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Research paper

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The environmental impact of dam construction in a wetland area. A case study Boukhroufa (El Taref) Algeria

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Summary

This article presents an approach to the assessment of the environmental impact of a dam construction for agricultural use in the Boutheldja region. This region's environment is rich in natural resources and forms a part of the El Kala National Park (P.N.E.K). It was designated a wetland of international importance under the Ramsar convention by UNESCO in 1983 and later declared a biosphere reserve in 1990. It is among the most significant aquatic areas in this region (contains about 40% of surface water resources). The physical characteristics of the watershed support the construction of the dam, although there could be a number of unfavorable effects: upstream – including soil erosion and reservoir sedimentation, reduced storage capacity, lower water quality and loss of productivity of flooded area; downstream – removal of silt from downstream flows, loss of fertilising functions, changes in water quality, changes in productivity, reduction in natural floods, loss of access to resources and ecological disturbance. Such processes will have an impact on an ecosystem so fragile. Although Boukhroufa dam provides significant benefits to the city, such as controlling stream regime, preventing floods, and supplying agricultural water from stored water, it also has significant negative effects on the surrounding watershed ecosystem.

Keywords

watershed • Boukhroufa dam • El Taref • environmental impact • flood

1. Introduction

A valuable and treasured resource, water is becoming as important politically and economically as oil has been over the past three decades. As river water flows downstream, its composition may change due to a variety of natural chemical, physical, and biological processes, interactions with riparian vegetation and even with rocks and groundwater [OECD 2011]. Furthermore, during floodings water undergoes significant temporal modification. In order to preserve the ecosystem, we have to maintain a balance between the amount of water used for consumption (drinking water, industry, and agricultural irrigation) and the amount needed to meet environmental flow requirements for the biodiversity and efficient functioning of river ecosystems [Mofizul et al. 2022]. As far as water supply is concerned, dams represent the largest human modifications to the hydrological cycle and have influenced social development for ages.

Dams are constructed on rivers to act as barriers for various purposes, such as water storage, flood control, irrigation supply, and drinking water [Dursun 2017]. The development of engineering infrastructure, such as dams on rivers, has altered riparian ecosystems, endangering the biodiversity that depends on the water and its quality. Dams reduce river water flows and cut off rivers from their wetlands and floodplains [Acreman 2000]. Reduced flows within the Basin have already resulted in environmental problems such as increased salinity, intensified algal blooms, and impaired wetland health [Mahmood et al. 2020]. Environmental consequences were not considered when dams were built, particularly in developed countries, and were not taken into consideration until the 1970s [Kondolf 2007].

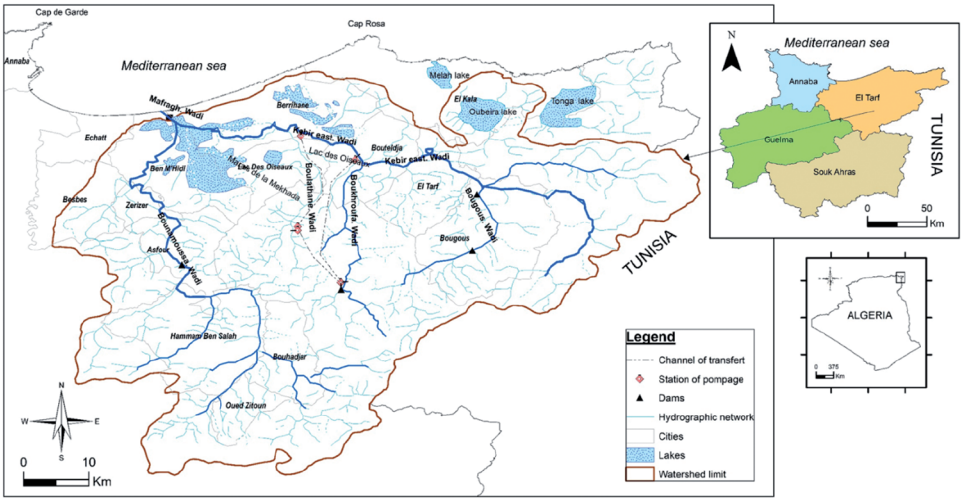
Algeria is one of the emerging countries and the majority of its dams were built recently. According to the Ministry of Water Resources and the National Agency for Dams and Water Transfer [2022], there are 72 dams in operation and further 61 proposed (under study) or under construction dams in various river basins. The Boukhroufa dam, originally known as Bouhaloufa dam, is being built near the town of El Tarf in north-eastern Algeria in order to meet its water needs for agriculture. Boukhroufa dam will be able to store 125 hm^3 of water after being transferred from the El Kebir and Boulatane wadies. However, it may also have a number of irreversible effects on the region at human, economic, and environmental level. An attempt was made to study to impact of the project on the environment, irrigation perimeter management and the inter-catchment water transfer system in this particular context [EPA 2005].

