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Anthropogenic Influence and Climate Change: Water and Nutrient Dynamics in the Kebir-Rhumel Basin, (Northeastern Algeria)

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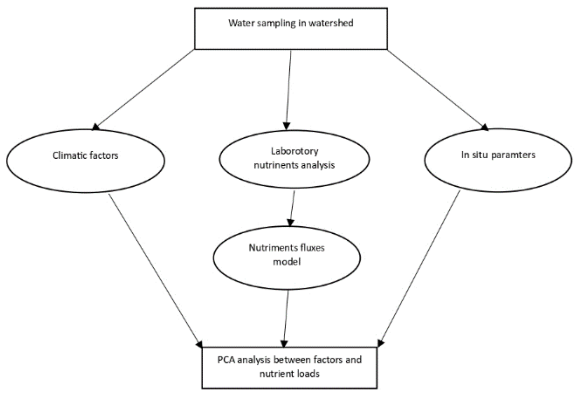
Graphical abstract



Abstract

This study investigates the Anthropogenic Influence and Climate Change: Water and Nutrient Dynamics in the Kebir-Rhumel Basin in Northeastern Algeria. Utilizing an advanced methodology and integrating ten physicochemical variables, this research provides a novel insight into the environmental factors shaping the basin's ecosystem. Employing a PCA analysis highlights two distinct factors accounting for 80.90% of the total variance and identifies a strong positive correlation between various variables, particularly NH_4 and PO_4 two contrasting river areas were noted: Oued Radjas and Oued Rhumel rivers, which display evidence of anthropogenic activities, and Oued Kebir and Oued El-Kotone rivers, which indicate pristine conditions. The observed seasonal fluctuations in atmospheric conditions and surface water parameters highlight the significant influence of human activities on water quality and ecosystem health. These insights emphasize the urgency for continuous environmental monitoring and effective management strategies to safeguard aquatic ecosystems against the detrimental effects of anthropogenic pressures. The findings here are not only significant in understanding the dynamics of water quality but also crucial in devising effective management strategies. High EC and TDS values in the Oued Radjas River point to anthropogenic pollution, and high nitrogen nutrient concentrations in the Oued El-Kotonne River hint at potential eutrophication. The study underscores the importance of understanding the interplay between human activities and natural processes in managing water resources and ecosystems. This research contributes to the existing body of knowledge by shedding light on specific aspects of water quality in the region, paving the way for more focused investigations and policy interventions for sustainable development.

Keywords: Anthropogenic activities, Kebir-Rhumel basin, Nutrient Dynamics, Parameters, Water Quality, Climate Change, Algeria.

1. Introduction

The pertinence of climate change to modern society cannot be overstated. As greenhouse gases escalate, the repercussions—shifts in temperature, precipitation regimes, and sea-level alterations—have begun destabilizing human and natural systems worldwide. Crucially, localized effects of climate change and human interventions, especially in areas such as northeastern Algeria, remain inadequately documented. This work aims to illuminate the nexus of anthropogenic influence and climate change, specifically concerning water and nutrient dynamics in the Kebir-Rhumel Basin.

Recent studies have accentuated the ramifications of climate change and urbanization on regional precipitation patterns (Deng *et al.* 2023). As global temperatures ascend, associated impacts on precipitation and atmospheric moisture patterns are anticipated, stemming from altered air circulation and amplified hydrological cycles (Dore, 2005; Terink *et al.* 2013). This interplay can result in heightened evaporation, inducing prolonged droughts; conversely, an atmosphere enriched with moisture may cause heavy rainfall (Trenberth, 2008; Kunkel *et al.* 2013).

The dual forces of climate change and human activity, influence water's critical role in the hydrological cycle. While climate change modulates water resources in quantity, distribution, and quality (Oliazadeh *et al.* 2022), human actions directly and indirectly, impact water quality. For instance, discharging wastewater directly alters stream chemistry, whereas infrastructural developments can influence hydrological pathways (Peters *et al.* 2005).

Moreover, dam constructions can wield profound influences on water and nutrient flows. By impeding natural flow, dams can engender alterations in water quality parameters, such as temperature and dissolved oxygen levels, impacting aquatic life and human consumption alike (Liermann *et al.* 2012; Baumgartner *et al.* 2022). Beyond this, dams' more significant ecosystemicimpacts span estuarine and marine habitats, with particular concern for the influence of changing climatic conditions on these impacts (Donald *et al.* 2015; Iyakaremye *et al.* 2021).

Agricultural practices, especially applying fertilizers and pesticides, present additional challenges to surface water quality despite the agronomic benefits of pesticides, excessive fertilization risks contaminating groundwater and surface water (Cooper, 1993; Kaur and Sinha, 2019).

