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MAPPING AND CHARACTERIZATION OF THE CHEFFIA WATERSHED RESERVOIR LAKE USING REMOTE SENSING DATA (NORTHEAST OF ALGERIA)

Abstract: This research focuses on the use of remote sensing tools and Geographic Information Systems (GIS) with the help of two software programs, ArcGIS 10.6 and ENVI 5.3, to map and analyze the Cheffia Dam Lake using the NDVI index. The methodology is based on the use of satellite images to identify and characterize various land cover classes, such as water, bare soil, and vegetation. The results reveal significant fluctuations in the lake reservoir area over the years, with an expansion observed between 1994 and 2004, followed by a gradual reduction until 2024. This dynamic is mainly explained by climatic factors, such as droughts and variations in precipitation, as well as anthropogenic factors, including increased water demand for human activities and agricultural practices. Monitoring and analyzing surface water in the study area provides crucial information for decision-makers. These data can help optimize water resource management, improve land-use planning, and make informed decisions regarding the use and allocation of water resources. Additionally, these tools allow for anticipating water scarcity risks and developing adaptation strategies aimed at preserving water resource availability in the face of growing environmental and human pressures.

Keywords: water, remote sensing, GIS, Cheffia Dam Lake, Algeria

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Introduction

The efficient and sustainable management of water, a vital resource for humanity, has become a crucial challenge in many countries worldwide, with particular attention given to Algeria (Benblidia, 2011; Bennabi et al., 2012). Algeria has significant water resources, as demonstrated by the presence of dams on its wadis and lakes. However, this potential is subject to geographical and seasonal variations (Touitou et al., 2018). The Cheffia Dam, located within the Oued Bouna Moussa watershed in the northeast of the country in the El Taref wetland, is an illustrative example of Algeria's water resource potential. This dam is one of the main dams in the Wilaya of El Taref and is notable for providing irrigation water for the surrounding agricultural lands. The Cheffia Dam reservoir is a vital source of fresh water for the surrounding region, and proper management is crucial to meeting the growing demand for water. Remote sensing is used to monitor water levels in dams, lakes, and wadis (Trabelsi and Bellaoueur, 2021), detect seasonal variations in water supply, and observe phenomena such as droughts, fires, floods, eco-environmental quality, and erosion (Khallef et al., 2018; Khallef et al., 2022; Chabbi et al., 2023). Data obtained through remote sensing allow governments and organizations to make informed decisions regarding water management, the preservation of aquatic ecosystems, and strengthening the resilience of local communities in the face of climate change challenges (Kramer, 2022).

Recent in-depth studies have demonstrated that the effective application of remote sensing in the mapping and characterization of water reservoirs can provide valuable and detailed data for their optimal and sustainable management (Boumaraf, 2010). Ould Sidi Mohamed (2016) used remote sensing data for a spatiotemporal study of the lakes in the El-Kala region (Northeast Algeria). Hamouda et al. (2012) applied remote sensing to study spatial analysis in monitoring the vegetation cover of the El-Kala National Park (Algeria). Khallef et al. (2021) used Landsat program images to study the dynamics of vegetation cover in the El-Kala National Park. Other research, such as those conducted by Khallef et al. (2023), Namous et al. (2023), Zennir et al. (2023), and Taharchaouche (2023), also utilized the Normalized Difference Vegetation Index (NDVI). This index is widely recognized and frequently used in remote sensing to assess land cover, particularly vegetation cover.

It is derived from reflectance data in the red and near-infrared spectral bands of satellite images. By measuring the photosynthetic activity of plants, the NDVI provides insights into vegetation density and health. It is useful for identifying and mapping various types of vegetation cover, such as forests, crops, grasslands, and arid lands. By comparing NDVI values across different areas, it becomes possible to quantify and characterize variations in vegetation and land cover (Brun, 2004). The use of NDVI allows researchers, environmental specialists, and natural resource managers to monitor changes in land cover over time. It also enables them to assess the effectiveness of agricultural practices, identify areas affected by drought or other environmental stresses, and make informed decisions regarding land and resource management (Cropin, 2021).

