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Monitoring surface water pollution in Algeria using database indices

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Abstract: This study investigated how remote sensing techniques can pinpoint pollution in surface water areas. Researchers focused on the municipalities of Boumerdes, Corso, and Tidjalabine in Algeria's Boumerdes province. The team used geographic information systems (GIS) to analyse pollution levels and their spatial distribution. Specifically, they employed the Normalised Difference Vegetation Index (NDVI) to identify areas teeming with biodiversity and healthy vegetation. Furthermore, the compactness index provided insights into the overall evolution of the drainage network. This data proved invaluable in identifying areas likely impacted by pollution. Our study is part of a scientific approach to detecting, monitoring, and intervening in water pollution. The core objective was to develop an alternate approach to protecting productive farmland and populated areas by mitigating pollution in these susceptible zones. The NDVI and compactness index, along with their associated database, hold significant promise for environmental preservation efforts. This spatial procedure effectively maps the spatial temporal distribution of pollutants, providing targeted management strategies. The method's user-friendly nature makes it easily applicable in other African countries.

Keywords: GIS; Landsat 8; NDVI; pollution; water quality assessment system

Pollution of surface water continues to be a major issue for both the environment and people. Surface water and groundwater quality control and monitoring are particularly crucial in light of climate change, industrialisation, and agricultural growth (Kausar et al. 2019). Protecting the public's health and identifying all forms of potentially harmful pollutants should be the main goals. Due to the release of untreated wastewater from farms, municipalities, and industry, human activity has deteriorated the condition of the majority of aquatic habitats. Urban waterways in developing nations are especially vulnerable to inorganic fertiliser and hazardous heavy metal contamination. Aquatic life is endangered by this pollution, which also exacerbates other serious environmental issues. As a result, rivers serve as a crucial location where pollution from different sources meets (Tsani et al. 2020).

The three municipalities of Boumerdes, Corso, and Tidjelabine on Algeria's northern coast are connected by Oued Corso, which is situated in a strategically important location with a view of the Mediterranean Sea (Alaeddine et al. 2022). However, in order to maintain the delicate balance between humans and nature, this geographical diversity also faces environmental issues that require special attention. An extensive examination of the physical environment of the area is the first step in this inquiry. Along with a thorough explanation of the province's demographic and climatic features, it will offer an overview. This strategy will help us pinpoint the main causes of the water deterioration that is harming Oued Corso.

Water contamination in the Corso Oued in Boumerdes may be efficiently monitored and managed with the help of Geographic Information Systems (GIS) by:

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– Identifying potential sources of pollution: GIS can be used to analyse spatial data such as land use patterns, proximity to industrial facilities, agricultural areas, and urban settlements to pinpoint potential contributors to water pollution.
– Assessing the impact of pollution on water quality: by integrating GIS with water quality monitoring data, it is possible to evaluate the spatial distribution and severity of pollution, identifying areas most affected and understanding the relationship between pollution sources and water quality degradation.
– Proposing effective pollution mitigation measures: GIS-based modelling can be employed to simulate the impact of various pollution control strategies, such as wastewater treatment plant upgrades, land use regulations, and riverbank restoration, to identify the most effective solutions for improving water quality in the Oued of Corso.

The background and exact monitoring technique used to examine and evaluate the condition of water resources, especially the Oued, are presented in this article. Lastly, it talks about the key conclusions.

Study area. Encompassing roughly 5.7% of Boumerdes province's territory, the three municipalities of Boumerdès, Corso, and Tidjelabine occupy an 83.53 km^2 area in the province's western sector (DPSB 2017). Their geographical coordinates (Figure 1) range from 36°43'12''N to 3°24'01''–3°33'00''E (ANIREF 2023). This region experiences a subhumid Mediterranean climate.

The region has seasonal changes and swings in rainfall throughout the year. This information can be extremely useful for agricultural planning, water resource management, and preparing for extreme weather events. There appears to be a tendency toward increasingly hot summers, which could be a sign of climate change or long-term weather changes.

Natural features of Oued Corso. The Oued Corso, named after the valley, it traverses, originates in the Djebel Bouzegza mountains, located west of the Kabyle Ridge. The river is fed by the Cap-Matifou sub-catchment, encompassing an area of 92.75 km^2 (Bouadjela 1993). The Oued Corso extends for approximately 15 km, winding northward towards the Mediterranean Sea, roughly paralleling the valley axis (Figure 2).

