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Environmental impact assessment of phosphate chemical complex in NE Algeria

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Abstract

Purpose. This study aims to assess the environmental impact of a proposed phosphate chemical complex in the Wadi Elkbarit region of northeastern Algeria, focusing on the potential risks associated with its operations.

Methods. A combination of analytical techniques was employed, including thermometers, turbidimeters, and various spectrophotometric methods, following standardized protocols (NF T and ISO) to assess water quality parameters. Chemical analyses of dam water and soil samples were conducted to determine heavy metal concentrations and nutrient content.

Findings. The facility is projected to generate significant environmental residues, including 2.07 to 2.53 million tons of phosphogypsum, approximately 2.3 thousand tons of sulfur emissions, and 5 to 10 thousand tons of fluoride compounds annually. Water quality analyses revealed alarming levels of heavy metals, with cadmium at 112.5 tons per year and lead at 50 tons per year, exceeding established standards. Soil analyses indicated nutrient and heavy metal concentration variability, raising concerns about soil health and agricultural safety.

Originality. This research contributes novel insights into the environmental implications of phosphate processing, particularly concerning contaminant migration through interconnected groundwater systems.

Practical implications. The findings underscore the urgent need for effective management strategies to mitigate environmental risks, particularly those linked to waste storage and wastewater discharge. Establishing robust monitoring systems and implementing remediation measures are essential for protecting water quality and promoting sustainable agricultural practices in the region.

Keywords: *phosphate, environmental, heavy metals, soil health, groundwater*

1. Introduction

Phosphoric acid production is a cornerstone of global agriculture and industry, serving as the basis for phosphate fertilizers that sustain food security and economic growth [1], [2]. With its substantial phosphate rock reserves, Algeria is well-positioned to expand this sector for domestic development and international trade [3]. However, a major environmental challenge arises from phosphogypsum (PG), a by-product of the production process. PG contains radionuclides and heavy metals, and its mismanagement has been linked to soil, water, and air contamination with serious health and regulatory implications [4]. In several mining regions, groundwater pollution from cadmium and lead has already exceeded safe drinking water thresholds [5]-[7].

Over the past decade, research has advanced significantly in characterizing PG and its environmental impacts. Recent studies have quantified primary, trace, and radioactive elements in PG from sites such as Turkey, highlighting the need for region-specific impurity profiling to inform management strategies [8]. The geochemical behavior of PG impurities, including fluorides, heavy metals, and radionuclides, has been shown to depend on environmental factors such as soil pH and redox conditions, which strongly influence leaching potential and ecological risk [9]. Other investigations report that PG disposal contributes to soil acidification, enhanced leaching of metals and radionuclides, microbial community disruption, and leachate concentrations several orders of magnitude higher than background levels [8]. At the nanoscale, PG particles can act as carriers for toxic and rare-earth elements (REEs), intensifying risks of bioaccumulation and long-term ecological damage [10].

Health-related consequences have also been documented. PG dust releases radon gas and heavy metal particulates that increase respiratory risks, including bronchitis and lung cancer, while promoting heavy metal uptake in crops with direct implications for food safety [11]. Promising remediation

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measures have been tested: for example, a 2023 study showed that mixing PG with topsoil and planting fast-growing woody species significantly reduced radionuclide emissions and limited their bioavailability to plants [12]. In addition, new approaches to resource recovery are emerging. A 2025 study proposed a bio-inspired adsorptive separation method for extracting REEs from PG, supported by life-cycle and techno-economic analyses. This approach demonstrated attractive profitability (IRR > 15%), although feasibility depends heavily on PG composition (REE content ≥ 0.5 wt%) and processing scale [13].

Despite these advances, significant gaps remain. Most studies have been conducted in America, Asia, or Europe, leaving MENA contexts largely unaddressed. Region-specific data on PG composition, transport pathways, and environmental behavior under semi-arid Mediterranean conditions are missing. Furthermore, few investigations provide long-term, integrated monitoring of contaminant dynamics across soil, water, and air compartments. While single-exposure pathways (for example, radionuclides or heavy metals) are often studied in isolation, comprehensive assessments that combine geochemical modeling, crop uptake, human health risk, and socio-economic vulnerability are scarce. Bioavailability experiments generally use model plants or generic agricultural systems, rather than local crops or endemic ecosystems relevant to Algeria. Finally, although vegetative capping and phytoremediation show promise, their feasibility, costs, and suitability under North African ecological and socio-economic conditions remain uncertain. Detailed information regarding the types of residues, concentrations of contaminants, health risk assessments, and environmental impact ratings is presented in Tables 1, 2, and 3.

