# MAPPING THE SPATIO-TEMPORAL DYNAMICS OF SURFACE WATER EXTENT IN THE GREAT SEBKHA OF ORAN IN NORTHWESTERN ALGERIA USING REMOTE SENSING TECHNIQUES

**Nezha Farhi, Yamina Benkesmia, Moulay Idriss Hassani, Sarah Kreri**

Nezha Farhi
Computer science engineer;
Department of Earth Observation,
Center of Space techniques, 31200, Arzew, Oran, Algeria
nfarhi@cts.asal.dz,

Yamina Benkesmia
Hydrogeologist;
Department of Earth Observation,
Center of Space techniques, 31200, Arzew, Oran, Algeria
Department of Geology,
University of Oran 2 Mohamed Ben Ahmed, "Georen Laboratory: Géoressources, Environnement & Risques Naturels", B.P. 1015 El M'naouer, 31000, Oran, Algeria;
yaminabenkesmia@gmail.com

Moulay Idriss Hassani
Hydrogeologist;
Department of Geology,
University of Oran 2 Mohamed Ben Ahmed, "Georen Laboratory: Géoressources, Environnement & Risques Naturels", B.P. 1015 El M'naouer, 31000, Oran, Algeria
hassanid@hotmail.com

Sarah Kreri
Geomatics science engineer;
Department of Earth Observation,
Center of Space techniques, 31200, Arzew, Oran, Algeria
skreri@cts.asal.dz

***Abstract***
*This study analyses the spatio-temporal dynamics of surface water extents in the Great Sebkha of Oran, situated in Northwestern Algeria. This area of high ecological importance, is characterized by seasonal water surfaces, high evaporation and frequent domestic and industrial discharges. After comparing several spectral indices, the Difference Water Index was selected to generate a binary classification: water and no water of used Landsat images. Based on these data, two water-occurrence maps were produced for the periods 1988-2009 and 2009-2022, along with a change-intensity map covering the entire period.*

*The obtained results demonstrate the usefulness of satellite data and water-occurrence analysis for wetlands monitoring, showing a major shift in the hydrological behavior of the Sebkha after 2009. Additionally, the change-intensity map reveals the appearance of a new seasonal water surface. These findings indicate a strong anthropogenic impact corresponding to effluents from the El Karma treatment plant, which began operating in 2009.*

***Keywords****: surface water extent, water occurrence, change intensity map, Difference Water Index, Landsat imagery*

## INTRODUCTION

Surface water monitoring is a major challenge for the sustainable management of water resources, land-use planning, and natural hazard prevention [1] [2]. Technological advances in remote sensing and geospatial data processing have significantly improved the water monitoring field, particularly due to the development of long-term satellite archives and cloud computing platforms such as Google Earth Engine [3] [4]. On another hand, Spatio-temporal analysis methods, including frequency of occurrence, seasonality, recurrence and change analysis, provide the conceptual framework for interpreting such data. These tools allow to extract the evolution of water bodies over time, distinguish natural dynamics from anthropogenic changes and characterize the different hydrological regimes within the same lacustrine or endorheic system [1] [5].

The Great Sebkha of Oran (GSO), located in northwestern Algeria, represents one of the most remarkable saline wetlands in the Mediterranean region [6] [7]. It is defined as a vast endorheic tectonic depression characterized by expanses of salt and a shallow salt lake, fed primarily by surface runoff from its surrounding watershed. The lake itself is devoid of vegetation, while the adjacent plains support halophytic species adapted to high salinity conditions. Due to its ecological, hydrological, and climatic importance, as well as its role in regional biodiversity, the GSO was designated a Ramsar site in 2001 [7].

Despite its international protected status, the GSO has suffered massive discharges of untreated urban and industrial wastewater over the past two decades. This phenomenon is primarily observed along its northern shore, and originates from several urban areas (El Kerma, Aïn Beida, Misserghin, Boutlelis, El Amria) as well as from Es Sénia Airport and the Brédeah desalination plant [8]. The commissioning in May 2009 of the El Kerma wastewater treatment plant, designed to treat up to 270,000 $m^3$/day using the treated water to irrigate 6,500 ha in the Mléta plain, situated south to GSO, was expected to mark a turning point. However, due to significant delays in launching the transfer project and persistent technical malfunctions, partially treated wastewater continued to be discharged directly into the Sebkha via an open channel, with recorded flow rates ranging from 60,000 $m^3$/day to 90,000 $m^3$/day in years 2013 to 2017, before the first effective transfers to the Mléta plain began only at the end of 2018 [8]. Field surveys combined with satellite imagery confirm that these discharges continue to this day, despite several efforts from local authorities.