The prevailing climatic conditions exert a significant influence on the morphology of Oued Corso. The river's bed width exhibits considerable variability due to topographic factors and periodic flood events. Observational research conducted during the dry season of 2023 underscored the substantial erosive capacity of the watercourse. With an average annual flow of 200 cubic meters per second, ranging from 185 to 325 m^3/s, the river's flow is subject to significant seasonal fluctuations.

The construction of the Kaddara Dam in 1987 has substantially reduced the river's flow. The spatial overlap between the dam site and the Cap-Matifou sub-catchment hinders the river's replenishment by upstream tributaries (Bouchehed 2017).

The perimeter of a catchment, such as the one feeding Oued Corso, is often measured using a curvimeter

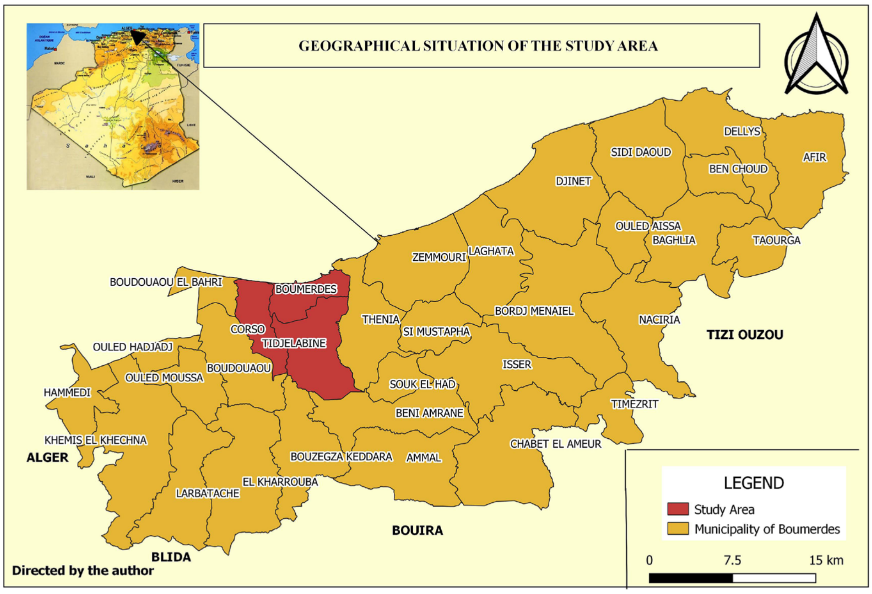

Figure 1. Geographical situation of the study area (author editing using QGIS 3.4 software)

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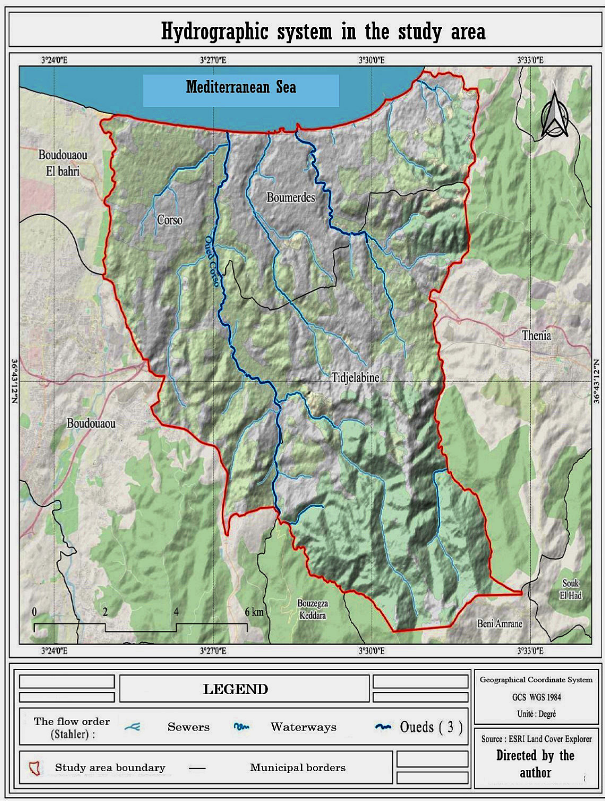

Figure 2. Hydrographic system in the study area (author editing)

on a topographic map or specialized software. The Corso catchment, for instance, has a perimeter of 46.7 km (PATW 2021). The morphology of a catchment exerts a substantial influence on its hydrological response (Figure 3), as depicted in hydrographs. Elongated catchments, such as the Corso catchment, typically experience lower peak discharges following rainfall events. This is because the elongated shape allows for a greater amount of time for the water to reach the outflow, resulting in a more progressive release than a more compact catchment. This phenomenon is related to the idea of time of concentration, which refers to how long it takes water to travel from the farthest point in the catchment to the outlet (Figure 4). Elongated catchments have a longer period of concentration, resulting in lower peak flows.