Table 1. Residue types and contaminant concentrations

Residue type	Main contaminants	Average concentration (mg/kg)	Range of environmental concerns	Toxicity level (scale)
Phosphoric sludge (moderate concern)	Heavy metals (Cd, Pb, Hg)	4.5 (high)	150	> 100
Process wastewater (high concern)	Phosphates, fluorides, heavy metals	3.0 (moderate)	500	> 200
Dust emissions (moderate concern)	Particulate matter, sulfur oxides	3.0 (moderate)	300	> 150
Solid by-products (high concern)	Arsenic, radionuclides	5.0 (very high)	1.5	> 0.5

Table 2. Health risk assessment of residues

Contaminant	Primary health effects	Exposure pathway	Risk level
Cadmium (Cd)	Kidney damage, bone fragility	Ingestion, inhalation	High
Lead (Pb)	Neurological effects, developmental delays	Ingestion, inhalation	High
Arsenic (as)	Skin lesions, cancer risk	Ingestion, dermal contact	Very high
Fluorides (F-)	Dental and skeletal fluorosis	Ingestion, inhalation	Moderate
Radionuclides	Increased cancer risk, genetic mutations	Ingestion, inhalation	Very high

Table 3. Environmental impact ratings of residue types

Residue type	Water contamination	Soil contamination	Air quality impact	Cumulative environmental
Phosphoric sludge	4	5	2	4
Process wastewater	5	3	3	4
Dust emissions	2	2	3	5
Solid by-products	3	4	1	4

Although recent research has clarified impurity profiles, contaminant pathways, potential for REE recovery, and tested some remediation strategies, there is still a lack of integrated, regionally adapted assessments for semi-arid areas such as Wadi Elkbarit. Specifically, no study has characterized PG waste and its mobility in local soils, groundwater, and air, nor examined contaminant bioavailability in endemic crops, ecological responses, or the suitability of tailored mitigation strategies. Addressing this gap, the present study develops a comprehensive baseline for Wadi Elkbarit by integrating environmental, ecological, and socio-economic data. The analysis assesses contaminant fates and risks, proposes context-specific remediation measures, and aligns with global sustainable development priorities, spotless water and sanitation (SDG 6), responsible production and consumption (SDG 12), and climate action (SDG 13) [14]. In doing so, it provides a framework for informed decision-making that supports sustainable industrial development without compromising the ecological integrity or socio-economic resilience of the Wadi Elkbarit region.

2. Study area

Wadi Elkbarit, located in the Souk Ahras province, northeastern Algeria, is approximately 40 km south of the chief town. This region is near the Mellegue Dam, a crucial water reservoir that supports local agriculture and communities and lies within the Medjerda-Mellegue watershed (35° 58′ 35″ N and 08° 01′ 50″ E). The area's diverse topography includes hills, valleys, and plains with elevations ranging from 400 to 1200 meters, influencing local hydrology and microclimates. The geological features, such as fractured bedrock formations and low-permeability marly layers, affect water drainage and soil stability.

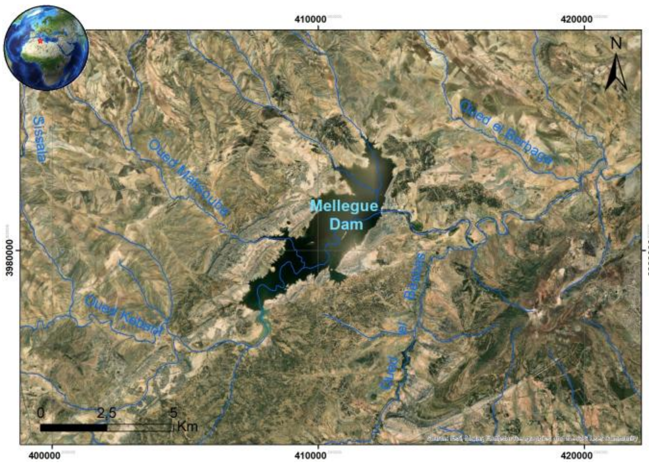

Figure 1. Site of the phosphoric acid production plant

Geological structures displayed numerous faults and inclined strata that can facilitate rapid contaminant migration, further complicating the environmental impact assessment (Fig. 2). The interconnected nature of surface and groundwater systems indicates that contamination from the plant could spread quickly, necessitating an integrated water resource management approach. Preventive measures, including impermeable liners and continuous monitoring, are essential to mitigate these risks.