As a results, multiple studies have been conducted to understand the Sebkha of Oran and its problems, as well as its environmental implications [9] [10]. Through the years, remote sensing based techniques such as spectral indices have proven to be particularly valuable by providing a unique opportunity to investigate such hydrological evolution over several decades [11] [12]. This work is based on multiple indices meant to identify water bodies in satellite imagery, especially the Water Difference Index (DWI) that showed in our case the best results following a comparison process.

While studies, such as in [8] analyzed the dynamics of the GSO water extent over time, using time series of Landsat images covering the period 1987–2019, the present methodology stands out with a more comprehensive approach integrating both spatial and temporal dimensions covering the period 1988–2022.

Indeed, our work offers a comprehensive spatio-temporal analysis of water surfaces of the GSO, presented as thematic maps. The frequency of water presence in each pixel over the entire study period is reported through a water occurrence map, while a water surface change intensity map, is used to locate, characterize, and quantify the hydrological changes that have occurred within this endorheic system.

The used cartographic approach provides a spatially explicit view of the transformations within the Sebkha's hydrological regime. The obtained results allow to precisely identify areas subject to increasing anthropogenic pressures, including sectors affected by discharges from the El Kerma wastewater treatment plant [8]. The main objective of the proposed study is thus to detect and quantify the spatio-temporal changes in the water surfaces of the Great Sebkha of Oran, in order to assess and map the anthropogenic impact on the hydrological regime of this wetland of international importance.

## STUDY AREA

The Great Sebkha of Oran is a salt lake located 10 km in the southwest of the city of Oran in the north-west of Algeria and 12 km away from the Mediterranean Sea (Figure 1). The site forms a closed saline depression, with an average altitude of 80 m, surrounded by two strong massifs: the Murdjadjo massif and the massif of Tessala. The region experiences a Mediterranean semi-arid climate, characterized by mild to relatively wet winters, hot and dry summers, and strong seasonal variability in precipitation. The rainfall rate with the region falls between 378 and 473 mm/year [13], with average wind speeds of over 15.7 km/h, mainly in the southwest direction [14]. In the Sebkha, saline water forms a shallow layer approximately 10–30 cm thick, whose extent varies in response to rainfall and which dries out completely during summer due to intense evaporation [13].

Surface water presence within the Sebkha is highly seasonal as well. During wetter months, rainfall and runoff lead to temporary flooding of the basin. In contrast, during dry seasons, intense evaporation causes rapid water loss, often leaving behind salt crusts [15] [16].

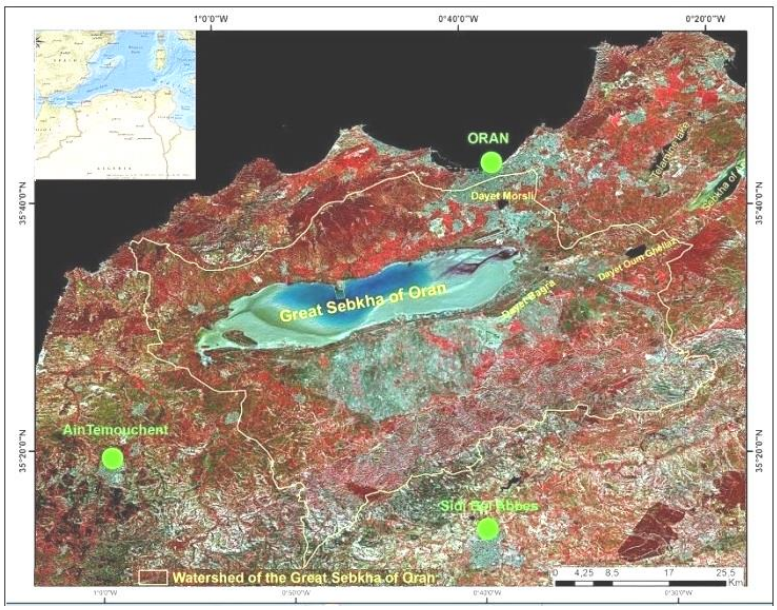



*Figure 1. The location of the Great Sebkha of Oran*

## METHODOLOGY

The methodology is mainly structured around remote sensing data and their derived products. Following the binarisation into “Water” and “No water” classes of all used images using the DWI, two water occurrences (WO) maps are computed for periods 1888-2009 and 2009-2022 to identify significant changes. Finally, a change intensity (CI) map is created based on the previous WO data to highlight and measure the noticeable shift in the Sebkha due to natural and anthropogenic inflows.

