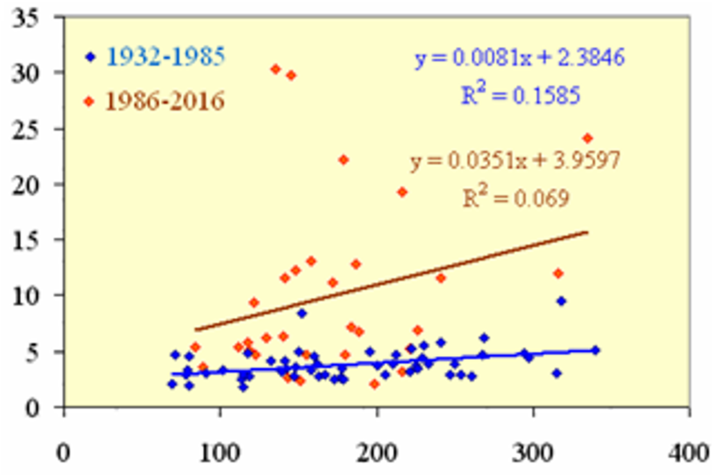

Fig. 1. Rainfall-Discharge Relationships on Mohamed V Dam.

Mohamed V Dam's correlation coefficient was 0.56 before and 0.26 after being filled in 1967. Moreover, contributions from Moulouya's tributaries, smaller rivers that join the main river, and springs, natural water sources, could supplement watercourse inputs and partially mitigate the impacts of water regulation.

The substantial variability in water resources' yield over different years and time periods following the dam's establishment will significantly influence the dam's total reservoir capacity and its fluctuations over time. The decrease in surface water resources is attributed to prolonged and more frequent droughts, intensified erosion processes stemming from soil desiccation and degradation, and diminished vegetation coverage. It is imperative to grasp that these interconnected natural factors, especially soil desiccation and diminished vegetation coverage, facilitate erosion processes during rainy seasons, diminishing the dam's total area between 1972 and 2023 (Fig.4).

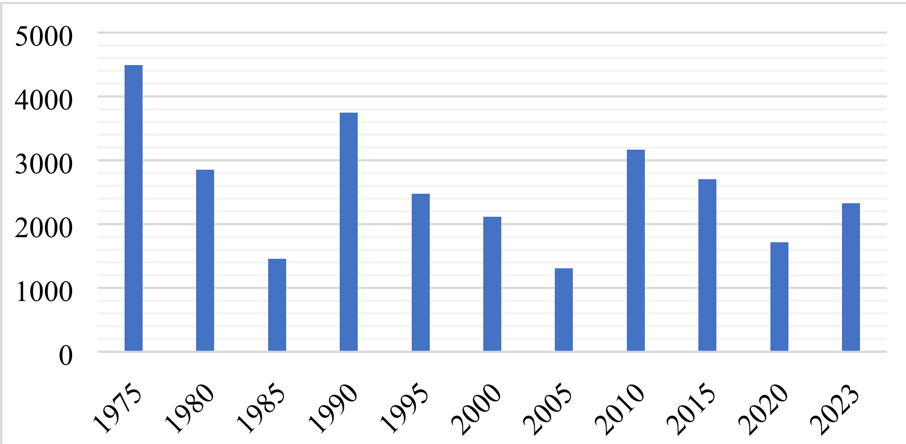

Fig. 1. Evolution of the Mohamed V Dam Reservoir in September between 1972 and 2023.

Figure 4 depicts the dam's evolution during a fixed period, selected based on the region's climatic characteristics, mainly after sudden thunderstorms concentrated at the end of summer and early autumn. A significant reduction of the dam's capacity was observed in 1985 due to a general drought in Morocco, recovering part of its volume in 1990, then shrinking again in 2005. The areas where the dam had receded saw the emergence of small agricultural activities, a testament to the adaptability of the surrounding area to changes in the dam's capacity.

Despite significant rainfall in 2010, the dam could not return to its original size, experiencing further fragmentation in its overall area (Fig.5). This indicates the fluctuations in the area's rainfall and the dam's silting. Importantly, the southwestern shore of the dam has now become permanent agricultural plots, underscoring the lasting changes brought about by the dam's evolution.

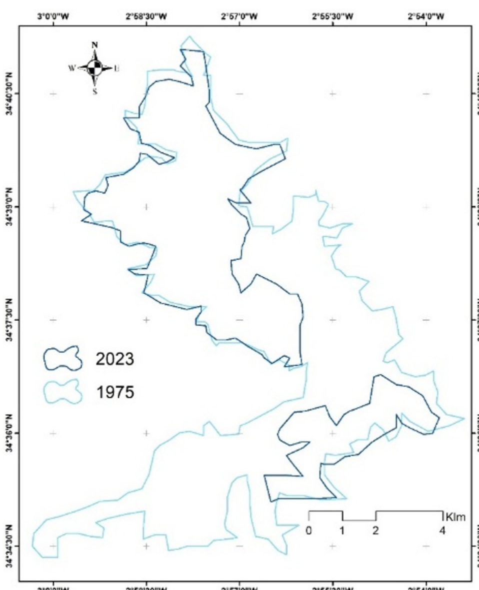

Fig. 1. Comparison of the Mohamed V Dam Area between 1972 and 2023.

Figure 5 depicts the depletion of the Mohamed V Dam's reservoir, with water-covered areas now replaced by sediment from the Moulouya River and its tributaries. Over 23 years, the dam has lost 35% of its capacity to siltation. This reduction is attributed to increased sediment influx from the erosion-prone Laayoune-Guenfouda corridor, notably observed in 2004 when levels dropped to 400 million cubic meters. By 2015, the volume further decreased to 327 million cubic meters from an initial 730 million cubic meters at the dam's establishment [6].

4 Conclusion

Consequently, water resources in the Laayoune-Taourirt corridor are dwindling, necessitating immediate action. The corridor's climate, marked by intense but localized rainfall, hinders efficient water management. Shallow topsoil saturates quickly, limiting water absorption and leading to inconsistent surface runoff, as evidenced by GIS monitoring of the Mohamed V Dam reservoir on the Moulouya River. The corridor faces a negative water balance exacerbated by rising temperatures, high evaporation rates, abundant sunshine, and desert winds.
The analysis of water dynamics at the Mohamed V Dam spotlight not only an impending crisis but also the pressing need for further investigation and solutions. The discrepancy between geographic area and actual water resources requires urgent attention, demanding a thorough examination supported by robust data and on-site research.

Funding
The authors declare that they received no funding for this research and there are no any potential conflicts of interest in this paper.
Author Contribution
All authors reviewed and approved the final manuscript, with Ahmed Amghar contributing to study design, methodology, and the draft manuscript, Abdelkader Sbai providing supervision and reviewing, Omar Mouadili providing interpreting the data.
Ethics approval and consent to participate
Not applicable.
Consent for publication
All authors have agreed to publish this article.
Competing interests
The authors declare that they have no competing interests.
Data Availability Statement
https://eartheexplorer.usgs.gov/. Landsat 5 and Landsat 8 Satellite imagery.
Acknowledgement
The authors express their gratitude to the Laboratory of Dynamics of Arid Environments and Regional Development at Mohammed I University for their invaluable support during this research. We are grateful to the U.S Geological Survey (USGS) Earth Explorer for offering access to Landsat 5 and Landsat 8 Satellite imagery, which played a crucial role in our analysis.

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