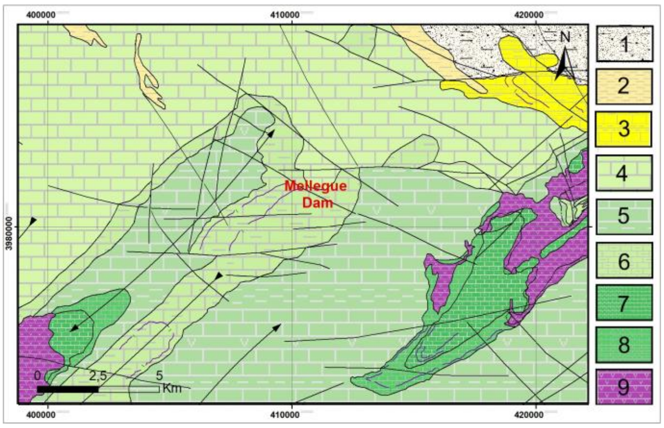

Figure 2. Geologic map of the study area: 1 – Quaternary (Holocene). Current and recent alluvium, local landslides from slopes, and piedmont accumulation (sands, gravels, and clays) and molasses; 2 – Quaternary: limestone crust – ancient quaternary deposits with a crusted surface; 3 – Lower Miocene: sandstones, marls, and limestone beds; 4 – Upper Cretaceous (Coniacian and Santonian): limestones; 5 – Upper Cretaceous (Cenomanian): yellow limestones, marls, gypsum, and dolomites; 6 – Upper Cretaceous (Turonian): limestones and marls; 7 – Lower Cretaceous (Albian): sandstones, ochre limestones, and clays; 8 – Lower Cretaceous (Aptian): limestones and sandstones; 9 – Triassic: gypsums, clays, and black dolomites

The ecology of Wadi Elkbarit is characterized by drought-resistant vegetation like Aleppo pine and holm oak, which provide habitats for wildlife, including endangered species such as the Barbary macaque [15]. Wetlands near the Wadi Mellegue Dam are vital for migratory birds, but face threats from pollution and reduced water flow. The proposed phosphoric acid plant could significantly impact water quality, with predictive models indicating a potential increase in phosphate levels by 15-25% and heavy metal concentrations in groundwater exceeding WHO guidelines by 20-30%. This situation raises concerns about agriculture, food security, and public health, underscoring the necessity for sustainable practices to mitigate these risks.

The region experiences a semi-arid climate with limited rainfall (300-400 mm annually) and high evaporation rates. Most precipitation occurs in winter, while summers are dry, contributing to water scarcity that affects agricultural productivity [16]. The Ouldjet Mellegue Dam captures seasonal runoff and supports groundwater recharge. Yet, reliance on these water resources makes the area susceptible to contamination from industrial activities.

The socio-economic landscape of Wadi Elkbarit is heavily reliant on the Wadi Mellegue Dam and groundwater for agriculture and domestic use. The population of approximately 200000, with nearly 60% under 30 years old, is primarily engaged in agriculture, livestock rearing, and small-scale trade [17], [18]. Key crops such as cereals, olives, and fruits depend on irrigation from the dam, while livestock farming supports rural livelihoods. However, this dependence on natural resources increases vulnerability to environmental degradation, including soil and water pollution, which can threaten food security [19]-[21].

3. Methods

The proposed chemical complex is planned to be constructed on a 350-hectare site in the Wadi El Kbarit region of northeastern Algeria, straddling the border of Tebessa and Souk Ahras provinces (Fig. 1). A variety of analytical methods were employed, including thermometers, turbidimeters, and multiple spectrophotometric techniques, adhering to standardized protocols (NF T and ISO standards) for assessing water quality parameters. The expected annual production of the complex includes 230 thousand tons of sulfuric acid (H_2SO_4), 460 thousand tons of phosphoric acid (H_3PO_4), 100 thousand tons of mono-calcium phosphate (MCP), 150 thousand tons of di-calcium phosphate (DCP), 120 thousand tons of triple super phosphate (TSP) fertilizer, 80 thousand tons of potassium sulfate (SOP) fertilizer, and 65 thousand tons of calcium chloride ($CaCl_2$).

The residues generated during the manufacturing processes were analyzed to assess the environmental impact of the proposed facility. The primary residues include phosphogypsum, generated from the reaction of phosphate ore with sulfuric acid, with an estimated range of 2070000 to 2530000 tons per year based on the planned production of phosphoric acid. Sulfur dioxide (SO_2) and sulfur trioxide (SO_3) emissions arising from sulfuric acid production are estimated at approximately 2300 tons per year, assuming a 1% emission rate. Fluoride compounds, released during phosphoric acid production, could generate residues ranging from 5000 to 10000 tons per year, depending on scrubbing efficiency. Solid waste from phosphate ore processing is estimated to be between 0.5 and 1.0 mln t/year.