### Water extraction methods

#### *Water spectral indices comparison*

For the Great Sebkha of Oran, the extraction of water surfaces was strictly limited to the perimeter of the site itself. Five indices are compared: the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI1 and NDWI2), Modified Normalized Difference Water Index (MNDWI) and unnormalized difference water index (DWI). Table 1 shows all selected indices formulas.

*Table 1. Spectral water indices evaluated in this study*

| Index | Equation | Formula | Reference |
|---|---|---|---|
| **NDVI** | (1) | ( NIR − RED) / ( NIR + Red) | [17] |
| **NDWI1** | (2) | (Green − NIR) / (Green + NIR) | [18] |
| **NDWI2** | (3) | ( NIR − SWIR1) / ( NIR + SWIR1) | [19] |
| **MNDWI** | (4) | (Green − SWIR1) / (Green + SWIR1) | [20] |

| | | | |
|---|---|---|---|
| **DWI** | (5) | (NIR − Green) / (NIR + Green) | [21] |

The objective of this approach is to identify the most relevant index and its associated optimal segmentation threshold to ensure reliable monitoring of the spatiotemporal dynamics of open water surfaces using LANDSAT imagery. This analysis was conducted under a binary classification scheme (water / no water). Information relating to extracted water masses was analyzed for all selected indices taking into account seasonal variations in open water reflectance on a single year 2017 as illustrated in figure 2 and table 2. Segmentation thresholds were determined empirically through iterative tests performed for each index and for all seasons, based on a comparative analysis of the spatial and spectral coherence of the identified water surfaces, without resorting to an automatic optimization procedure.




*Figure 2. Comparison of extracted water surface using different spectral indices during each season of the year 2017*

*Table 2. Extracted water surface and Segmentation Threshold (ST) for each period in year 2017*

| | **01/03/2017** | | **05/06/2017** | | **27/10/2017** | | **14/12/2017** | |
|---|---|---|---|---|---|---|---|---|
| | *ST* | *WS (Km²)* | *ST* | *WS (Km²)* | *ST* | *WS (Km²)* | *Seuil* | *WS (Km²)* |
| **DWI** | <0.12 | 177 | <0.0025 | 41 | <0.025 | 7 | <0.12 | 68 |
| **NDVI** | <0 | 172 | <-0.05 | 43 | <-0.08 | 6 | <0 | 66 |
| **NDWI1** | >0 | 169 | >0 | 41 | >0 | 6 | >0 | 61 |
| **MNDWI** | >0.85 | 192 | >0.55 | 81 | >0.85 | 13 | >0.8 | 87 |
| **NDWI2** | >0.5 | 214 | >0.2 | 183 | >0.7 | 32 | >0.5 | 125 |

According to the obtained results, the most effective indices for detecting water surfaces in the Great Sebkha of Oran are those based on the combination of the near-infrared (NIR) band and the visible bands (blue, green, and red), namely the DWI, NDVI, and NDWI1 indices. The comparison of these three indices highlights the superiority of DWI, which offers the best accuracy for identifying small bodies of water, turbid water, and areas where the water is receding or gradually drying out, as illustrated in Figure 2.

Conversely, indices incorporating the mid-infrared (SWIR) band, such as MNDWI and NDWI2, show more limited performance. In particular, water surface extraction using NDWI2 is frequently affected by spectral noise related to wet, saline, or polluted soils, as well as certain types of vegetation cover, leading to an overestimation of water surfaces. The MNDWI improves water discrimination compared to NDWI2 by partially reducing these spectral interferences, although its performance remains inferior to that observed for indices based on the NIR band.

### *Water Surface Extraction Method for the Time Series (1988/1989–2021/2022)*

A total of 371 Landsat Level-1 images acquired between the years 1988 and 2022 were processed using Google Earth Engine, which enables large-scale geospatial analysis and efficient management of multi-temporal satellite archives.