NDVI is a key tool for assessing the density and health of forests, monitoring changes in their coverage over time, and identifying areas affected by stress or damage caused by pests, diseases, or other factors. It also helps estimate forest biomass and carbon sequestration potential, playing a crucial role in environmental management and monitoring (Pettorelli et al., 2005). In agriculture, NDVI is a valuable indicator for assessing crop health, identifying nutrient deficiencies, and detecting pest infestations at an early stage. Its use enables farmers to optimize the application of fertilizers and pesticides, thereby minimizing excessive chemical use and reducing environmental impact. When integrated into precision agriculture platforms, NDVI enhances irrigation management and fertilizer distribution, leading to increased crop yields and more sustainable farming practices (Hatfield et al., 2008).

Moreover, NDVI plays a crucial role in environmental monitoring by detecting changes in vegetation cover caused by human activities or natural phenomena, such as deforestation, land use changes, and periods of drought. It also enables the observation of vegetation regeneration after disturbances such as wildfires or floods, providing valuable data for effective land and resource management (Priya et al., 2024).

This study demonstrates the effectiveness of using remote sensing and Geographic Information Systems (GIS) through two software programs, ArcGIS 10.6 and ENVI 5.3, to map and analyze the retention areas of the Cheffia Dam based on the NDVI index. This approach will facilitate optimized water resource management, appropriate land use planning, and strategic decision-making in the Oued Bouna Moussa watershed.

Material and methods

Study area

The Cheffia Dam is located in the municipality of Cheffia, in the El Tarf Wilaya, in northeastern Algeria. The following geographical coordinates bound it: latitude between 36°30'N and 36°46'N and longitude between 7°52'E and 8°12'E.Whereas the Cheffia dam watershed on the Oued Bouna Moussa is located 40 km southeast upstream from the city of Annaba and 42 km southwest of El Tarf. It covers an area of 204 km² and is bounded to the north by the territories of the municipalities of Cheffia and Asfour, to the west by the territories of the municipalities of Asfour, Beni Salah, and Bouchekouf, to the south by the municipalities of Béni Salah and Bouhadjar, and to the east by the territories of the municipalities of Zitouna and Ain Kerma (Figure 1).

The elevation of the Cheffia watershed ranges from 50 m to 983 m, encompassing both mountainous areas and coastal plains. This information is derived from data obtained from a Digital Elevation Model (DEM) of the Shuttle Radar Topography Mission (SRTM) in 2005, with a spatial resolution of 83 meters, and was extracted and analyzed using ArcGIS 10.6 software. The sub-basin's climate is Mediterranean, characterized by relatively warm and dry summers and cold, humid winters during which temperatures sometimes reach 0°C. Average rainfall ranges between 750 and 850 mm, occasionally exceeding 1,000 mm during the rainy season, which spans from November to May However, rainfall data recorded at the Cheffia Dam station indicate significant variations over the years. The annual precipitation for the years 1994, 2004, 2014, and 2024 are 500 mm, 850 mm, 750 mm, and 480 mm, respectively. These fluctuations suggest a notable interannual variability in precipitation in the region, directly influencing the availability of water resources in the watershed. The Cheffia dam watershed has a diverse geology, influenced by its position within the Tellian chain.

This geological diversity plays a key role in the region's hydrological characteristics, soil morphology, and environmental dynamics. This watershed is underlain by formations dating primarily from the Mesozoic and Cenozoic, and the dominant rock types include limestones, sandstones, marls, and clays.

The hydrographic network of the Cheffia dam watershed is a complex and well-structured system that contributes to the hydrological and ecological dynamics of the northeastern region of Algeria, particularly in the Wilaya of El Tarf. The main watercourse is the Oued Bouna Moussa, which originates in the mountainous heights near the Cheffia dam. With a length of 90 km, it traverses mountainous areas, agricultural plains, and wetlands before joining the Oued Mafragh, which flows into the Mediterranean Sea. Several seasonal wadis and streams feed the Oued Bouna Moussa these tributaries generally have a low flow during the summer but become active during periods of heavy rainfall (Bensari, 2024).