Phosphate ore samples were systematically collected using standardized protocols to ensure representativeness. The samples were analyzed in SOMIPHOS laboratories for their characterization. Advanced techniques such as X-ray fluorescence (XRF) for elemental composition and inductively coupled plasma mass spectrometry (ICP-MS) for trace heavy metal detection were employed to quantify key elements, including phosphorus, cadmium, lead, arsenic, chromium, uranium, and mercury. This collaboration enhanced data quality and ensured alignment with industry standards.

Soil sampling involved collecting 15 samples from various land-use types in the Wadi Elkbarit region, focusing on areas at risk of contamination. Soil analyses measured pH, nutrient content, and heavy metal concentrations. Water quality analysis included samples from the Wadi Mellegue Dam and nearby groundwater sources to assess risks associated with phosphoric acid production. Air quality monitoring establishes baseline levels of particulate matter and gaseous pollutants near the plant site using advanced monitoring equipment. Hydrogeological surveys mapped subsurface characteristics and aquifer dynamics to assess potential contaminant migration pathways [22]-[24].

4. Results and discussion

The estimated annual residues from the proposed facility present significant environmental implications. Specifically, phosphogypsum, a by-product of phosphoric acid production, could reach between 2.07 and 2.53 million tons. Additionally, sulfur emissions are projected at approximately 2.3 thousand tons annually, while fluoride residues may range from 5 to 10 thousand tons. The concentration of heavy metals in the phosphate ores, including cadmium, lead, arsenic, and uranium, raises concerns about their accumulation in phosphogypsum and wastewater.

The chemical analysis of heavy metal residues in dam water, presented in Table 4, reveals concerning levels of several toxic metals. Cadmium (Cd) is estimated at 112.5 tons/year, raising alarms due to its potential to accumulate in the environment and pose health risks. Lead (Pb), estimated at 50 tons/year, is particularly hazardous, especially for neurological development of children. Arsenic (As) levels are estimated at 70 tons/year; this metal is known for its carcinogenic properties, posing serious health threats if present in drinking water. Chromium (Cr) at 500 tons/year presents additional health risks, including respiratory issues and skin irritation. Uranium (U), estimated at 375 tons/year, poses dangers due to its radioactive nature, while mercury (Hg) at 2.5 tons/year is highly toxic to aquatic organisms and humans.

Table 4. Estimated heavy metal residues

Heavy metals	% ppm	Estimated heavy metal residues tons/year,
Cadmium (Cd)	45	112.5
Lead (Pb)	20	50.0
Arsenic (As)	30	70.0
Chromium (Cr)	200	500.0
Uranium (U)	150	375.0
Mercury (Hg)	1	2.5

These heavy metal levels are alarming compared to established water quality standards. Regulatory bodies like the World Health Organization (WHO) set stringent limits for contaminants in drinking water, recommending maximums of 0.003 mg/L for cadmium, 0.01 mg/L for lead, and 0.01 mg/L for arsenic. The estimated heavy metal residues significantly exceed these permissible levels. Furthermore, Table 5 highlights the substantial waste outputs from the proposed facility, including approximately 2.07 million tons of phosphogypsum, 2300 tons of SO_2/SO_3 emissions, and around 5000 tons of fluoride compounds.

Table 5. Estimated residues from the proposed facility

Waste streams	Estimated quantities million tons/year
Phosphogypsum	~2.07
SO_2/SO_3 Emissions	~0.0023
Fluoride Compounds	~0.005

These indicate a high potential for environmental impact, particularly regarding the leaching of heavy metals into local water sources. These high levels of heavy metal residues and the extensive waste generated by the proposed facility emphasize the critical need for effective management and remediation strategies. These measures are essential to mitigate contamination risks and protect the water quality in the region.

Soil analyses indicated significant risks of acidification and heavy metal contamination, particularly near potential spill points and agricultural lands. Preliminary findings suggest that the proposed plant could exacerbate soil quality degradation, potentially leaching pollutants into groundwater systems. The chemical analysis of soil samples from the study area, detailed in Table 6, indicates significant variability in key nutrients and oxides critical for assessing soil fertility and health. Moisture content (H_2O) ranges from 2.09 to 11.22%, reflecting diverse soil moisture retention capabilities. Phosphorus pentoxide (P_2O_5) levels are generally low, with a maximum of 0.55% in Sample 1 and a minimum of 0.02% in Sample 6. This suggests that phosphorus availability may limit plant growth, as optimal phosphorus levels are essential for healthy root development.