Riverine inputs of freshwater and sediments are paramount for estuarine and coastal ecosystems. Nevertheless, the influx of anthropogenic nutrients into these systems has surged, disrupting ecological equilibriums (Ittekkot *et al.* 2000). The balance of critical nutrients such as silicates (Si), nitrogen (N), and phosphorus (P) remains crucial for water bodies' ecological stability (Scibona *et al.* 2022). While the impact of nitrogen and phosphorus has been well-researched, emerging studies underscore the significance of silicates, especially for diatom proliferation (Conley *et al.* 1993).

With climate change and human interventions being dominant forces shaping the present, their collective effects, including on water and nutrient dynamics, in the northeastern Algerian coastline are undeniable. Understanding the repercussions of these intertwined dynamics becomes paramount, given the implications on aquatic health and human water security. Despite the critical situation, there is a lack of research concerning the northeastern Algerian coastline.

Therefore, this study rigorously examines how human activities and climate change impact the water and nutrient dynamics of the Kebir-Rhumel Basin, which is essential for environmental studies but remains inadequately researched. This basin plays a vital role in local hydrology, biodiversity, and agriculture, providing insights into broader environmental processes and issues. Despite its importance, there is a noticeable lack of comprehensive research on the basin, highlighting a significant gap in environmental literature that must be filled to enhance sustainable management practices in the area. Aiming to amalgamate environmental conservation with regional development imperatives, the study's objectives encompass 1) Analyzing a decade's meteorological data (2010-2020) to discern climate fluctuations; 2) Probing physical and nutrient dynamics during the 2022 wet period; 3) Ascertaining nutrient loadings at strategic points; and 4) Deploying statistical tools to discern patterns and deviations. Our guiding hypotheses are: 1) Climate variables exhibit seasonal oscillations influencing water and nutrient flows; 2) Anthropogenic imprints are discernible in water quality across specific water bodies; 3) Nutrient imbalances are detrimental to the region's aquatic ecosystems.

Subsequent sections delineate the study area, expound on methodologies, and traverse the results concerning extant literature. The culmination lies in synthesizing findings, introspecting the study's limitations, and contemplating future trajectories—casting light on the intricate interplays in a river basin under the looming shadow of global change.

2. Material and Method

2.1. The study area

The KebirRhumel Watershed is located in northeast Algeria (Figure 1). It borders the Mediterranean Sea to the north, Constantine and Oum El Bouaghi to the east, Batna to the south, and Setif to the west. It spans an area of 8,843 km², located between 5°40' and 6°40' E longitude and 35°50' and 36°40' N latitude. It is recognized as a major watershed in the country and houses the largest dam in Algeria, with a capacity of nearly 1 billion cubic meters (Bouchareb *et al.* 2013).

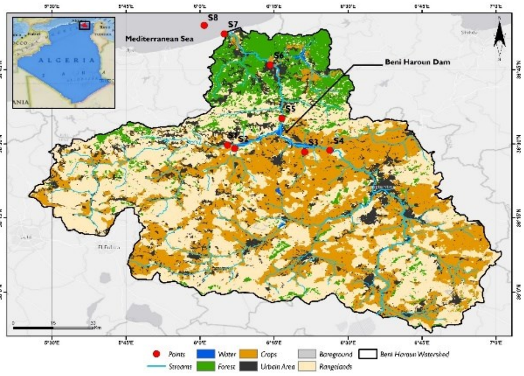


Figure 1. Location of the Kebir-Rhumelbasin and sampling stations in the coastal River of Kebir-Rhumel (S1: Oued Endja River (OE-R); S2: Oued Radjas River (ORa-R); S3: Oued El-Kotonne River (OK-R); S4: Oued Rhumel River (ORh-R); S5: Downstream dam (D-D); S6: Milia River (M-R); S7: Month of Kebir-Rhumel River (M-KRR); S8: Jijel Offshore (J-OS)).

The watershed is divided into the western Oued Enndja Basin and the eastern Oued Rhumel Basin (Figure 1). The Oued Enndja Basin covers an area of 3454.85 km² and has a mountainous topography with high precipitation (681.33 mm/year). The average elevation is 819.50 m, ranging from 114 to 1659 m. The Oued Rhumel Basin extends from the south to northeast, is characterized by a softer topography, and has moderate precipitation (600 mm/year) (NMO, 2021). It covers an area of 4062.42 km² with an average elevation of 775.27 m, ranging from 127 to 1722 m. The confluence of the Oued Enndja and Oued Rhumel forms Oued El Kebir(Zeghmar *et al.* 2022). A Mediterranean climate, with mild, rainy winters and hot, dry summers, characterizes the study area. The climate varies from semi-humid in the north to semi-arid in the south and has diverse water resources, including rain, hail, and snow. Snowfall occurs mainly in high mountain areas, and rainfall is the primary factor that affects river flow. The average annual rainfall in the Kebir-Rhumel Watershed is between 638 -and 738 mm, with more rainfall in the north declining as one moves southward. The yearly average temperature is 21.24°C with a maximum temperature of 31.3°C and a minimum temperature of 12.15°C.The topography of the Kebir-Rhumel Watershed is primarily mountainous, with steeper slopes found mainly in the northern region. The average height is 745.12 m, with the lowest and highest points being 0 and 1723 m, respectively (Figure 1). The average slope is 15.66%, with areas of very steep slopes (over 30%) covering 14.55% of the total area, primarily located in the northwest. Agriculture, such as growing wheat, barley, and animal feed crops, is an everyday activity in the area. The northern part of the watershed is covered with forests of oak and cork trees, while vegetation decreases towards the south. The lack of vegetation has contributed to soil erosion.

