Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2023, Volume 14, Issue 9, Page 1162-1170

http://www.jmaterenvironsci.com

Mapping and characterization of the Bin El-Ouidane Dam lake reservoir by remote sensing using NDVI (Central High Atlas, Morocco)

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Received *31 July 2023,*
Revised *21 Sept 2023,*
Accepted *25 Sept 2023*

Citation*: Layati E., Karoual M., Hamid M., El Ghachi M. (2023) Mapping and characterization of the Bin El-Ouidane Dam lake reservoir by remote sensing using NDVI (Central High Atlas, Morocco), J. Mater. Environ. Sci., 14(9), 1162-1170*

Abstract: The present research discusses the utilization of remote sensing and GIS tools to map and characterize the Bin El-Ouidane dam lake (located in the High Central Atlas, Morocco) using the NDVI index. The methodology involves the use of satellite images to extract information on various thematic classes such as water, bare soil, and vegetation. The results indicate a fluctuation in the area of the reservoir over the years, with an increase from 2002 to 2013 followed by a decrease until 2021. This variation is primarily attributed to climatic and anthropogenic factors. The monitoring and characterization of surface water in our study area can aid officials in the effective management of water resources, land-use planning, and decision-making regarding the use and allocation of water.

Keywords: *GIS, remote sensing, NDVI, Bin El-Ouidane dam lake*

1. Introduction

Water is a vital resource for humanity, but its effective management has become a major challenge in many countries, including Morocco. The Bin El-Ouidane Dam is one of the major dams in Morocco, constructed in 1953 to provide water for irrigation and agricultural land in the Beni Mellal-Khenifra region (Ouakhir et *al.*, 2018; Qadem et *al.*, 2019; Layati et *al.*, 2021a). The impoundment of the Bin El-Ouidane Dam lake is a critical source of freshwater for the surrounding area, and its effective management is essential to meet the increasing demand for water.

Remote sensing is a method used to monitor water levels in dams, lakes, and rivers, detect seasonal fluctuations in water availability, and track events such as droughts and floods (Kramer 2022; Sogno et *al.*, 2022). Remote sensing data can assist governments and organizations in making informed decisions regarding water management, safeguarding aquatic ecosystems, and strengthening the resilience of local communities against climate change.

Recent studies have shown that using remote sensing to map and characterize water reservoirs can provide valuable information for their management. For example, Arid et al. (2022) used spatial remote sensing and GIS for the integrated management of aquaculture potential. Layati et al. (2021a) used remote sensing data to map land use in the Oued El-Abid watershed. El Orfi et al. (2020) used remote sensing to study the spatio-temporal evolution of the Ahmed El Hansali dam water reservoir between 2002 and 2018.

Other studies, such as those carried out by Zaitunah et *al*., (2018); Singh et *al*., (2020); Aburas et *al*., (2015) and Aryastana et *al*., (2022), have also used the Normalized Difference Vegetation Index (NDVI) index. This index is a valuable and commonly used indicator in remote sensing to assess land cover, particularly with regard to vegetation. It is calculated from reflectance data in the red and near-infrared spectral bands of satellite imagery.
NDVI measures the photosynthetic activity of plants and provides information on vegetation density and health. It can be used to identify and map different types of vegetation cover, such as forests, crops, grasslands and dry lands. By comparing NDVI values in different areas, it is possible to quantify and characterize variations in vegetation and land cover (Martín-Sotoca et *al.*, 2019; Spadoni et *al.*, 2020).
Using NDVI, researchers, environmental professionals and natural resource managers can monitor changes in land cover over time, assess the effectiveness of agricultural practices, detect areas affected by drought or other environmental stresses, and make informed decisions about land and resource management.
This study showcases how the utilization of remote sensing and GIS tools can be beneficial in mapping and characterizing the areas of the Bin El-Ouidane Dam Lake impoundment using NDVI index. This approach will facilitate effective water resource management, land-use planning, and strategic decision-making in the Oued El-Abid watershed.

2. Material and methods

2.1 Geographical context of the study area

The study area is located in the region of Beni Mellal-Khénifra, Morocco, and more precisely in the Oued El-Abid watershed (**Figure 1**). This area is characterized by a semi-arid to arid climate, with mean annual precipitation ranging from 109 to 1020 mm in the upstream part of the watershed (Tizi Nisli station) and from 198 to 698 mm in the middle of the watershed (Ait Ouchene station). The topography of the area is essentially mountainous, with altitudes varying between 776 and 3671 meters (Layati and El Ghachi, 2021b). Bin El-Ouidane is one of the most important dams in the region, with a capacity of 1.2 billion cubic meters. This area is also marked by the presence of various socio-economic activities such as agriculture, livestock and tourism, which depend heavily on water resources. Therefore, the study of this area is importance for the management and planning of water resources in the region.