MATERIAL AND METHODS

The present study also utilised spatial tools and techniques (Ima et al. 2024) such as Landsat imagery acquired by the US Geological Survey (USGS) between 2016 and 2023. The selection of these images was strategic, focusing on the dry season (Perpiña et al. 2020), a period known for its exceptional ability to distinguish various land cover features. The imagery was then processed and analysed using the QGIS (Ver. 3.4) software environment. To achieve detailed spatial analysis, this study leverages a 25-m resolution for all Landsat imagery (Khallef & Brahamia 2019). Additionally, a Universal Transverse Mercator (UTM) zone 32-north projection system is consistently applied to all data (CFSD 2010). This specific projection ensures accurate spatial relationships for optimal analysis.

After processing the satellite images, two indices and one indicator were used:

– Normalised Difference Vegetation Index (NDVI). This index is used to assess the health and density of vegetation (Haraldur & Iman 2021).
– Index matrix for each parameter of the physico-chemical analyses and production of a water quality map using QGIS software. For example, a higher index indicates a shorter water concentration time towards the outlet. (Faurie et al. 2011) Superimpose the results with those of the NDVI index.
– Complement the satellite data and capture the human perspective on land health, water quality indicators were used (Roche 2000).

Figure 3. Minor bed of the Oued Corso

Figure 4. Major bed of the Oued Corso

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Table 1. Characteristics of sampling stations

Sampling stations	Station 1	Station 2
Geographical coordinates	3°28'0"E/36°43'18"N	3°27'6"E/36°43'10"N
Appointment of the site	the three natural pools	agglomeration of corso
Site Identification	upriver	bottom

NDVI spatial-temporal analysis tool. This study uses the NDVI and is of major utility to analyse (Ilies et al. 2024) the historical and current state of the land bordering the oued (Miomir et al. 2018). We focus on the agricultural land base in 2016 and compare it with the updated situation in 2023 (Figure 2). The aim of this comparison is to highlight the encroachment on land bordering the oued (Koull et al. 2022).

According to the normalised difference in the vegetation index based on the following formula:

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

where:
RED – infrared;
NIR – near infrared.

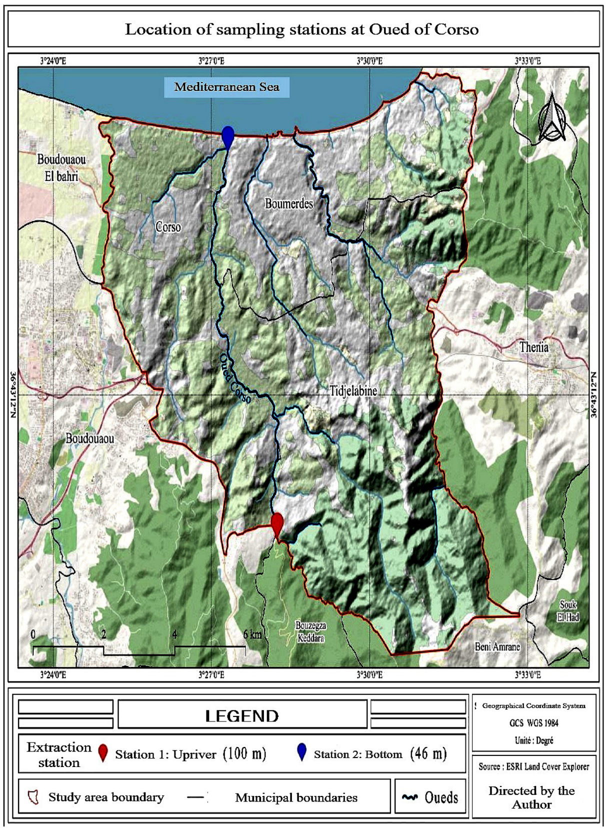

Figure 5. Location of sampling stations at Oued of Corso (author editing)

The ongoing nature of this encroachment is a major concern. By monitoring its evolution through NDVI analysis over time, we believe we can obtain valuable information on the landscape's evolution.