The watershed of the Cheffia Dam is characterized by diverse Mediterranean vegetation, including Quercus suber and Quercus canariensis. It also features maquis-type vegetation, such as Quercus coccifera, Arbutus unedo, Pistacia lentiscus, Myrtus communis, Cistus spp, Rosmarinus officinalis, and Thymus spp.Wetland vegetation is present, including Phragmites australis, Juncus spp, Carex spp, and Tamarix spp.Herbaceous and steppe vegetation consists of species such as Poa spp, Bromus spp, Stipa tenacissima, Medicago spp, Trifolium spp, Carduus spp, Onopordum spp, Foeniculum vulgare, Matricaria chamomilla, Mentha spp., Artemisia herba-alba, Aristida pungens, and Euphorbia spp.Additionally, reforested areas in the region include species like Eucalyptus spp., Pinus pinea, and Pinus halepensis (Haou and Bouamrane, 2020).

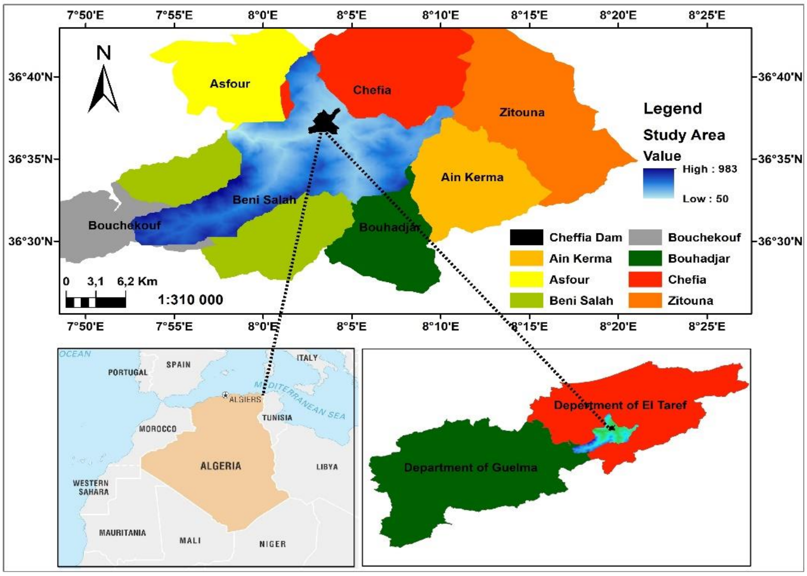

Fig. 1. Location of the Study Area

Method

The methodology is based on the analysis of satellite images for calculating the Normalized Difference Vegetation Index (NDVI) using ArcGIS 10.6 and ENVI 5.3 software at several key dates: 1994, 2004, 2014, and 2024. This index allowed us to identify and characterize various thematic classes, such as water bodies, bare soils, and vegetation cover. The NDVI is widely used for land cover analysis and mapping. It is based on the difference between near infrared and red wavelengths (Rouse et al., 1973; Khallef et al., 2023). The values of this index, ranging from -1 to +1, are obtained using the following equation.

$$NDVI = (NIR - R)/(NIR + R) \tag{1}$$

Where

NIR = near infrared band (Band 5 for Landsat8 and 9, Band 4 for Landsat7 and Landsat 5) (United States Geological Survey, 2024).

R = red band (Band 4 for Landsat 8 and 9, Band 3 for Landsat 7 and 5) (United States Geological Survey, 2024).

NDVI Classification Range

NDVI values are often grouped into specific intervals to interpret land cover and vegetation health. Table 1 presents a widely used classification based on the work of Atun et al. (2020) to determine fire risk in the Mati region, located in the northeast of Athens, Greece. This NDVI classification method is used to interpret land cover and vegetation health (Holben, 1986).

Table 1. NDVI classification range

NDVI range	Classification type
NDVI < 0	Water
0 < NDVI < 0,03	Bare soil
0,03 < NDVI < 0.3	Sparse vegetation
0.3 < NDVI < 0.5	Moderate vegetation
NDV > 0.5	Dense vegetation

(Atun et al., 2020)

Data Collection

To map the reservoir zones of the Cheffia dam using remote sensing (Table 2), various types of data were utilized. First, satellite images from Landsat sensors were collected at different spatial and temporal resolutions (1994, 2004, 2014, and 2024) from the data available on the website http://earthexplorer.usgs.gov. These images form the basis of this study, underwent preprocessing, and were all acquired during the dry season the period when the water surface is most distinctly differentiated from other land cover elements. It is important to note that the images from this Landsat program (Collection 2 Level 1) are geometrically corrected. The spatial resolution of the work is 30 m, and the projection system is UTM Zone 32N. To map and characterize the reservoir of the Cheffia dam lake, two types of software were used: ENVI 5.6 and ArcGIS 10.8.