2.2 Methodology adopted

In this study, the methodology adopted was based on the use of satellite images to calculate the normalized difference vegetation index (NDVI) for different dates, namely 2002, 2007, 2013, 2017 and 2021. Using this index, it was possible to extract information on the different thematic classes, including water, bare soil and vegetation.
The Normalized Difference Vegetation Index (NDVI) is the most commonly used for mapping and land cover, it is defined as the difference between the near infrared and red bands (Rouse et *al*., 1973; Shrahily et *al*., 2022). The values of this index vary between -1 and +1 and can be calculated from the following equation (Eqn. 1):

Eqn. 1 $$NDVI = \frac{PIR-R}{PIR+R}$$

Where: PIR = near infrared band and R = red band
The table 1 below shows the NDVI classification intervals (Akbar et *al*., 2019).

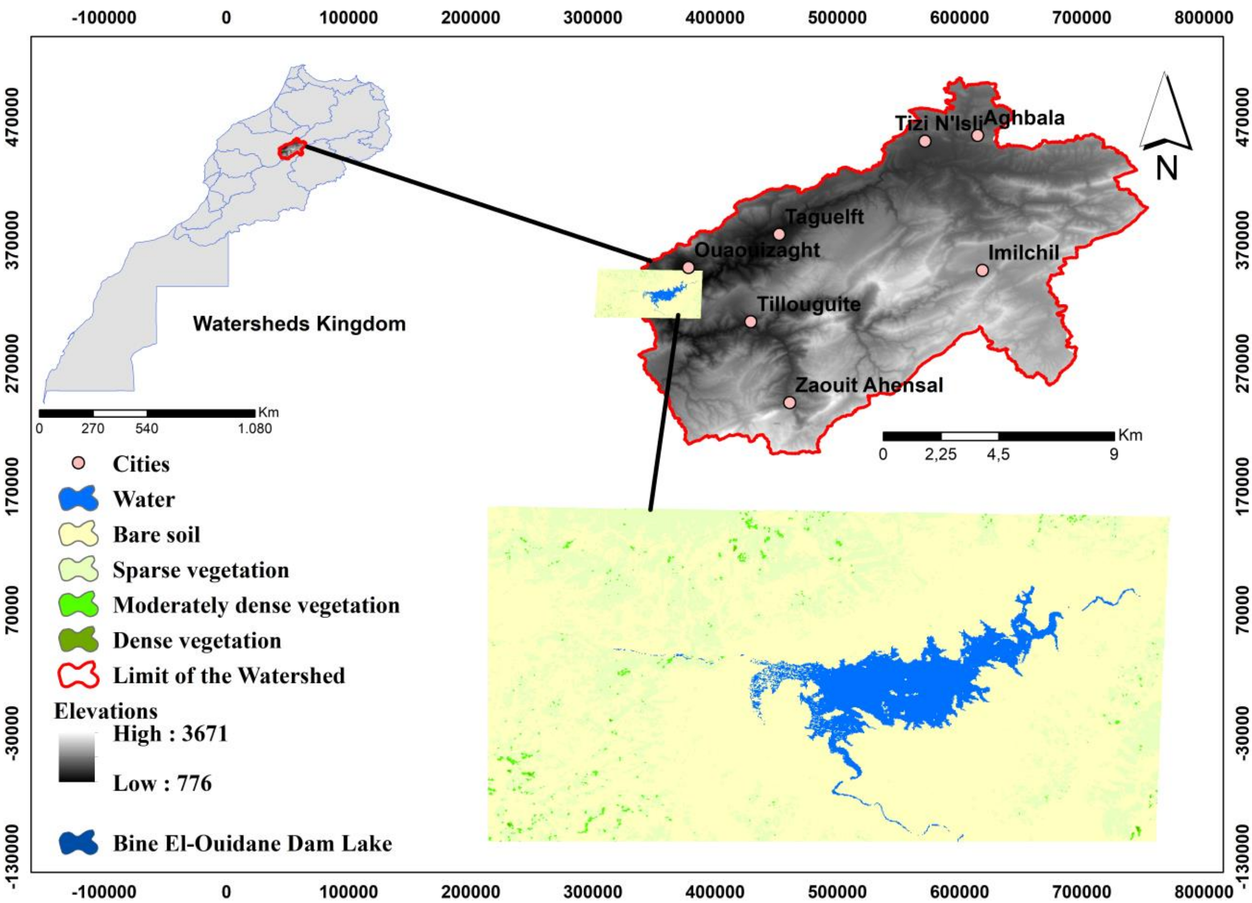

Figure 1: Location of the study area

Table 1. NDVI classification intervals

NDVI values	Classification
NDVI < 0.015	Water
0.015 < NDVI < 0.14	Bare soil
0.14 < NDVI < 0.26	Sparse vegetation
0.26 < NDVI <0.36	Moderately dense vegetation
NDVI > 0.36	Dense vegetation