The Beni Haroun Dam is crucial in the northeast region of Algeria, near Mila (Figure 1). The surrounding area features mountainous regions in the north and a mix of plains and highlands in the south constructed in 2003, the dam collects water from a catchment area of 8815 km2 and has a storage capacity of 795 million cubic meters. The water stored in the dam is used for two primary purposes: (1) irrigation, providing water to approximately 40,000 hectares of agricultural land in the High Plains of Constantine region, including the 2272-hectare Ouled Hamla area, which is mainly used for growing crops such as cereals, and vegetables, and (2) supplying drinking water to six provinces including Constantine, Jijel, Mila, Oum El Bouaghi, Khenchela, and Batna, providing for a population of over 2.5 million people(Bouaroudj *et al.* 2019). The Beni Haroun Dam (BHD) is fed primarily by precipitation from the Rhumel and Nedja River watersheds and untreated domestic and industrial wastewater from the Constantine and Mila provinces discharged into the reservoir through the hydrographic network. The BHD also receives treated wastewater from the Sidi Marouane treatment plant, which has a daily capacity of 20550m^3. The region has a semi-arid climate with two distinct seasons: a cold and wet winter with an average temperature of 7.3°C in January and a hot and dry summer lasting four months, with the warmest month being August with a temperature of 24.2°C. Rainfall in the area is irregular, ranging from 4mm in July to 89mm in January (Solatani *et al.* 2020).

2.2. Data Analysis

The speed of the river water flow was evaluated using the CM-2 current meter from Toho Dentan Co. Ltd, Tokyo, at the time of sampling from the same water mass. The water's electrical conductivity (E.C.) and total dissolved solids (TDS) were measured using the multiparameter probe WTW 197i. To calculate the flow rate ($m^3\ s^{-1}$), the water velocity ($m\ s^{-1}$) was multiplied by the total surface area (m^2) of the river's transect at the outlet station. Every month, two liters of water were taken from the middle of the watercourse at each station, where the minimum average depth is 0.5 meters. These samples were collected throughout the study period to analyze the nutrients. These water samples were frozen in polyethylene bottles and processed within two days of collection. In the laboratory, the samples were filtered through Whatman GF/C glass filters (0.45µm porosity). The concentrations of dissolved inorganic nitrogen (DIN), including ammonia (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-), as well as silicates ($Si(OH)_4$), were determined using standard colorimetric methods described in Parsons *et al.* (1989); Rodier (2009) and Aminot *et al.*, (2007).

From January 2022 to March 2022, hydrological parameters and nutrient levels were measured monthly at eight stations in the K.R. basin. The selection of these stations was reasoned to better understand the inflows and outflows to the dam, as well as geochemical variations during the wet season (Figure 1). These stations were strategically located at the entrances of Endja, Radjas, El-Kotonne, and Rhumel branches, as well as at the Beni-Haroun dam's exit and the Kebir-Rhumel River outlet. To determine the instantaneous fluxes of nutrients, their concentrations were multiplied by the river's flow. The estimation of wet seasonal loads for nutrients, using the method of average instantaneous loads, as described by Preston *et al.* (1989).

$$F = K\sum_{i=1}^{n}\frac{CiQi}{n} \tag{6}$$

Where *F* is the wet seasonal load (tons/wet season), *Ci* is the concentration of nutrients (µM converted to kg m^{-3}), *Qi* is the concomitant instantaneous flow ($m^3\ s^{-1}$ converted to $m^3\ day^{-1}$), *n* is the number of days with concentration and flow data, and *K* is the conversion factor to consider the period (90 days) and unit of estimation.

2.3. Statistical analysis:

The multivariate technique known as correspondence analysis (C.A.) was employed to examine potential associations between inorganic nutrients across the aquatic continuum of a river system, spanning from the dam openings to the river outlet. C.A. offers several advantages over other multivariate techniques like principal component analysis (PCA) and is better suited for the collected data. Presenting the variables and objects together in a biplot graphic interprets the cloud points and associations easier. C.A. is essentially a dual principal component analysis conducted on both the variables (columns) and objects (rows), comparing them through a double Euclidean distance (Khi-square distance). Unlike PCA, there is no need for data normalization, which can often distort reality (Dervin, 1988). The Principal Component Analysis (PCA) was used SPSS Statistics 26.0 Software with Varimax rotation. The contingency table analyzed with C.A. consists of a matrix showing the monthly average of six nutrient loads (variables) observed at eight sites (objects), including the dam entrance and exit of the Kebir-Rhumel basin.