Table 2. Dates and characteristics of Landsat images used

Satellite	Sensor	Acquisition date	Resolution (m)	Bands used
Landsat 9	OLI/TIRS-2	09/08/2024	30	B5,B4
Landsat 8	OLI/TIRS	22/08/2014	30	B5,B4
Landsat 7	ETM +	02/08/2004	30	B4,B3
Landsat 5	TM	06/08/1994	30	B4,B3

Results

The calculated Normalized Difference Vegetation Index (NDVI) values range between -0.51 and 0.79. Extreme negative values are associated with water bodies, while values close to 0 to 0.03 indicate bare soil. In contrast, positive values above 0.03 signify the presence of vegetation (see Table 3). It is important to note that all NDVI values fall within the standard range of -1 to 1, as stated by Rouse et al. (1974). The table below illustrates NDVI variations over the different years, with the minimum and maximum values corresponding respectively to the periods when NDVI was at its lowest and highest levels.

Table 3. NDVI variations over the years

Year	NDVI			
	Minimum	Maximum	Mean	Standard deviation
1994	-0.2	0.67	0.37	0.15
2004	-0.51	0.75	0.44	0.22
2014	-0.48	0.79	0.47	0.21
2024	-0.51	0.75	0.47	0.9

The surface areas of the Cheffia dam lake were determined for each study period using land use maps generated by calculating the Normalized Difference Vegetation Index (NDVI) for each satellite image. These maps allowed for the identification of water and vegetation zones based on NDVI variations over time (Table 1). The results, presented in Figure 2 and Table 4, were carefully analyzed to observe and quantify the spatio-temporal changes of the lake's surface area. This analysis made ible to evaluate the evolution of the Cheffia dam lake's surface over the years, highlighting the variation trends resulting from both natural and anthropogenic factors.

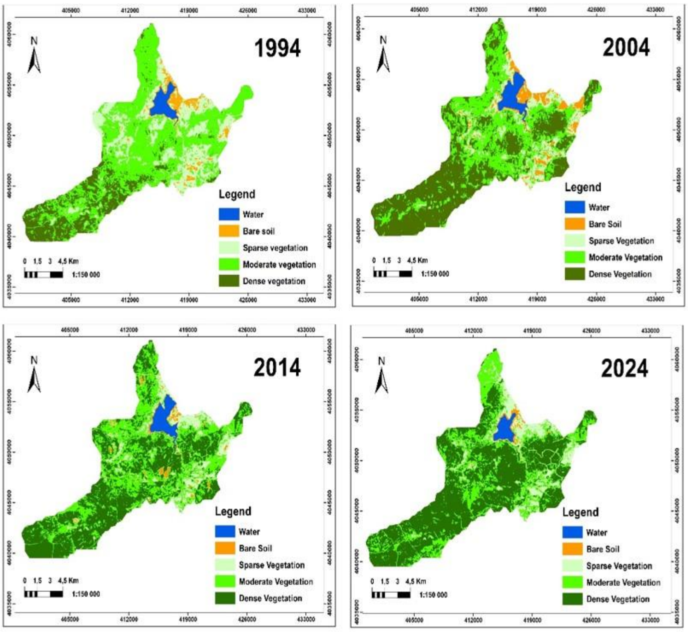

Fig 2. Changes in the surface areas of the different thematic land use classes over the years 1994, 2004, 2014 and 2024

Following the analysis of satellite images and the calculation of the Normalized Difference Vegetation Index (NDVI) over several periods, the results reveal a significant variation in the surface areas of the different thematic classes over the years. This evolution forms the basis for the land use map of the Cheffia dam region.