Evaluation system of water quality. This study employs a weighted quality index approach to assess the water quality of the oued based on data collected between June 26, 2023, and August 31, 2023 (MEDD 2003). The National Observatory for the Environment and Sustainable Development (ONEDD) will conduct physicochemical analyses of water samples collected from two designated sampling stations (Figure 5 and Table 1). The sampling period is three months, as this is the season when agriculture needs irrigation and the peak use of water by the population and an extremely short dry season, lasting just a few days between late March and early April. Add to that the very high prices for analyses carried out over long periods. We took a holistic approach to station placement, considering every possible pollution source to ensure a thorough study.

Continuous monitoring of water quality is crucial for safeguarding our waterways. In the case of Oued Corso, this involves a multi-step process: (Figure 6)

The formula for calculating the weighted index is as follows (MEDD 2003):

$$IPpa = Ii + [(Is - Ii)/(bs - bi)] \times (bs - pa)$$

where:
IPpa – weighted index of the parameter analysed;
Ii – lower index;
Is – upper index;
bi – lower bound;
bs – upper limit;
pa – parameter analysed.

The index for a parameter is obtained by weighting, and the index for a change is obtained by averaging the weighted values.

RESULTS AND DISCUSSION

The methodologies implemented provided significant insights that enriched and complemented our

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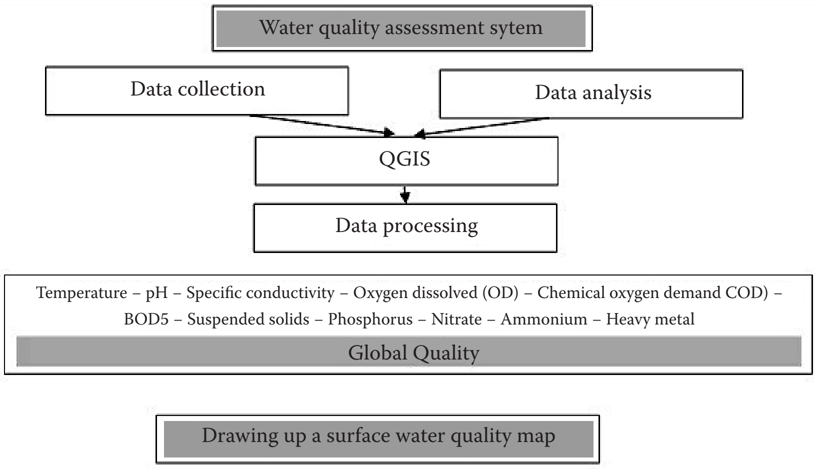

Figure 6. Steps to follow in the methodology for implementing a water quality assessment system

comprehension of the environmental status of the study area. The principal findings of this research are as follows:

The NDVI results. According to Figure 7, the results are in the form of more pronounced contrasts for water braids (Yuanmao et al. 2021), gravel and sediment banks, pioneer vegetation, lowland vegetation, and wooded areas of mountainous terrain (in dark green). According to scientific standards, NDVI values range from −1 to 1 (Vélez et al. 2023). Five classes were identified, reflecting three types of land use:

≥ −0.478 −0.478 × −0.321	Urbanised land
−0.321 × −0.163	Water braids, gravel and sediment banks, pioneer vegetation
0.0.152 × 0.1 0.153 × 1	Agricultural land

Results of weightings and modifications to water quality indices. Physico-chemical parameters were monitored (Table 2) in order to obtain basic information on the nature and quality of the water (Addouche et al. 2022).

These graphs (Figures 8 and 9) show the results of the parameters measured, providing a better understanding:

To efficiently target pollution control efforts, our water quality assessment system focuses on identifying key water quality degradation types. We calculate weighted indices for individual parameters and impairment indices for categories of water quality degradation. This approach groups related parameters, enabling a more targeted analysis of pollution sources.