3. **Results**

3.1. Mean changes in atmospheric temperature, precipitation, humidity, and wind speed for the period from 2010 to 2020 in the Kebir-Rhumel basin

3.1.1. Temperature (T)

The mean temperature increases from January to July, with the highest temperature observed in July (28.6°C). It then decreases from August to December (Figure 2), with the lowest temperature observed in January (8.9°C). This pattern indicates seasonal temperature fluctuations, with warmer temperatures in the summer and cooler temperatures in the winter.

3.1.2. Precipitation (P.P.)

The highest mean precipitation occurs in February (99 mm) and March (96 mm), suggesting that these are the wettest months in the Kebir-Rhumel basin (Figure 2). Precipitation decreases from April to July, with the lowest value in July (7 mm), indicating that this is the driest month. Precipitation then increases from August to November, followed by a slight decrease in December.

3.1.3. Humidity (H)

The highest mean humidity values are observed in the winter months of January (74%), February (76%), and December (76%). Humidity decreases from March to July (Figure 2), reaching its lowest value in July (43%). It then increases from August to December, indicating higher moisture content in the air during the cooler months.

3.1.4. Wind speed (Ws)

The highest mean wind speeds are observed in February (22 m/s) and September (22 m/s), while the lowest wind speeds occur in June (16 m/s) and July (17 m/s). Wind speed generally decreases from the beginning of the year until mid-year and then increases again towards the end of the year (Figure 2).This data shows that the Kebir-Rhumel basin experiences seasonal fluctuations in temperature, precipitation, humidity, and wind speed. These factors can influence the flow of water and nutrients to the northeastern coast of Algeria and the impact of human activities on the region's water and nutrient cycles (Table 1).

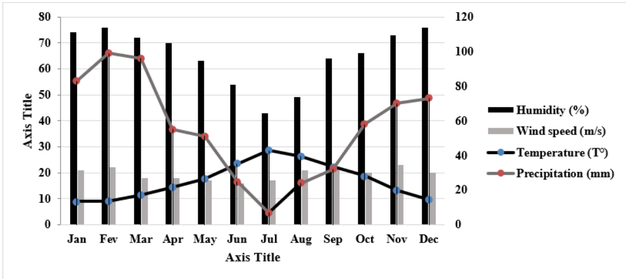


Figure 2. Mean changes in atmospheric temperature, precipitation, humidity, and wind speed for the period from 2010 to 2020 in the Kebir-Rhumel basin.

Table 1. Physical parameters of surface water in the Kiber-Rhumel basin and water delivery to the Jijel coastal region during the wet period of 2022

	Station	E.C. (µs/cm)	TDS (mg/l)	pH	D.O. (mg/l)	Water delivery (10^6 m^3)
January 2022	**S1 :**OuedEndja River (OE-R)	1614	811	7.9	40.8	136
	S2 : OuedRadjas River (ORa-R)	5350	3340	7.2	34.6	20
	S3 : Oued El-Kotonne River (OK-R)	1481	795	8.0	40.6	61
	S4 : OuedRhumel River (ORh-R)	2200	1170	7.1	33.4	750
	S5: Downstream dam (D-D)	1550	887	8.2	40.7	225
	S6 : Milia River (M-R)	1400	787	7.7	40.3	/
	S7 : MonthKebir-Rhumel River (M-KRR)	1018	543	7.7	37.1	330
	S8 : Jijel Offshore (J-OS)	1748	941	7.9	40.3	/
February 2022	**S1 :** Oued Endja River (OE-R)	1788	936	8.45	39.3	113
	S2 : Oued Radjas River (ORa-R)	7180	3870	7.60	39.6	15
	S3 : Oued El-Kotonne River (OK-R)	1472	782	8.30	40.0	42
	S4 : Oued Rhumel River (ORh-R)	2100	1140	8.20	33.8	359
	S5 : Downstream dam (D-D)	1548	826	8.40	40.2	225
	S6 : Milia River (M-R)	1548	828	8.26	40.3	/
	S7 : Month Kebir-Rhumel River (M-KRR)	1355	723	8.10	33.4	300
	S8 : Jijel Offshore (J-OS)	1130	670	8.10	40.5	/
March 2022	**S1 :** Oued Endja River (OE-R)	1413	753	8.90	40.8	380
	S2 : Oued Radjas River (ORa-R)	5850	3180	8.17	36.6	20
	S3 : Oued El-Kotonne River (OK-R)	1252	670	8.90	40.7	56
	S4 : Oued Rhumel River (ORh-R)	1809	983	8.63	34.6	313
	S5 : Downstream dam (D-D)	1245	684	8.86	41.5	250
	S6 : Milia River (M-R)	1208	681	8.70	32.7	/
	S7 : Month Kebir-Rhumel River (M-KRR)	989	532	8.81	40.8	462
	S8 : Jijel Offshore (J-OS)	46	27	8.61	41.3	/