To ensure temporal consistency of the series and limit the effects of redundant acquisitions, only one image per month was used. When multiple images were available for a given month and year, the scene corresponding to the maximum seasonal water surface area (WSA) was selected, while minimizing cloud contamination and data redundancy. All the data used, including acquisition dates and sensor types, are summarized in table 3.

*Table 3. Used Landsat Level-1 images over the study period (1988 – 2022)*

| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aut | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **L5 TM** | 1988-2011 | 15 | 15 | 14 | 12 | 13 | 21 | 18 | 22 | 19 | 17 | 13 | 12 |
| **L7 ETM+** | 1999-2022 | 11 | 11 | 10 | 11 | 9 | 10 | 10 | 3 | 7 | 5 | 8 | 14 |
| **L8 OLI** | 2013-2022 | 5 | 3 | 7 | 7 | 6 | 4 | 5 | 8 | 5 | 7 | 5 | 4 |
| **L9** | 2020-2022 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| **Total** | | 31 | 30 | 31 | 31 | 29 | 35 | 34 | 34 | 31 | 29 | 26 | 30 |

## Water Occurrence (WO) and Change Intensity (CI) Analysis

### *Water Occurrence map (WO)*

Multiple studies on dynamic changes in water bodies, highlighted the importance of a WO analysis. In this work, two water-occurrence maps were generated corresponding to period 1 from 1988 to 2009 and period 2 from 2009 to 2022.

Water occurrence represents the frequency at which a given pixel was classified as water during each period. This metric provides insight into the persistence and seasonality of surface water. The formula of WO according to extracted water bodies, is given as follows:

$$WO = \frac{\sum_{i=1}^{N}(\varepsilon_i = 1)}{N} \times 100\% \quad (1)$$

Where $\varepsilon$ is the corresponding cell value (1 for Water and 0 for Non water) of the $ith$ water body map, and N indicates the total valid observations.

According to [22] water bodies can be reclassified into permanent (WO > 75%), seasonal (25% < WO ≤ 75%), and ephemeral water bodies (0 < WO ≤ 25%).

### *Change Intensity map (CI)*

Additionally, to comprehend the evolution of the Sebkha of Oran, a CI map was produced for the entire 1988–2022 period. This map is calculated using WO products and it highlights areas where water presence significantly increased or decreased between the two time intervals. Thereby achieving a more precise change detection process, particularly in identifying places undergoing notable hydrological shift.

This product therefore constitutes a spatial indicator of long-term hydrological trends that reveals permanent water contrasting with areas of high dynamics, often associated with water-soil transitioning surfaces and shallow water.

The Occurrence Change Intensity map is derived from homologous pairs of months (that is, the same months contain valid observations in both WO periods). The occurrence difference between period 1 and 2 was computed for each pair and the average of all differences is calculated to create the surface water occurrence change intensity map. Its formula id defined as follows:

$$CI = \frac{1}{N}\sum_{i=1}^{N}(WO_{2,i} - WO_{1,i}) \quad (2)$$

Where $N$ is the number of valid homologous month pairs, and $WO_{2,i}$ and $WO_{1,i}$ are water occurrence values for the same valid month in the two selected periods.

It is noted that, pixels where no homologous monthly pairs exist (e.g., due to missing images or poor quality data) cannot be computed and remain unmapped. Finally, the averaging of monthly results mitigates temporal inconsistencies in data distribution and yields a more robust estimation of changes in water occurrence.

## RESULTS AND DISCUSSIONS

In this study, surface water is extracted using the DWI, identified as the best index to separate water bodies from saline soils and surrounding landuse. Difference indices without normalization are rarely used in a configuration with multiple dates and sensors [23]. Indeed, the normalization step can compensate for different irradiational conditions [24]. However, because the water bodies in the Sebkha of Oran are shallow, saline, and contrast strongly with surrounding salt flats with little vegetation or slope variation, DWI without normalization is usually sufficient. The DWI index provided a clear discrimination between water and salt-encrusted surfaces, reduced confusion with moist soils and produced consistent results across sensors.