Table 6. Soil chemical analysis in the study area, %

Sample	H_2O	P_2O_5	CO_2	MgO	CaO	Fe_2O_3	Na_2O	K_2O
1	06.90	0.55	15.94	2.21	20.18	4.46	0.61	0.15
2	05.92	0.17	10.63	2.35	13.48	5.80	0.60	0.08
3	04.16	0.12	6.64	1.21	8.35	3.14	0.32	0.17
4	06.22	0.14	9.96	1.18	12.55	3.12	0.49	0.09
5	02.92	0.05	9.30	1.16	11.82	3.20	0.36	0.08
6	02.78	0.02	7.97	1.14	10.05	3.17	0.42	0.14
7	07.52	0.06	9.96	1.21	12.53	3.12	0.49	0.15
8	02.09	0.04	9.96	1.11	12.58	3.06	0.61	0.10
9	04.81	0.06	9.30	1.23	11.90	0.72	0.76	0.12
10	11.22	0.12	6.64	1.19	8.41	3.23	0.64	0.06
11	11.21	0.06	6.64	1.16	8.55	3.26	0.58	0.08
12	05.19	0.05	9.96	1.03	12.51	3.00	0.71	0.15
13	11.60	0.07	9.30	1.01	11.86	3.03	0.30	0.19
14	04.49	0.008	6.64	1.09	8.31	2.92	0.69	0.24
15	12.59	0.01	9.30	1.00	11.85	3.51	0.31	0.14

Calcium oxide (CaO) levels vary between 8.31% and 20.18%, indicating that some samples may provide good structural integrity for crops, while others may require soil amendments. Magnesium oxide (MgO) concentrations range from 1.00 to 2.35%, generally acceptable for plant nutrition. Additionally, iron oxide (Fe_2O_3) levels range from 0.72 to 5.80%, highlighting its importance in various biochemical processes within plants.

Table 7 presents the analysis of heavy metals in the same soil samples, revealing concerning concentrations of toxic elements. Arsenic (As) levels range from 0.73 to 6.76 ppm, with Sample 10 showing the highest concentration. These values may exceed acceptable limits for agricultural soil, as the U.S. Environmental Protection Agency (EPA) recommends a maximum of 0.2 ppm for arsenic in residential soils.

Table 7. Analysis of heavy metal content in soil in the study area

Sample	As, ppm	Hg, ppm	Cd, ppm	Pb, ppm
1	1.51	0.02	0.12	50.00
2	0.84	0.08	0.65	35.76
3	0.73	0.14	0.54	23.65
4	0.92	0.34	0.32	45.54
5	0.88	0.08	0.15	43.34
6	1.46	0.09	0.17	32.54
7	1.59	0.11	0.16	34.12
8	1.09	0.32	0.14	35.87
9	1.20	0.03	0.22	38.45
10	6.76	0.04	0.22	37.34
11	0.89	0.09	0.43	39.98
12	1.59	0.22	0.16	39.37
13	1.97	0.06	0.14	30.63
14	2.46	0.02	0.13	37.65
15	1.49	0.11	0.10	43.98

Mercury (Hg) concentrations are low, ranging from 0.02 to 0.34 ppm, but even minimal levels can be harmful, particularly in food crops. Cadmium (Cd) levels vary from 0.10 to 0.65 ppm, with some samples approaching or exceeding the 0.1 ppm limit for agricultural soils. Lead (Pb) concentrations are particularly high across all samples, reaching up to 50.00 ppm in Sample 1, which significantly exceeds the EPA's residential soil limit of 400 ppm.

In conclusion, while the nutrient levels indicate varying degrees of soil fertility, the presence of heavy metals, especially lead and arsenic, raises serious concerns regarding soil health and safety for agricultural use. These findings underscore the urgent need for further investigation and potential remediation strategies to address contamination and ensure the safety of the soil for environmental and agricultural applications.

In addition to groundwater, the Ouldjet Mellague dam, a vital water source, meets regulatory standards but requires protective measures due to its proximity to the proposed site. The potential for pollution from industrial discharges or accidental spills necessitates establishing a robust monitoring system to protect this resource. The chemical composition of groundwater from the study area is detailed in Table 8. Whereas Table 9 presents the physicochemical analysis of the Ouldjet Mellegue dam water at a depth of 1 m.

Table 8. Chemical composition of groundwater from the study area

Well	pH	CE µS/cm	RS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Cl mg/l	SO_4^{2-} mg/l	NO_3^- mg/l	HCO_3^- mg/l
P1	6.90	2440	1660	260.88	64.32	144.00	1.00	125.00	716.00	30.00	329.40
P2	8.22	1730	1130	39.36	22.49	335.00	8.00	40.00	116.00	00.00	939.40
P3	7.18	1510	1000	139.58	53.33	102.00	6.00	170.00	320.00	05.00	225.70
P4	6.92	6240	4000	321.02	183.79	770.00	5.00	815.00	1860.00	00.00	91.00
P5	7.08	4520	3000	259.01	98.90	540.00	7.00	695.00	940.00	12.00	366.00
P6	7.12	3020	1990	231.80	88.86	255.00	5.00	340.00	776.00	11.00	262.30
P7	7.13	3080	2010	224.80	61.92	345.00	6.00	365.00	848.00	19.00	244.00
P8	6.53	4090	2700	292.60	52.42	540.00	5.00	440.00	1360.00	00.00	103.70
P9	7.21	4330	2726	459.60	204.47	130.00	4.00	300.00	1536.00	97.00	146.40