3.2. Physical parameters of surface water in the Kiber-Rhumel basin and water delivery to the Jijel coastal region during the wet period of 2022

The results indicate that Electrical Conductivity (E.C.) and Total Dissolved Solids (TDS) are elevated in the Kiber-Rhumel basin, especially in the Oued Radjas River (ORa-R), suggesting poor water quality due to increased concentrations of dissolved salts and contaminants. These parameters are critical as they indicate high salinity and the presence of dissolved pollutants, thereby degrading overall water quality according to regional or international standards. The pH varies slightly from slightly acidic (7.1) to slightly alkaline (8.9) in the basin, with the Oued Rhumel River (ORh-R) showing the lowest pH (7.1) in January and the Oued Endja River (OE-R) the highest (8.9) in March. These variations can influence aquatic biodiversity and ecosystem health. Dissolved Oxygen (D.O.) levels are crucial for aquatic ecosystem health, and the measured high levels (32.7 mg/l to 41.5 mg/l) generally indicate favorable conditions for aquatic life in the Kiber-Rhumel basin. Water delivery values show volumes transported to the coastal region of Jijel during the wet period, with the Oued Rhumel River (ORh-R) delivering the highest volume, reaching 750 million cubic meters in January. This seasonal variation in water delivery can influence regional water resource management, especially for agriculture and drinking water supply. These parameters (E.C., TDS, D.O.) play a critical role in assessing water quality, aquatic ecosystem health, and water resource management in the Kiber-Rhumel basin, highlighting potential challenges and the need for ongoing monitoring to maintain optimal environmental conditions.

3.3. Nutrient concentration in the Kebir-Rhumel basin during the wet period of 2022

Ammonium (NH_4), Nitrite (NO_2), and Nitrate (NO_3) are essential for the growth of aquatic plants and algae, but their excessive concentrations can lead to eutrophication and water quality issues (Zhang *et al.* 2023). The levels of these nutrients vary across sampling stations and months, with some of the highest concentrations observed in the Oued El-Kotonne River (OK-R) for NO_3 in February and March and the Oued Rhumel River (ORh-R) for NH_4 in January (Table 2).Dissolved Inorganic Nitrogen (DIN) represents the combined availability of nitrogen as ammonium, nitrite, and nitrate. The highest DIN concentration was observed in the Oued El-Kotonne River (OK-R) in February, indicating high levels of nitrogen nutrients in this river, which could potentially contribute to eutrophication and degradation of water quality. Phosphate (PO_4) is another essential nutrient for aquatic life, but excessive levels can also lead to eutrophication. The PO_4 concentrations are generally low across all sampling stations, with the highest values observed in the Oued Radjas River (ORa-R) and Oued Rhumel River (ORh-R) in February.Silicate (SiO_4) is an essential nutrient for the growth of diatoms, a group of algae that plays a vital role in aquatic ecosystems. The SiO_4 concentrations are highly variable across the sampling stations, with the highest values observed in the Oued El-Kotonne River (OK-R) in February and March (Table 2).

Table 2. Displays the nutrient concentration (in mg/l) in the Kebir-Rhumel basin, during the wet period of 2022

	Station	NH_4 (mg/l)	NO_2 (mg/l)	NO_3 (mg/l)	DIN (mg/l)	PO_4 (mg/l)	SiO_4 (mg/l)
January 2022	**S1 :** Oued Endja River (OE-R)	0.43	0.41	0.78	1.62	0.04	11.22
	S2 : Oued Radjas River (ORa-R)	0.49	0.17	0.58	1.24	0.40	14.90
	S3 : Oued El-Kotonne River (OK-R)	0.39	0.02	1.52	1.93	0.10	14.61
	S4 : Oued Rhumel River (ORh-R)	0.69	0.39	0.82	1.89	0.49	13.52
	S5: Downstream dam (D-D)	0.18	0.01	0.55	0.75	0.00	7.35
	S6 : Milia River (M-R)	0.53	0.11	0.38	1.02	0.02	12.15
	S7 : Month Kebir-Rhumel River (M-KRR)	0.56	0.13	0.63	1.32	0.02	15.66
	S8 : Jijel Offshore (J-OS)	0.58	0.16	0.42	1.16	0.01	14.45
February 2022	**S1 :** Oued Endja River (OE-R)	0.48	0.27	2.52	3.27	0.08	1.28
	S2 : Oued Radjas River (ORa-R)	0.68	0.48	1.65	2.81	0.72	13.93
	S3 : Oued El-Kotonne River (OK-R)	0.48	0.59	5.29	6.36	0.30	19.95
	S4 : Oued Rhumel River (ORh-R)	0.44	0.53	2.61	3.57	0.67	15.71
	S5: Downstream dam (D-D)	0.06	0.00	0.64	0.71	0.03	12.37
	S6 : Milia River (M-R)	0.61	0.20	0.58	1.39	0.01	3.31
	S7 : Month Kebir-Rhumel River (M-KRR)	0.48	0.31	0.81	1.59	0.02	3.79
	S8 : Jijel Offshore (J-OS)	0.19	0.00	0.06	0.24	0.01	0.44
March 2022	**S1 :** Oued Endja River (OE-R)	0.03	0.50	2.90	3.43	0.07	9.42
	S2 : Oued Radjas River (ORa-R)	0.14	2.03	2.95	5.11	0.33	8.91
	S3 : Oued El-Kotonne River (OK-R)	0.10	0.11	7.01	7.23	0.23	16.15
	S4 : Oued Rhumel River (ORh-R)	0.22	1.21	0.56	1.99	0.38	10.25
	S5: Downstream dam (D-D)	0.17	0.02	0.67	0.86	0.02	5.49
	S6 : Milia River (M-R)	0.35	0.26	0.68	1.28	0.03	9.13
	S7 : Month Kebir-Rhumel River (M-KRR)	0.17	0.33	0.88	1.38	0.04	8.83
	S8 : Jijel Offshore (J-OS)	0.04	0.06	0.25	0.34	0.03	1.80