### Water Occurrence dynamics

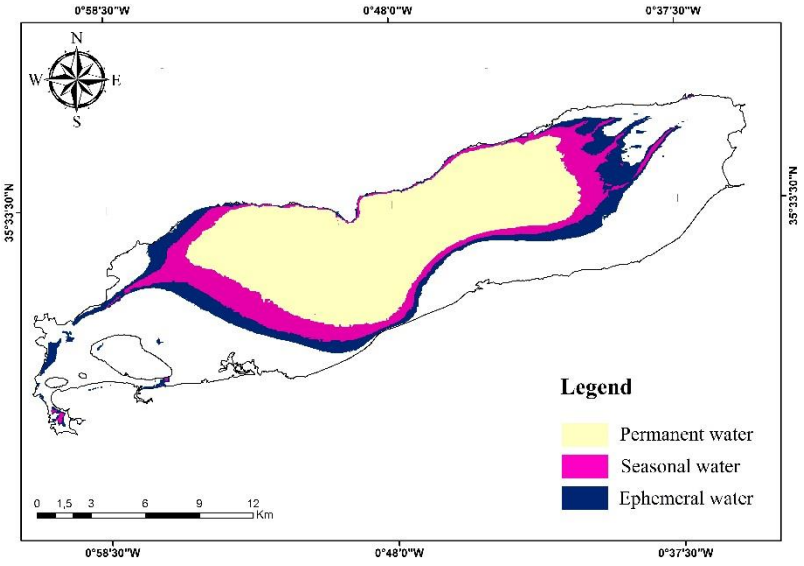
The comparison of water-occurrence maps, displayed in figure 3 for the two selected periods (1988-2009 and 2009-2022) reveals a strong shift of the hydrological regime of the Great Sebkha of Oran, primarily driven by the commissioning of the El Kerma wastewater treatment station in 2009.

Permanent water surfaces exhibit a moderate increase from 106.3 km² to 118 km² (+11.7 km²), followed by stabilization of the central water body. This phenomenon suggests a sustained water input that mitigates seasonal desiccation, which could largely be attributable to continuous treated effluent discharges.

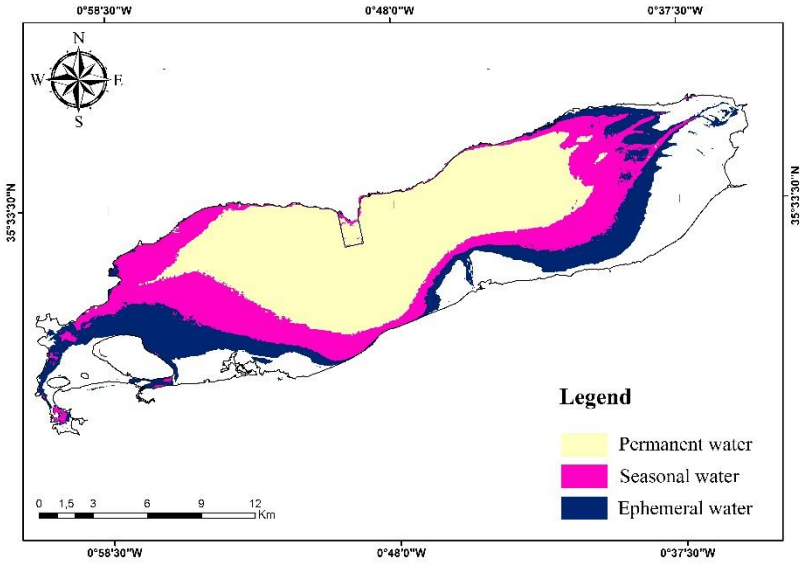
Seasonal water display the most significant expansion, increasing from 34.8 km² to 68.6 km² (+33.8 km²). This noticeable enlargement reflects an increase in both the frequency and duration of inundation, consistent with intermittent but recurrent flows, particularly during periods of hydraulic overload.

Ephemeral water surfaces also increase substantially, from 31.2 km² to 59.6 km² (+28.4 km²), mainly along the outer margins of the Sebkha, extending to areas previously not constantly submerged.

Collectively, these results highlight the pronounced anthropogenic impact on the hydrological dynamics of the Sebkha, with the El Kerma station acting as the main driving factor influencing the extent, recurrence and stability of GSO waters.



*(a)*




*(b)*

*Figure 3. WO maps for each study period: (a) 1988-2009 and (b) 2009-2022*

## Change Intensity patterns

The obtained CI map, showed in figure 4 highlights distinct spatial patterns of hydrological transformations over the 1988–2022 period.