Table 4. Surface area of different thematic classes between 2004 and 2024

Class	Year			
	1994	2004	2014	2024
	Area (Km²)	Area (Km²)	Area (Km²)	Area (Km²)
Water	6,16	7,40	7,28	4,28
Bare Soil	8,46	11,64	4,70	2,43
Sparse Vegetation	49,27	24,55	23,14	23,44
Moderate Vegetation	104,21	71,22	75,15	57,76
Dense Vegetation	35,81	89,10	93,64	116,00
Total	203,91	203,91	203,91	203,91

Water

The water surface showed a marked increase in 2004, followed by a decline in 2014 and 2024. This trend is primarily explained by a gradual reduction in precipitation, indicating an increased likelihood of prolonged droughts in recent years. According to the hydrological report conducted by the National Agency for Water Resources (NAWR) and the Constantine-Seybouse-Mellegue Basin Agency (BA-CSM), a reduction in the water level of the Cheffia Dam has been confirmed, partially attributed to the decrease in precipitation between 2014 and 2024. Moreover, this trend is reinforced by an ever-growing demand for water, notably for intensive irrigation in the agricultural sector and for domestic uses (Oulmane, 2018). Indeed, irrigation essential for agriculture requires significant amounts of water, which contributes to the depletion of available resources.

Moreover, other economic activities such as intensive agriculture, the expansion of irrigated areas, and the exploitation of construction materials also intensify the pressure on water resources. These findings highlight the effects of climate change on water availability, with rising temperatures, increased evaporation, and reduced precipitation. In the absence of real statistical data, field inspection allows for direct observation of the impacts of human activities on water resources. In the Cheffia watershed, clear signs of deforestation are visible through the reduction of forested areas, which have been replaced by agricultural land or construction zones. Rapid urbanization is evident in the unregulated expansion of infrastructure, leading to increased soil impermeability and a decrease in natural areas capable of retaining water. Moreover, field observations reveal concerning pollution in watercourses, with the presence of plastic waste, wastewater, and agricultural residues, indicating a direct impact on the quality and availability of water resources. These empirical findings confirm the pressure exerted by human activities on the local environment.

The reduction in water surface observed in 2014 and 2024 cannot be attributed to natural variability between the years, as several factors indicate a more pronounced anthropogenic or climatic cause. This therefore raises serious concerns about potential shortages, particularly for the agricultural sector, which heavily depends on a stable water supply to sustain its production. Access to drinking water could also be compromised, directly affecting local populations and posing major challenges for regional water resource management.

Bare soil

Between 1994 and 2024, the area of bare soil decreased significantly, demonstrating the effectiveness of the national reforestation and soil management programs implemented in the region by the General Directorate of Forests. These initiatives aim to restore and strengthen vegetation cover through tree replanting, the rehabilitation of degraded soils, and the promotion of natural regeneration. They play a crucial role in preserving local ecosystems by reducing soil erosion, enhancing water retention, and creating a favorable environment for biodiversity development. Reforestation plays a key role in stabilizing soils, reducing the risks of erosion caused by wind and rainfall, while also improving the soil's water retention capacity (FAO, 2025). Moreover, dense vegetation enriches the soil with organic matter, which is essential for its regeneration and the improvement of long-term fertility.

Soil management efforts also include practices such as planting hedges, establishing terraced cultivation, and maintaining permanent vegetation cover. These techniques are designed to reduce erosion, limit nutrient leaching, and enhance soil structure. They also promote biodiversity by creating habitats for various local animal and plant species (Pimentel et al., 2013). Despite these advances, the region remains vulnerable to prolonged droughts and intensive agricultural practices, which can compromise the gains achieved. It is therefore crucial to continue adopting sustainable strategies to preserve these achievements and reduce future risks of soil degradation and biodiversity loss (Khallef et al., 2018).

Sparse and moderate vegetation

The sparse vegetation class is characterized by a low and often-discontinuous vegetation cover, dominated by a temporary herbaceous layer with species adapted to climatic conditions, as well as scattered shrubs such as *Juniperus phoenicea* and *Pistacia lentiscus*. The moderate vegetation class corresponds to areas where the vegetation cover is more significant but not dense enough to be considered a closed forest. Moderate vegetation consists of a mix of trees, shrubs, and herbaceous plants, including *Myrtus communis*, *Cistus spp.*, *Erica arborea*, and *Typha spp.* The sparse vegetation category encompasses areas with light or scattered vegetation cover. Between 1994 and 2024, a significant reduction in area was observed, decreasing from 49.27 km² in 1994 to 23.44 km² in 2024. This decline may be linked to fluctuations resulting from anthropogenic or climatic pressures.