3.4. Nutrient loadings (t/wp) at Beni-Haroun dam and the Kebir-Rhumelriver outlet during the wet period 2022

Ammonium (NH4), Nitrite (NO2), and Nitrate (NO3) loadings vary across sampling stations, with the highest loadings observed in the Oued Rhumel River (ORh-R) for NH4 and NO3, and the Oued Endja River (OE-R) for NO2 (Table 3). These high nutrient loadings could result from human activities in the watershed, contributing to eutrophication and water quality issues in the downstream areas.The highest DIN loading is found in the Oued Rhumel River (ORh-R), followed by the Oued Endja River (OE-R). This suggests that these two rivers are the primary sources of nitrogen nutrients in the region and may significantly impact water quality and ecosystem health on the northeastern coast of Algeria. The PO4 loadings are highest in the Oued Rhumel River (ORh-R) and the Milia River (M-R). High phosphate loadings can lead to eutrophication and other water quality issues in downstream areas. SiO4 loadings are relatively low across all sampling stations (Table 3). Nonetheless, the highest SiO4 loading is observed in the Milia River (M-R), which could influence the growth of diatoms and other algae in the receiving waters.

Table 3. Nutrient loadings (in tons per wet period, t/wp) in the Beni-Haroun dam and the outlet of the Jijel coastal region during the wet period of 2022

	Station	NH_4 (t/wp)	NO_2 (t/wp)	NO_3 (t/wp)	DIN (t/wp)	PO_4 (t/wp)	SiO_4 (t/wp)
Wet period	**S1** :OuedEndja River (OE-R)	324	220.5	907.2	1451.7	33.3	11.22
	S2 :OuedRadjas River (ORa-R)	58.5	40.5	55.8	154.8	16.2	14.90
	S3 :Oued El-Kotonne River (OK-R)	130.5	45.9	415.8	592.2	25.2	14.61
	S4 :OuedRhumel River (ORh-R)	1917.9	675.9	1008	3601.8	604.8	13.52
	S5 :Downstream dam (D-D)	378	6.3	253.8	638.1	9.9	7.35
	S7 : Month Kebir-Rhumel River (M-KRR)	1049.4	153.9	495	1698.3	26.1	15.66

3.5. Statistical analysis results

For the PCA analysis, we included ten physicochemical variables: pH, C.E., TDS, D.O., NH_4, NO_3, NO_2, DIN, PO_4, and SiO_4. The correlation analysis of these variables revealed that most exhibited substantial and statistically significant correlations (Figure 3). The PCA applied to these parameters resulted in two distinct factors that accounted for 80.90% of the total variance. Factor 1 (F1) alone explained 55.70% of this variance (Figure 3). F1 selected positively the variables with the highest factorial charges were E.C. (0.803), NH_4 (0.718), PO_4 (0.911), SiO_4 (0.600), T (0.502) and TDS (0.796) and opposed pH and DO. Factor 2 (F2) accounted for 25.20% of the total variance, selected positively the remaining variables NID, NO_3 and SiO_4.The asterisk (*) denotes the strongest correlations in the matrix. Consequently, a robust positive correlation is observed between SiO_4 and NH_4, as well as between DIN and NO_3 ($p< 0.001$). Furthermore, NH_4 exhibits a relatively strong positive correlation with PO_4 (Figure 3).The factorial plan projection F1 × F2 from the correspondence analysis reveals two distinct areas: the Oued Radjas and Oued Rhumel rivers characterized by high levels of pH, TDS, E.C., NH_4, and PO_4 resulting from various anthropogenic activities in their watersheds, in contrast to the Oued Kebir and Oued El-Kotone rivers, which display high levels of NO_2, NO_3, and SiO_4, indicating pristine river conditions. Notably, the studied rivers are characterized by elevated NH4 and PO_4 levels, particularly in the Oued Radjas and Oued Rhumel rivers, while SiO_4 levels are deficient. These biogeochemical conditions are likely to significantly impact the river systems and the functioning and productivity of the Ben Haroune dam, which receives water from these rivers.