2.2 Data used

For mapping the areas of the bin El-Ouidane dam lake reservoir by remote sensing (**Table 2**), several types of data were used. First, satellite images were acquired from Landsat sensors at different spatial and temporal resolutions (2002, 2007, 2013, 2017 and 2021) using data the website (http://earthexplorer.usgs.gov).

Table 2. Characterized dates of selected LANDSAT images

	Satellites	Date of acquisition
Bin El- Ouidane Dam	LANDSAT_5 (TM)	2002-05-16
	LANDSAT_7(ETM)	2007-04-04
	LANDSAT_8 (OLI)	2013-05-30
	LANDSAT_8 (OLI)	2017-04-07
	LANDSAT_8 (OLI)	2021-05-20

These images were used to visualize and analyze the dynamics of the lake impoundment of this dam, as well as to identify vegetation and water surface areas. The hydrological data (annual contributions in Mm³ to the Bin El-Ouidane Dam) used in this work were provided by the Oum Er-Rbia Hydraulic Basin Agency (ABHOER) to correlate with the results from remote sensing.

3. Results and Discussion

Calculated values of the normalized difference vegetation index (NDVI) range from -0.21 to 0.58. Extreme negative values correspond to water, values close to zero represent soil, and positive values greater than 0.14 indicate the presence of vegetation formations (**Table 3**). It is important to note that all NDVI values fall within the standard interval of -1 to 1, consistent with the cited reference (Mohajane, 2018). The table below illustrates the variations in NDVI over the different years. The minimum and maximum values correspond to the periods when the NDVI index was at its lowest and highest, respectively.

Table 3. NDVI variations over the years

	NDVI	
Years	Minimum	Maximum
2002	-0,11	0,43
2007	-0,12	0,36
2013	-0,21	0,58
2017	-0,21	0,57
2021	-0,16	0,52

The areas of the Bin El-Ouidane dam lake were calculated for each date from the land use maps obtained through the calculation of the NDVI index (**Table 1**). The results obtained (**Figure 2** & **Table 4**) were analyzed to evaluate the spatiotemporal evolution of the surface of the Bin El-Ouidane Dam Lake over the years studied.

Table 4: Areas occupied by thematic classes between 2002 and 2021

Bin El- Ouidane Dam					
Years	**2002**	**2007**	**2013**	**2017**	**2021**
			Areas		
Classes	Km^2	Km^2	Km^2	Km^2	Km^2
Water	19.05	22.98	36.28	24.33	20.29
Bare soil	230.52	216.10	106.97	77.87	133.74
Sparse vegetation	63.16	73.31	144.73	161.04	120.46
Moderately dense vegetation	2.07	0.50	71.74	47.34	39.29
Dense vegetation	0.06	0.00	8.35	4.30	1.12

Following analysis of satellite images and calculation of the normalized difference vegetation index (NDVI) for different periods, the results show a significant change in the surface area of the various thematic classes over the years. This evolution forms the basis of the land use map of the Bin El-Ouidane dam area.

- **Water:**

The water area recorded a significant increase in 2013, followed by a decrease in 2017 and 2021. This variation can be attributed to the decline in precipitation, reflecting the probation of drought periods in recent years (Qadem et *al*., 2019; Layati et *al*., 2021a). In addition, this trend can also be attributed to the growing demand for water, particularly for economic activities such as irrigation. This observation is in line with the conclusions of several studies on the effects of climate change on water availability and the impact of human activities on water resources (Bouchaou et *al*., 2011; Bennouna, 2020). The decrease in water surface area in 2017 and 2021 raises concerns about possible water shortages for the region's agricultural, industrial and domestic sectors.