To corroborate the reliability of our physico-chemical analyses across various seasons, we will examine the concentrations of heavy metals. These parameters exhibit limited seasonal variability and are predominantly influenced by wastewater discharge. Notably,

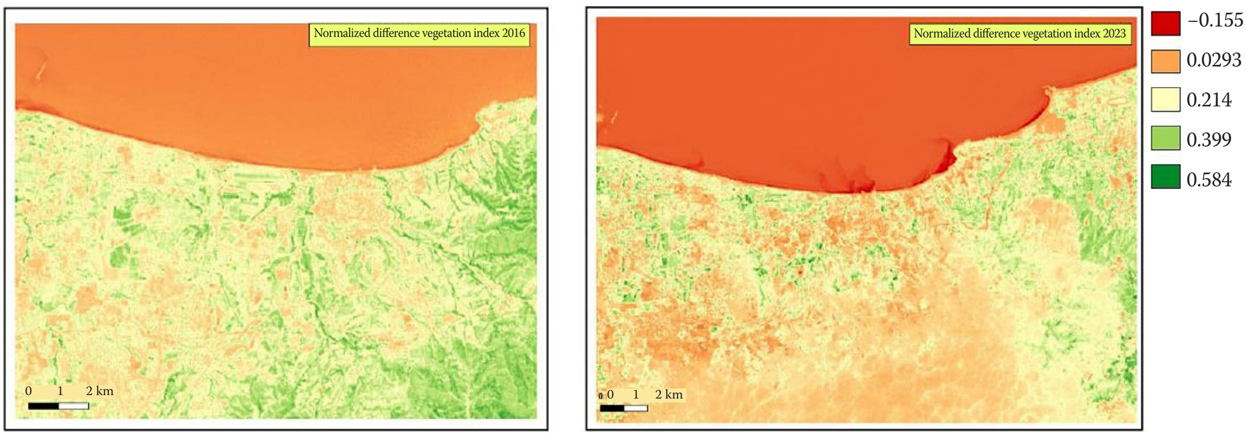

Figure 7. Evaluation of the Normalised Difference Vegetation Index 2016–2023 (author editing using QGIS 3.4 software)

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Table 2. Summary of physical-chemical values

Settings		Values station 1	Values station 2
Temperature (°C)		31.4	31.2
pH		8.2	8.2
Specific conductivity (µS/cm)		1 548	1 568
Oxygen dissolved (OD) (mg/L)		4.0	4.2
Chemical oxygen demand (COD) (mg/L)		250	270
Biological oxygen demand in 5 days (BOD5) (mg/L)		165	155
Suspended solids (SS) (mg/L)		46	46
Phosphorus total (mg/L)		6.3	6.3
Nitrite (mg/L)		0.09	0.07
Nitrate (mg/L)		2.2	2.2
Ammonium (mg/L)		52	48
Heavy metal (mg/L)	cadmium	0.03	0.03
	chrome	0.03	0.03
	copper	0.1	0.1
	lead	0.1	0.1
	zinc	0.2	0.2

heavy metal concentrations are significantly affected by water flow, particularly during periods of intense rainfall (Rebehi 2017). Consequently, we excluded the rainy season (winter), characterized by a substantially higher flow rate of 325 m^3/s, in comparison to the 185 m^3/s recorded during our study period (FAO 2024).

Assessment matrix for the overall quality of the water in Oued Corso. An iterative approach is employed to acquire knowledge through an interactive exchange of information. This methodology facilitates the continual refinement of results, transforming them into a dynamic interplay of various parameters and indices. This process is underpinned by a QGIS database comprising indices defined by equations, statistical evaluations, and sophisticated algorithms.

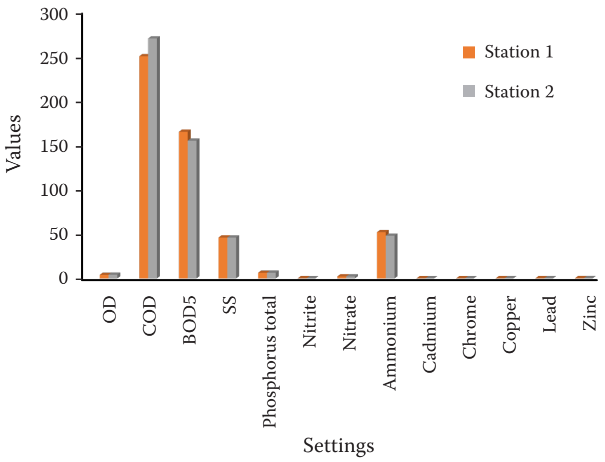

Figure 8. Graph of physico-chemical analyses (author editing)

OD – oxygen dissolved; COD – chemical oxygen demand; BOD5 – biological oxygen demand in 5 days; SS – suspended solids

Based on the analysis of the various physico-chemical parameters, it is evident that:

Analysis of Oued Corso's water reveals alarmingly high levels of various physical chemical parameters, indicative of significant pollution. These concerning results likely stem from two primary sources: discharge of untreated wastewater and highly mineralised waste.