4. **Discussion**

The present study investigates the anthropogenic influence and climate change on water and nutrient dynamics in the Kebir-Rhumel Basin located in Northeastern Algeria by analyzing meteorological data, physical parameters of surface water the Kebir-Rhumel Basin from 2010 to 2020, along with nutrient concentrations during the wet season of 2022. Our findings reveal notable seasonal fluctuations in atmospheric temperature, precipitation, humidity, and wind speed, which could significantly impact the flow of water and nutrients in the region and the effects of human activities on the water and nutrient cycles. These findings are broadly consistent with other studies that show higher water temperatures also affect chemical processes in lakes, leading to increasing pH (Psenner and Schmidt,1992). The seasonal differences in surface runoff, precipitation, inflow, groundwater flow, and the pumped-in and outflows strongly influence River discharge and the concentration of pollutants in river water (Vega *et al.*1998).The data on physical parameters of surface water (E.C., TDS, pH, D.O.) and nutrient concentrations (NH4, NO2, NO3, DIN, PO4, SiO4) indicate potential influences of human activities on water quality and ecosystem health in the Kebir-Rhumel basin. The high values of Electrical Conductivity (EC) and Total Dissolved Solids (TDS) observed in the Oued Radjas River suggest poorer water quality in this area, which can be attributed to anthropogenic factors such as agricultural runoff, urbanization, or industrial pollution. Agricultural runoff is often rich in fertilizers and pesticides, which increase the levels of dissolved salts in the water, leading to high EC and TDS values. Similarly, urbanized and industrialized areas can contribute to water pollution through the discharge of industrial waste and untreated wastewater.(Khrief, *et al.* 2018; Kabour *et al.* 2023)

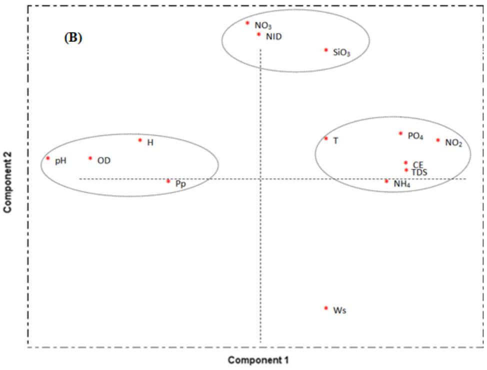
Numerous recent research papers concur that the levels of nitrogen and phosphorus in surface waters are substantially affected by human-related factors linked to land cover, land use, and specific source points for example, as suggested by Castillo *et al.*(2000); Ferrier *et al.*(2001; Valiela and Bowen, (2002);Marouf et Remini., (2016); Marouf *et al.* (2019); .Soltani et al ., (2020) His seasonal variations in nutrient concentrations highlight the importance of understanding how human activities interact with natural processes to shape water and nutrient flow in the study region.

Correlation matrice

	EC	TDS	pH	DO	NH_4	NO_2	NO_3	DIN	PO_4	SiO_4	H	Pp	T	Ws
EC	1,000													
TDS	***0,999	1,000												
pH	*-0,815	*-0,818	1,000											
DO	-0,353	-0,347	0,701	1,000										
NH_4	0,339	0,335	-0,645	*-0,771	1,000									
NO_2	*0,807	*0,797	-0,834	*-0,710	0,602	1,000								
NO_3	0,112	0,099	0,145	0,179	-0,005	0,202	1,000							
DIN	0,291	0,278	-0,082	-0,035	0,192	0,434	***0,968	1,000						
PO_4	0,704	0,697	*-0,761	-0,691	0,457	**0,902	0,308	0,501	1,000					
SiO_4	0,334	0,326	-0,254	-0,330	0,273	0,473	*0,793	**0,851	0,673	1,000				
H	-0,636	-0,643	0,584	0,285	-0,613	-0,391	0,153	0,018	-0,237	-0,032	1,000			
Pp	-0,006	0,004	0,323	*0,744	-0,332	-0,479	0,046	-0,078	-0,653	-0,322	-0,218	1,000		
T	0,135	0,129	-0,439	-0,376	*0,737	0,440	0,250	0,376	0,284	0,194	-0,218	-0,143	1,000	
Ws	0,146	0,150	-0,304	-0,316	0,116	0,138	**-0,895	*-0,794	-0,079	*-0,728	-0,218	-0,143	-0,143	1,000

(A)

* P value (Significant correlation) at the 0.05 level; **P Value at the 0.01 level; ***P Value at the 0.001 level



(C)

	F1	F2
EC	0,803	-0,155
TDS	0,796	-0,165
pH	-0,878	0,374
DO	-0,739	0,322
NH_4	0,718	-0,202
NO_2	0,951	-0,071
NO_3	0,261	0,950
DIN	0,487	0,852
PO_4	0,911	0,112
SIO_4	0,600	0,718
H	-0,527	0,370
Pp	-0,439	0,069
T	0,502	0,104
Ws	-0,014	-0,958

Figure 3. Statistical analysis results. **(A):** Correlation matrix of the physicochemical parameters of water samples; **(B):** Factorial plan projection 1 × 2 of principal component analysis; **(C):** Factorial charges and variance explained in the factorial analysis of the variables assessed, after rotation using the varimax method.