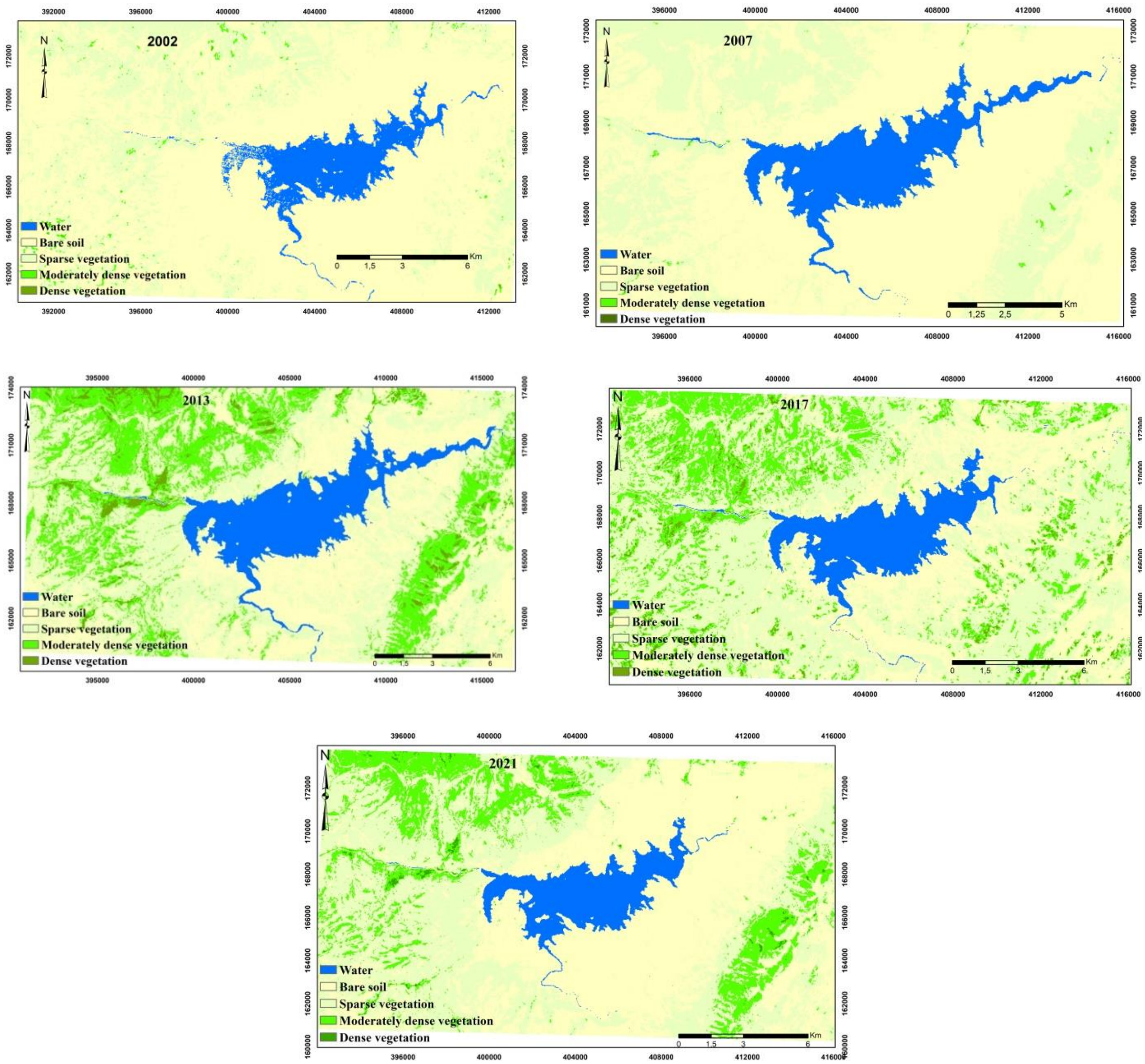

Figure 2. Evolution of the areas of the land use thematic classes for the years 2002, 2007, 2013, 2017 & 2021

- **Bare soil:**

The area of bare soil showed a significant reduction between 2002 and 2017, followed by an increase in 2021. This fluctuation can be attributed to the implementation of reforestation and soil management programs in the region. These initiatives to improve vegetation cover and soil health are of crucial importance, as a soil devoid of vegetation can induce soil degradation, erosion and loss of biodiversity (Roose et *al*., 2010). The increase in bare soil by 2021 may also be influenced by various other factors, such as agricultural practices and human activities. Research has shown that agricultural intensification can contribute to soil degradation and reduced vegetation cover (Sallak et *al*., 2019; Alzamil et *al*., 2019; Shrahily et *al*., 2022).

- **Sparse vegetation:**

The "Low Dense Vegetation" category encompasses areas with light or scattered vegetation cover. Between 2002 and 2017, there was a significant increase in area, from 63.16 km² to 161.04 km². This expansion may be associated with factors such as reforestation initiatives, the natural regeneration of ecosystems or changes in agricultural practices. However, a reduction in area is observed in 2021 (120.46 km²), suggesting fluctuations in anthropogenic or climatic pressures (Yengoh et *al*., 2011).