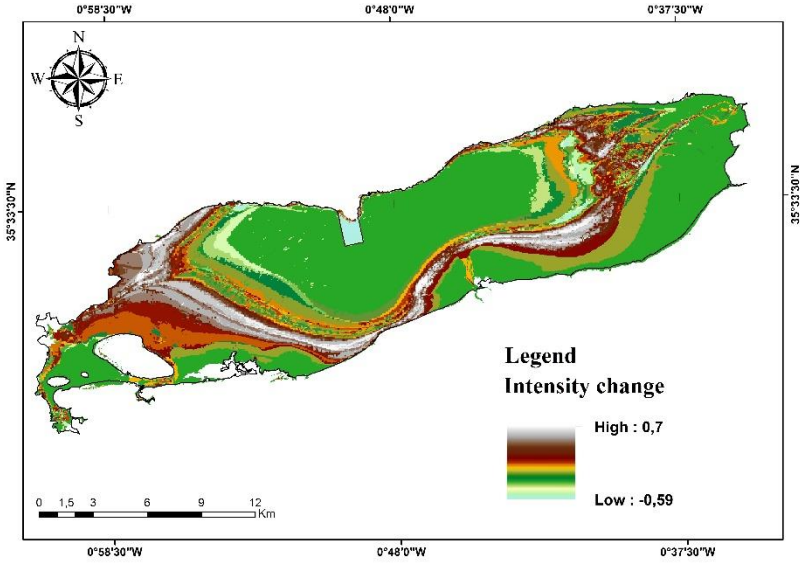



*Figure 4. Occurrence Change Intensity map for the entire study period 1988-2022*

High-intensity change areas (values ~0.7), represented by dark red to light brown tones, delineate areas of high hydrological fluctuations. These zones reflect a transition from a pre-2009 tendency dominated by natural variability, which potentially included seasonal drying trends, to a post-2009 tendency characterized by sustained anthropogenic inputs. The most affected surfaces correspond to effluent discharge points (treated, partially purified, or untreated) which flow and then stabilize in the north-central part of the Sebkha (Brédeah area). In recent years, both a replenishment and an expansion of water surfaces has been observed in this area.

Moderate change areas (orange to light green) indicate a progressive hydrological transition. These zones likely represent the gradual spatial propagation of treated wastewater over the period 2009 to 2022, as well as the apparition of mixing zones between natural and anthropogenic water inputs.

In contrast, low-intensity or stable area, displayed in dark green, correspond to surfaces with minimal hydrological changes, including permanent water bodies (central region of Bredeah), and perpetually dry lands and outer areas unaffected by water-level fluctuations: topographic level of the raised Sebkha in the southeast and central enclosed zone in the north.

### Combined analysis

The combined analysis of water-occurrence and change-intensity maps shows a fundamental shift in the functioning of the Sebkha after 2009. While pre-2009 dynamics were primarily driven by climate factors (direct precipitation) and hydrological factors (inflows from Wadi floods), the tendency has since transitioned toward an anthropogenically regulated structure.

The expansion of all water categories (permanent, seasonal, and ephemeral) demonstrates not only an increase in surface water extent but also a modification of its temporal evolution. This shift reflects the apparition of a quasi-continuous hydrological input, fundamentally modifying the previously established natural intermittency of the site.

Such changes are likely to have significant ecological implications, particularly through alterations of salinity gradients, habitat distribution, and biogeochemical processes at the level of the Sebkha and in its immediate surroundings.

## CONCLUSION

The proposed work demonstrated the effectiveness of long-term Landsat time series when combined with water-occurrence analysis for detecting hydrological changes in arid and semi-arid wetlands. The methodology mainly employed spectral indices, particularly the DWI that have proven its efficiency to correctly identify and delimitate water bodies. Multiple level 1 Landstat images were exploited in order to produce water occurrence and change intensity maps of the Sebkha of Oran, situated in the north-west of Algeria, and considered a crucial area for human and faunal activities.

The obtained results showed a significant shift in water bodies, driven by constant discharges from the El Kerma treatment plant since its commissioning in 2009. A noticeable modification of the hydrological regime of the site is observed on water expansion, recurrence, and stability.

These findings highlighted the extent to which anthropogenic infrastructure can reshape natural hydrosystems, emphasizing the need for integrated monitoring and management strategies.

Given the outcomes, future perspectives may include an exhaustive study of several spectral indices as well as the exploitation of machine learning based water extraction techniques known for their high precision depending on data availability.

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## BIOGRAPHY

Ms. Nezha FARHI is a computer science engineer worker specializing in remote sensing data processing and coding applications. Her research is focused on satellite imagery classification to develop smart decision support tools based on established algorithms.