Critical pollution indicators like low dissolved oxygen, elevated biological oxygen demand in 5 days (BOD5), chemical oxygen demand (COD), suspended solids (SS), total phosphorus, and ammonium paint a clear picture (Gola et al. 2016). The presence of heavy metals further underscores the severity of the

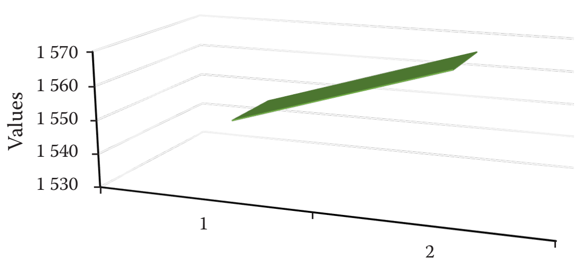

Figure 9. Graph of specific conductivity (author editing)

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situation, pointing to a combination of organic and chemical contamination.

A marked disparity was observed between the pollution levels at Station 2 and Station 1 (Table 3). Station 1 demonstrated relatively low levels of pollution, whereas Station 2 exhibited a multitude of pollution sources, with leachate discharges from the adjacent technical landfill constituting a primary contributor.

Mapping pollution: A spatial view. Figure 10 provides a visual representation of the spatial distribution and intensity of pollution across the region. It delineates areas affected by landfill leachate, illegal dumping, industrial waste, and agricultural fertilizers. This map serves as a valuable tool for determining the precise location and extent of pollution sources (Nadjai et al. 2024).

Discharges into Oued Corso have resulted in significant environmental consequences. Concentrated pollution zones, leachate releases from the nearby landfill, and uncontrolled dumping all contribute to a worrisome decline in water quality and ecosystem health.

Formed largely by settlements (Agglomeration of Corso, Dar Djanane, Amssetass, etc.) and hamlets along the Oued Corso, which means that the results for the two stations are identical. Immediate corrective and preventative actions are crucial to safeguarding this vital resource and protecting the health of surrounding communities and the environment.

Table 3. Interaction of water quality parameters

	Stations	
	S1	S2
Temperature	60	55
pH	95	78
Specific conductivity	35	18
Oxygen dissolved (OD)	78	79
Chemical oxygen demand (COD)	19	17
BOD5 (biological oxygen demand in 5 days)	18	18
SS (suspended solids)	65	53
Phosphorus Total	19	18
Nitrite	35	34
Nitrate	28	25
Ammonium	30	38
Cadmium	32	17
Chrome	35	23
Copper	39	19
Lead	28	17
Zinc	37	15
Overall quality	38.75	31.31

Quality class: excellent 100–80; good 80–60; medium 60–40; bad 40–20; very bad 20

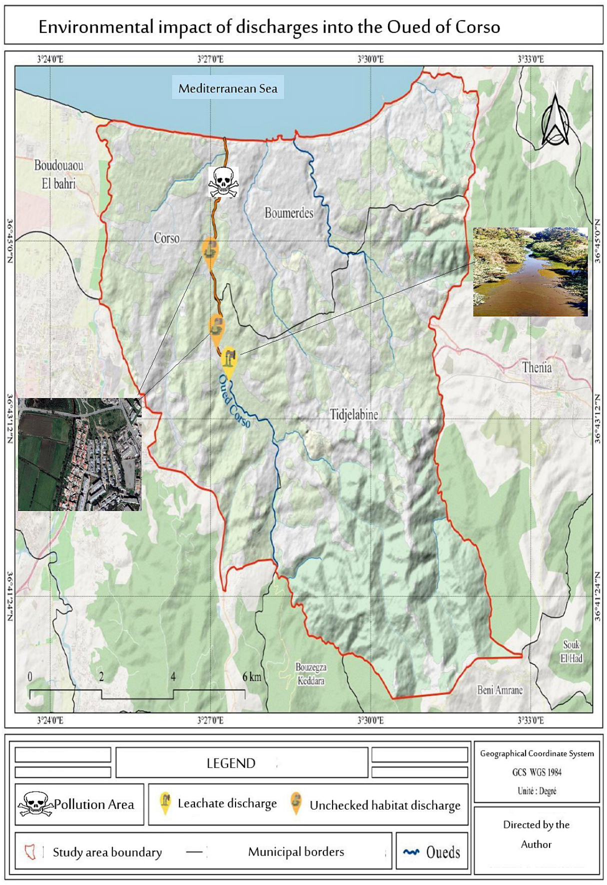

Figure 10. Environmental impact of discharges into the Oued of Corso (author editing)