The chemical analysis of the dam water permits to assess its quality in relation to established standards. The temperature measured at 25°C falls within the acceptable range, remaining below the maximum limit of 30°C, which is conducive to aquatic life. The pH value of 7.58 is also appropriate, as it falls within the recommended range of 6.5 to 8.5, indicating a balanced level of acidity. Conductivity at 1538 µS/cm is significantly lower than the maximum threshold of 2800 µS/cm, suggesting that the water has a low ionic concentration, indicating good quality.

However, the dry residue recorded at 1140 mg/l exceeds the acceptable limit of 2000 mg/l, indicating a concerning concentration of dissolved solids. The turbidity level is slightly elevated at 2.8 NTU, above the permissible limit of 2 NTU and may hinder light penetration in the water, potentially affecting aquatic ecosystems. The concentration of suspended solids is low at 10.25 mg/l, which is significantly below the maximum allowable limit of 40 mg/l.

A notable concern is the total hardness, which is measured at 644 mg/l, surpassing the recommended limit of 500 mg/l. This high hardness level could impact both domestic use and agricultural applications. Additionally, calcium and magnesium levels are elevated, at 618.63 and 175 mg/l, respectively, exceeding their respective limits of 200 and 150 mg/l.

Chloride levels are acceptable at 205.9 mg/l; however, sulfate concentrations are alarmingly high at 898.41 mg/l, which exceeds the maximum limit of 400 mg/l and raises potential environmental concerns, including risks of eutrophication. On a positive note, nutrient levels are favorable, with nitrates and phosphates below detection limits, and ammonium is very low at 0.03 mg/l.

Conversely, the organic matter concentration is significantly elevated at 49.2 mg/l, far exceeding the limit of 3.5 mg/l, which suggests potential pollution. Dissolved oxygen levels are healthy at 9.6 mg/l, supporting aquatic life, and all tested heavy metals are below their maximum permissible limits, indicating minimal contamination from these substances. Piezometric measurements indicate a potential "swelling" of the aquifer at Jebel Krorza, suggesting that the natural hydraulic regime of the aquifer may remain stable. However, seasonal variations could alter groundwater dynamics, increasing contamination risks. The primary concern is the leaching of pollutants from phosphogypsum stacks and wastewater discharge into the aquifer, which could compromise drinking water supplies and agricultural irrigation. The study recommends installing additional piezometers to monitor aquifer behavior and groundwater levels to address these risks. This data is crucial for understanding how the plant's operations might affect groundwater dynamics and for identifying contamination pathways. Integrating these findings into the environmental impact assessment will allow stakeholders to develop targeted mitigation strategies, such as lined containment systems for phosphogypsum and advanced wastewater treatment solutions.

Table 9. Analysis of the Ouldjet Mellegue dam water (depth 1 m)

Parameter	Unit	Limit value	Analysis method	Result
Temperature	°C	30	Thermometer	25
pH	pH Unit	6.5-8.5	NF T 90-008	7.58
Conductivity at 25°C	µS/cm	max 2800	ISO 7888	1538
Dry residue after drying at 105°C	mg/l	max 2000	NF T 90-029	1140
Turbidity	NTU	2	Turbidimeter	2.8
Suspended solids (SS)	mg/l	40	NF T 90-105	10.25
Total hardness (TH)	mg/l	max 500	ISO 6059	644
Calcium (Ca^{2+})	mg/l	max 200	ISO 6058	618.63
Magnesium (Mg^{2+})	mg/l	max 150	ISO 6058	175
Carbonates (CO_3^{2-})	mg/l	//	ISO 9963-2	2.2
Bicarbonates (HCO_3^-)	mg/l	//	NF T0-036	53
Chlorides (Cl^-)	mg/l	max 500	NF T90-014	205.9
Sulfates (SO_4^{2-})	mg/l	max 400	ISO 9280	898.41
Potassium (K^+)	mg/l	max 20	ISO 9964-3	2
Sodium (Na^+)	mg/l	max 200	ISO 9964-3	150
BOD_5	mg/l	(O2)	ISO 5815-2	7
COD	mg/l	–	ISO 6060	22
Organic matter (OM)	mg/l	3.5	Acid Method	49.2
Dissolved oxygen	mg/l	–	Oximetry	9.6
Ammonium NH_4^+	mg/l	max 7.5	Spectrophotometry	0.03
Nitrates (NO_3^-)	mg/l	max 50	T 90-012	00
Nitrites (NO_2^-)	mg/l	max 1.0	ISO 5667	0.23
Phosphorus (P)	mg/l	max 0.5	Spectrophotometry	0.0
Cadmium (Cd)	mg/l	max 0.1	ISO 11885	< 0.0002
Iron (Fe)	mg/l	–	ISO 6332	0.7
Lead (Pb)	mg/l	max 0.01	Spectrophotometry	0.0001
Chromium (Cr)	mg/l	max 0.75	ISO 9174	0.01
Manganese (Mn)	mg/l	max 0.5	Spectrophotometry	0.01
Aluminium (Al)	mg/l	max 5.0	Spectrophotometry	< 0.001
Arsenic (As)	mg/l	max 0.01	Spectrophotometry	< 0.0001
Mercury (Hg)	mg/l	max 0.01	Spectrophotometry	< 0.0002