Human activities play a crucial role in the variations of nutrient concentrations and water quality. For example, the elevated levels of DIN (dissolved inorganic nitrogen) in the Oued El-Kotonne River in February can be attributed to increased agricultural runoff during the wet season. This increase in runoff carries nitrogen-rich fertilizers from agricultural fields to watercourses, which can exacerbate the process of eutrophication. In contrast, the low phosphate concentrations observed at most sampling stations may be influenced by specific human activities. For instance, the use of phosphate-free detergents reduces the input of phosphates into aquatic systems. Additionally, wastewater treatment processes that efficiently remove phosphates from effluents also contribute to this decrease(Mebarki, 2005; Mebarki, 2010; Marouf ,2016; Bouchareb,2022) . Conversely, agricultural operations that aren't well-managed can lead to the pollution of both surface and groundwater due to the presence of nutrients and pesticides, as discussed by Spalding and Exner (1993); Pereira *et al.* (1996); Kolpin *et al.* (1998); Novotny (1999); Gunningham and Sinclair (2005). Regular use of these agricultural substances can lead to their dispersion into the environment through drift, runoff, and drainage as found by Kolpin *et al.* (1998); Guzzella *et al.*(2006); Papastergiou and Papadopoulou (2001). This can ultimately lead to the detection of these residues in groundwater (Lacorte and Barcelo,1996), river waters (Irace-Guigand *et al.* 2004; Claver *et al.* 2006), as well as coastal waters and lakes (Konstantinou *et al.* 2006). These findings suggest that these residues can mobilize and be found at considerable distances from their original application points. The data on water delivery to the Jijel coastal region reveals that the Oued Rhumel River contributes the highest volume of water during the wet period. This suggests that this river may be crucial in transporting nutrients and other contaminants to the coastal area (; (Ounissi, 2014; Bouchareb, 2022). Understanding the factors that drive changes in water delivery, such as seasonal precipitation patterns or human interventions like water extraction and dam construction, is essential for managing water resources and protecting the ecological integrity of the northeastern coast of Algeria.

5. **Conclusion**

This study underscores the importance of understanding the complex interplay between human activities and natural processes in shaping the flow of water and nutrients in the Kebir-Rhumel basin. By identifying the key drivers of water quality and nutrient dynamics, our findings can inform targeted management strategies to mitigate the impacts of human activities on the region's water resources and ecosystems. Future research should focus on elucidating the specific human activities contributing to water quality degradation and nutrient imbalances, as well as exploring potential mitigation measures and management strategies to promote sustainable development on the northeastern coast of Algeria.

The significant characteristics of the studied rivers are the high values of NH_4 and PO_4, contrary to SiO_4 levels that were remarkably lowered because of their retention in dams. The other particularity is that direct wastewater inputs from the neighboring big cities and several villages heavily polluted the dams. Surprisingly, the K.R. and K.W. dams' entrances, supposed to be protected, were heavily polluted by vital inputs of NH_4 and PO_4.

The findings highlight the urgent need for targeted intervention strategies to balance the anthropogenic activities that contribute to water quality degradation and nutrient imbalances. Future research should focus on identifying specific activities causing these imbalances, exploring potential mitigation measures To ultimately reduce the input of pollutants such as NH4 and PO4 into the Kebir-Rhumel basin, it is essential to develop and implement strict wastewater treatment regulations, improve dam management strategies to minimize the negative impacts of nutrient retention, create protective buffer zones around rivers and dam inlets, promote sustainable agricultural practices to reduce nutrient runoff, and intensify continuous water quality and nutrient level monitoring efforts while supporting research initiatives to identify specific human activities contributing to water quality degradation and explore effective mitigation strategies.

Authors contribution

N. B: Conceptualization, Methodology, Software, formal analysis, Writing - Review and Editing. S.B, A.L and K.H data curation, writing-original draft, Writing - Review and Editing. A.A; M.Cand R.B: data collection, data analysis

Data availability

All the data examined in this research are incorporated within this published paper along with its supplementary information materials.

Declarations

"All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors".

Competing interests

The authors declare no competing interests.

Ethics approval

The stated authors have agreed to be authors, have read and approved the work, and have given their consent for the manuscript to be submitted and published in the future. The author of this article further warrants that they will abide by Springer's publishing guidelines and agrees to submit it for publication as any sort of open-access article, thereby reaffirming their commitment to the subscriber accesscriteria and licensing.

Consent to participate

Not applicable.

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