Criteria evaluation summary. To elucidate the relationship between the utilized criteria, a summary analysis was conducted, the results of which are presented in Table 4. This innovative approach, integrating physico-chemical analyses with high-resolution remote sensing data (Rakhmanov et al. 2024), revealed a significant correlation with heavy metal pollution in Oued Corso. As a result, the probable sources of contamination were identified, namely the sewage systems, followed by the watercourses, and ultimately the oued itself.

From Table 4 it is clear that the indices and indicators used under GIS supervision have an extremely high degree of correlation and consistency. This will create a standard approach to monitoring water pollution and the state of the catchment area in the study zone.

Metallocapt project – the recycling industry. Our approach hinges on the Metallocapt process

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Table 4. Correlation analysis

Acronym	River catchment characteristics	Pollution levels	Acronym adaptation level
NDVI	x	x	2
GIS	x	x	2
water quality parameters S1		x	1
water quality parameters S2		x	1
weighted index	x	x	2
Degree of correlation	3/5	5/5	3/5

NDVI – Normalised Difference Vegetation Index; GIS – geographic information systems; x – correlation link

(Nicolas 2021), a cost-effective solution for capturing and recovering metal ions from wastewater. This innovative technology transforms these recovered metals into a valuable resource – polymer foam. This versatile material, known for its robustne1s, flexibility, and viscoelastic properties (Figure 10), finds applications in diverse sectors like car interiors, seating, and mattresses.

The implementation of Metallocapt will not only address pollution concerns but also create a sustainable business opportunity. The establishment of a dedicated manufacturing unit will serve as a valuable asset for the region, fostering economic growth and development.

CONCLUSION

The application of GIS facilitated the mapping of the spatial-temporal distribution of these contaminants and enabled the prediction of their changes throughout the study region. The data indicate that the studied area is significantly contaminated. The findings indicate that the research area is significantly polluted by unprocessed industrial effluent and untreated residential wastewater. Through the integration of precise data and the promotion of a comprehensive approach to water management, GIS enables the clear and definitive storage of information, efficient management of diverse object attribute data, profound comprehension of the studied phenomena, and swift generation of maps to enhance the understanding of pollution dynamics and formulate effective strategies for the protection and enhancement of water quality in the Oued Corso. The sustainability of this crucial environment for both the current and future generations depends on this multifaceted and technological approach. Additionally emphasised are GIS's capabilities as a decision-making tool, which provide a wide range of options to satisfy all relevant requirements. A diversified strategy is required to maintain the water quality at Oued Corso. To guarantee that the industrial sector complies with current environmental standards, the state must police them strictly. This involves putting in place a mechanism for ongoing observation of possible sources of contamination. Furthermore, there is a lot of promise in investigating novel and alternative methods for heavy metal removal. In the upcoming years, this will be the main focus of our continuing study.

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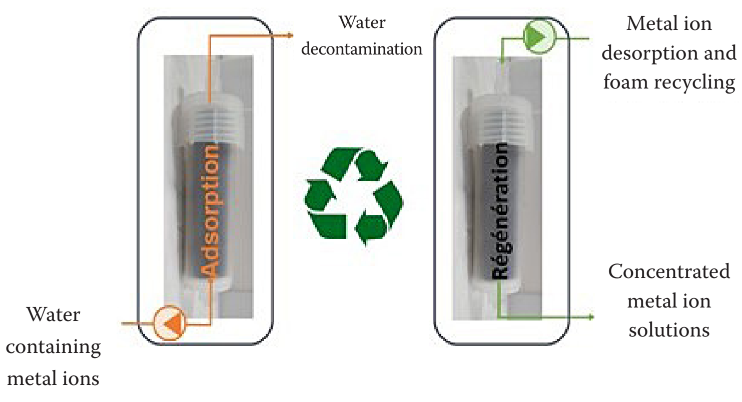

Figure 11. Schematic diagram of the metallocapt device (source: Hubert Curien Multidisciplinary Institute & Charles Sadron Institute)

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