Protecting the region's groundwater resources is essential for maintaining agricultural productivity, ensuring drinking water safety, and preserving ecological health. Proactive monitoring and adaptive management will ensure that the plant's operations align with sustainable water resource management practices in the Wadi Elkbarit region.

Air quality in Wadi Elkbarit is generally favorable, with levels of particulate matter (PM2.5 ranging from 20 to 30 µg/m^3 and PM10 from 40 to 50 µg/m^3) remaining within acceptable limits. However, dust storms can occasionally increase these levels [22]. Gaseous pollutants such as sulfur dioxide (5 to 10 µg/m^3) and nitrogen oxides (10 to 15 µg/m^3) are also low, indicative of limited industrial activity in the area [23]. Trace amounts of hydrogen fluoride (0.5 to 1.0 µg/m^3) and silicon tetrafluoride, likely originating from natural or agricultural sources, can be observed. While strong winds and low humidity facilitate the dispersion of pollutants, they also heighten the risk of dust transport [24]. These baseline measurements serve as a crucial reference point for assessing potential changes in air quality resulting from the proposed phosphoric acid plant, informing effective emission control strategies to safeguard public health and environmental integrity.

The proposed phosphoric acid plant in Wadi Elkbarit poses significant socio-economic challenges, particularly given the region's reliance on agriculture. Environmental degradation from industrial activities threatens livelihoods by contaminating soil and water with heavy metals and phosphates, reducing agricultural productivity and jeopardizing food security. Additionally, poor water quality may increase household expenses for safe drinking water. At the same time, airborne pollutants like hydrogen fluoride and particulate matter can worsen respiratory and cardiovascular health, disproportionately affecting vulnerable groups such as children and older people. Biodiversity loss may further disrupt traditional livelihoods, exacerbating community inequalities.

To address these risks, practical risk assessment is crucial in prioritizing concerns such as water contamination from phosphogypsum leaching and wastewater discharge, which threaten water safety and agricultural productivity. Soil degradation from heavy metals and excess phosphates poses significant risks, while medium-priority risks include air pollution that can harm public health. Low-priority risks, such as habitat loss and biodiversity decline, can be managed through targeted conservation efforts.

Robust waste management practices are essential for minimizing environmental impacts. Phosphogypsum should be contained in engineered facilities to prevent leaching of contaminants. Furthermore, advanced wastewater treatment technologies can effectively remove harmful substances, ensuring compliance with environmental standards and allowing for repurposing treated wastewater for irrigation or industrial use.

Pollution control measures are also vital for reducing emissions from the plant. Advanced scrubbing systems and particulate matter management technologies can significantly improve air quality. Continuous monitoring will ensure compliance with regulations and protect public health.

Protecting water resources is critical. Measures such as lined containment ponds, stormwater management systems, and monitoring wells can help prevent surface and groundwater contamination. A closed-loop water system will further enhance resource conservation.

Ongoing environmental monitoring is necessary to identify and mitigate emerging risks. Regular sampling and real-time pollutant tracking will foster transparency and allow adaptive management strategies. Engaging the local community in these efforts will further enhance sustainability.

Overall, this study highlights the complex implications of the phosphoric acid plant in the Wadi Elkbarit region. Predictive modeling indicates significant risks to water quality, soil health, air quality, and biodiversity, emphasizing the urgent need for sustainable practices and proactive mitigation strategies. The socio-economic impacts, particularly on vulnerable populations, underscore the necessity for inclusive policies and community engagement to ensure long-term resilience and well-being in the region. By integrating environmental protection with socio-economic development, stakeholders can foster a sustainable future for Wadi Elkbarit.