However, the moderately dense vegetation class exhibits an interesting dynamic over the years. Between 1994 and 2024, a decrease in the area of moderately dense vegetation was observed, which can be explained by the expansion of human activities, such as agricultural extension, particularly through the clearing of moderately dense vegetation. Moreover, this vegetation category shows a more varied evolution over time. Between 1994 and 2024, a notable decline in its area was recorded, mainly due to the intensification of human activities. The expansion of agricultural land, overgrazing, and logging for fuelwood or construction have led to a depletion of vegetation cover and degradation of ecosystems.

Dense vegetation

The area of dense vegetation has significantly increased between 1994 and 2024, reflecting a notable improvement in the management and conservation of forest ecosystems. This progression can be attributed to a combination of environmental, human, and policy factors that have contributed to the improvement of vegetation cover and the restoration of forest ecosystems.

Discussion

The study of the Cheffia dam reservoir, conducted using the NDVI derived from Landsat images over several decades, provides an in-depth analysis of the spatio-temporal evolution of the various land use classes in the region. Several essential aspects emerge from this investigation.

Water Surface Dynamics

The results show an expansion of the water surface, increasing from 6.16 km² in 1994 to 7.40 km² in 2004, before experiencing a gradual decline to 7.28 km² in 2014 and 4.28 km² in 2024. This evolution reflects the interplay between climatic factors such as reduced precipitation and drought episodes and human activities, notably the rising demand for water for irrigation and other uses (Boursali et al., 2025). The recent decrease in water surface is particularly concerning in the context of climate change, where heightened variability in rainfall patterns intensifies pressure on the watershed.

Evolution of Bare Soil and Vegetation Cover

The significant reduction in bare soil area, decreasing from 8.46 km² in 1994 to only 2.43 km² in 2024, illustrates the effectiveness of the reforestation and soil management programs implemented in the region. This change is accompanied by a notable improvement in vegetation cover, particularly in dense vegetation, which increased from 35.81 km² in 1994 to 116.00 km² in 2024. This increase in dense vegetation reflects the positive effects of conservation initiatives, forest ecosystem restoration, and the adoption of sustainable agricultural practices.

Variation between different types of vegetation

Although the area of sparse vegetation has significantly decreased, the moderately dense vegetation category shows a more nuanced dynamic, marked by a decline between 1994 and 2024. These fluctuations likely reflect the interaction between anthropogenic pressures (intensive agriculture, resource exploitation) and reforestation and environmental restoration initiatives, thus highlighting the need to adapt management strategies to the observed changes.

Implications for Resource Management and Land Use Planning

The results of this study clearly illustrate the impact of climate change and human activities on the Cheffia dam watershed. The reduction in water surface area, coupled with changes in vegetation cover, poses significant challenges in terms of water resource management and the preservation of local ecosystems. These findings are essential for developing adaptation and conservation strategies, including strengthening reforestation programs, adopting sustainable agricultural practices, and implementing integrated water management policies.

Conclusion

Remote sensing and Geographic Information Systems (GIS) tools provide crucial information for the effective management of water resources in the study area, located in the Cheffia dam sub-watershed in the extreme northeast of Algeria. By utilizing the Normalized Difference Vegetation Index (NDVI) derived from satellite images covering the period from

1994 to 2024, it was possible to accurately map the areas of the Cheffia dam lake reservoir. This analysis has highlighted significant changes in the various thematic classes that make up the land use maps around the dam.

The results notably reveal substantial changes in the distribution of land use classes, including vegetation areas, water surfaces, and bare soils. These transformations can be attributed to several factors, such as climatic variations, the expansion of agricultural activities, fluctuations in the dam's water level, and increasing anthropogenic pressures.

The data produced thus provide a solid foundation for decision-makers, enabling them to plan water resource conservation actions, designate priority areas for reforestation or soil improvement, and develop sustainable land use planning policies. Integrated management of water and soil resources thus becomes even more essential.

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