- **Moderately dense vegetation:**

The "Moderately dense vegetation" class shows an interesting dynamic over the years. Between 2002 and 2013, there was a significant increase in the area of this class, potentially indicating an improvement in vegetation cover and a growth in medium-dense vegetation ecosystems. This trend can be attributed to factors such as reforestation programs, sustainable agricultural practices or conservation interventions (Laouina 2006; Hili et *al*., 2022).

However, as of 2017, there has been a decrease in the area of medium-dense vegetation. This decrease could be due to factors such as an expansion of human activities like agriculture or urbanization (Hili et *al*., 2022). The effects of climate change, such as extreme weather events, vegetation fires, and prolonged droughts or periods of intense heat, could also have contributed to this decline. These factors could have affected the health and growth of moderately dense vegetation ecosystems.

- **Dense vegetation:**

As for dense vegetation, its area also increased between 2002 and 2013, before decreasing significantly in 2017 and 2021. Researchers have identified several factors responsible for forest degradation, including demographic pressure, anthropogenic disturbances, climatic anomalies, increased fires and crop expansion (FAO 2006; Bouzekraoui et *al*., 2016; Velasco et *al*., 2020). The decrease in the area of dense vegetation may be cause for concern, as forests play a crucial role in preserving biodiversity and regulating the water cycle. The results of this research concur with the findings of previous research on the importance of forests in conserving water resources, protecting biodiversity and reducing the impacts of climate change (Cortez et *al*., 2009; ONF 2017; Kengoum, et *al*., 2013; Jerneck et *al*., 2013; Joseph 2022). It is important to continue conservation and reforestation efforts to preserve and restore these essential ecosystems.

Figure 3 shows the evolution of Bin El-Ouidane dam area and annual water inflow. The Pearson correlation coefficient was calculated, the value is 0.6 indicating a moderate positive correlation. This variation between the two parameters can vary depending on different factors: The low and irregular rainfall and the increase in the needs of the population in different uses. These results were confirmed by Qadem *et al*., (2019) in his study.

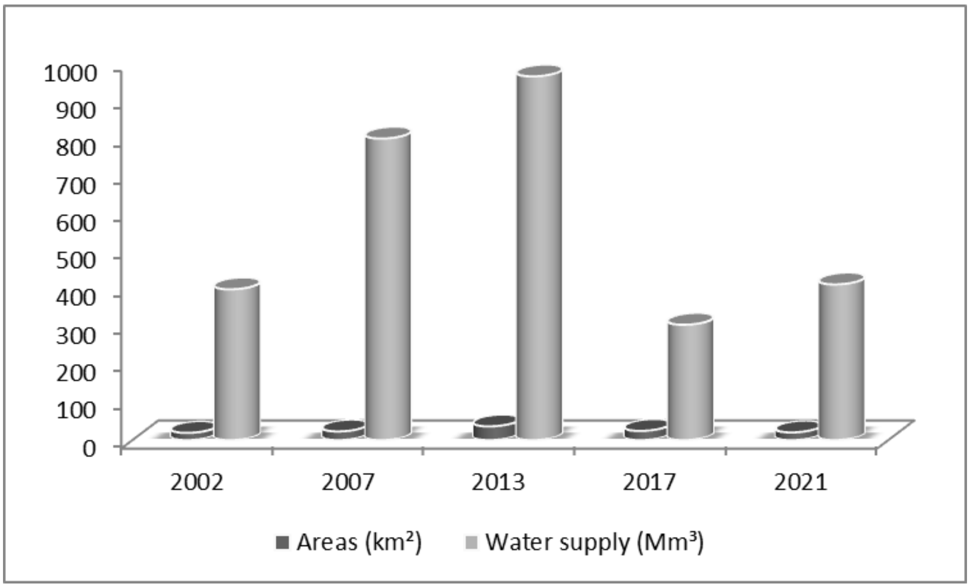

Figure 3. Evolution of the surface area of the Bin El-Ouidane dam (km^2) and the annual water inflow (Mm^3)

Conclusion

Remote sensing and GIS tools can provide valuable information for water resources management in the study area, located within the Oued El-Abid watershed in Morocco. Indeed, the use of the NDVI index, from satellite images, allowed to map and characterize the areas of the Bin El-Ouidane dam lake reservoir between 2002 and 2021, and thus to highlight the significant evolutions of the different thematic classes, constituting the land use maps of the Bin El-Ouidane dam area, have known. The results obtained can constitute a reliable database allowing decision makers to make informed decisions for water resources management and land use planning.

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