5. Conclusions

The proposed phosphoric acid plant in Wadi Elkbarit poses significant environmental and socio-economic challenges that require urgent attention. This study identifies risks associated with water and soil contamination, air quality degradation, and their impacts on community health and livelihoods. By integrating predictive modeling and risk assessment, the research thoroughly explains how industrial activities could jeopardize agricultural productivity and public well-being.

To safeguard the interests of the Wadi Elkbarit community, it is essential to implement proactive strategies that prioritize environmental health and public safety. Utilizing advanced waste management practices and pollution control technologies, coupled with robust monitoring and adaptive management, will be crucial in mitigating the adverse effects of the plant. Moreover, fostering community engagement and inclusive policies will ensure vulnerable populations have a voice in decision-making processes, enhancing resilience against socio-economic disparities.

This research underscores the need for a balanced approach integrating industrial development with environmental sustainability. By committing to responsible practices and prioritizing the health of ecosystems and communities, stakeholders can create a sustainable future for Wadi Elkbarit, preserving the region's resources for future generations. The findings highlight the vulnerabilities of water resources, potential soil degradation, air pollution risks, and threats to biodiversity.

The socio-economic implications are significant, with potential effects on livelihoods, food security, and healthcare costs, particularly for vulnerable groups. To address these challenges, the study recommends adopting advanced waste management, pollution control measures, and biodiversity conservation and sustainable land use practices. Robust environmental monitoring and community engagement are vital for ensuring transparency and long-term sustainability.

This research emphasizes integrating scientific evidence into policy and practice to guide sustainable industrial development. By adopting the recommended mitigation strategies, stakeholders can minimize the adverse impacts of the phosphoric acid plant while enhancing its economic benefits. This study is a valuable resource for policymakers, industry operators, and local communities, offering a roadmap for achieving sustainable development that balances economic growth with environmental and social well-being in the Wadi Elkbarit region. Future research should focus on long-term ecological monitoring, innovative production technologies, and interdisciplinary management approaches. By combining scientific research with community engagement and policy innovation, this study advocates for sustainable industrial practices that protect ecological integrity and strengthen socio-economic resilience, serving as a model for other regions facing similar challenges.

Author contributions

Conceptualization: KR, RH; Data curation: KR, AH; Formal analysis: KR, TD, RH; Funding acquisition: LB, CM; Investigation: KR, CM; Methodology: KR, RH; Project administration: KH, LB; Resources: TD; Software: RH; Supervision: RH, TD; Validation: KR, RH; Visualization: KR, RH; Writing – original draft: KR; Writing – review & editing: RH. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

Authors RH declares that he was editorial board members of the Mining of Mineral Deposit journal at the time of submission, which had no impact on the peer review process or the final decision. The remaining authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Оцінка впливу фосфатно-хімічного комплексу на навколишнє середовище у північно-східному Алжирі

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Мета. Оцінка впливу досліджуваного фосфатно-хімічного комплексу на довкілля в регіоні Ваді-Елкбаріт на північному сході Алжиру, зосереджуючись на потенційних екологічних ризиках для водних і земельних ресурсів, пов'язаних з його діяльністю.

Методика. У дослідженні використано комбінацію аналітичних методів, включаючи термометри, мутноміри та різні спектрофотометричні методи, дотримуючись стандартизованих протоколів (NF T та ISO), для оцінки параметрів якості води. Були проведені хімічні аналізи проб води і ґрунту дамби для визначення концентрації важких металів та вмісту поживних речовин

Результати. Визначено, що об'єкт буде генерувати значні обсяги відходів, які впливають на навколишнє середовище, зокрема від 2,07 до 2,53 млн т фосфогіпсу, приблизно 2,3 тис. т викидів сірки та від 5 до 10 тис. т фторидних сполук щорічно. Виявлено за допомогою комплексу аналізів якості води загрозливі рівні вмісту важких металів: кадмію – 112,5 т на рік і свинцю – 50 т на рік, що перевищує встановлені екологічні норми. Аналіз ґрунту показав мінливість концентрації поживних речовин і важких металів, що викликає занепокоєння щодо стану ґрунту та безпеки сільського господарства.

Наукова новизна. Проведене дослідження сприяє новому розумінню екологічних наслідків переробки фосфатів, зокрема щодо міграції забруднюючих речовин через взаємопов'язані системи ґрунтових вод.

Практична значимість. Результати дослідження підкреслюють нагальну необхідність розробки ефективних стратегій управління для зменшення екологічних ризиків, особливо тих, що пов'язані зі зберіганням відходів та скиданням стічних вод. Створення надійних систем моніторингу і впровадження заходів з відновлення є надзвичайно важливими для захисту якості води та сприяння сталому розвитку сільського господарства в регіоні.

Ключові слова: *фосфат, навколишнє середовище, важкі метали, стан ґрунту, ґрунтові води*

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