2. Materials and methods

2.1. Study area

Situated between the Guerguour and Boulatane wadis, the Boukhroufa wadi is a significant tributary of the Kebir East wadi. The Boukhroufa wadi, which is near to Zitouna, starts in Hanachir Mechta (600 m) and runs for about 41 km until it meets El Kebir East. The catchment area is about 176,50 km^2. Its inter-annual discharge is about 27,71

hm³. The dam is located about thirty kilometres south of El Tarf [Derradji 2004]. The data of the El Tarf Forests Conservation Agency from 2019 indicates that the area is mountainous, with a peak elevation of 1,041 meters, and covered in oak cork and maquis woods (Fig. 1).



Source: Authors' own study

Fig. 1. Study area location

The hydro-climatic analysis of the Boukhroufa catchment is based on the data of the meteorological station closest to the study area (8° 12' 22" E, 36° 47' 22" N, altitude 20 m, code: 03-17-01). The database that we have access covers 20 years (2000–2020). The studied area has relatively high annual precipitation of 755.96 mm, which is indicative of a subhumid Mediterranean climate. This type of landscape is characterized by an effective infiltration rate of approx. 13% and evapotranspiration of approx. 63%. The predicted annual runoff is 185.40 mm (24.53%). The lowest temperature is recorded in December (–0.6°C), the maximum appears in July and August (46°C). The monthly air humidity is highest in December and January. The average annual wind speed is estimated at 27.5 m/s.

The geological investigation of the area was conducted by Joleau L. in 1936, Vila J.M. in 1980, and Marre A. in 1992. The formations are part of the north-eastern Tell-Algerian geological complex that extends from the Constantinean region to the Algerian-Tunisian border. The Eocene-Oligocene Numidian series includes the area that forms the base of the dam basin [Joleau 1936]. These lands are formed by the alternation of sandstone that mainly consists of quartz sandstone and Numidian sandstone and marl [Vila 1980]. Superficial soils are formed by sandstone and clayey-gravelly colluvium on the slopes [Marre 1992]. Four ancient faults, located subparallel to the Boukhroufa wadi, indicate the tectonic position.

2.2. Institutional directives

Algeria's institutional development with regard to environmental issues began in 1974 with the establishment of the National Environmental Council (CNE) . This was followed by the creation of the Secretariat for Environment in 1996, the Ministry of Territory and Environment Planning (MATE) in 2000, and finally, the Ministry of Environment and Tourism Territory Planning (MATET) in 2007. The Framework Law 83-03 of 5 February 1983 on the environmental protection and the Executive Decree No. 90-78 of 27 February 1990 on the Environmental Impact Assessment were promulgated.

The Environmental Impact Assessment (EIA), which was established under the Decree 90-78, is an essential tool for preventing environmental damage caused by human activity. It is a procedure for determining if a project conforms with environmental protection regulations. For industrial, agricultural, or commercial entities whose operations could result in pollution or environmental deterioration, the EIA is necessary in order to receive any administrative authorisation. Under this procedure, the client has to prepare the EIA, review the EIA, initiate the proceedings and publicise the EIA and finally, the Ministry of Environment makes a decision and the EIA is approved without reservations [Brennecke et al. 2008].

The EIA's content must take into account the anticipated effects of dam construction on the study area's environment, and it must include: a description of the project, an analysis of the initial state of the site, criteria for site selection, the measures taken to reduce or eliminate the environmental damage of the project, as well as its direct and indirect, short medium and long-term environmental impacts [WCD 2000].

3. Results and discussion

3.1. Site description

The study of the site's original condition and the surrounding environment was carried out with a focus on natural resources, biodiversity, and any terrestrial, marine or hydrological areas likely to be affected by the project.

The 176.50 km² of agricultural land in the Boukhroufa watershed is frequently affected by flood damage. Despite the dredging and dike installations in the El-Tarf lowlands, the limitations of these efforts have been evident [Sahin et al. 2002]. Constructing a substantial hydraulic structure will support to the agricultural development of this plain (including irrigation equipment) by preventing recurrent flooding and safeguarding the farmland. It will also facilitate the inter-dam transfer (from El Kebir wadi and Boulatane wadi to the dam) [Kondolf 2022]. The morphometric characteristics of the Boukhroufa watershed are presented in table below (Table 1).

A 125 hm³ storage capacity will be available due to the transfer of water resources to an area of 969 km² in total, including a water supply system of 1.4 km by gravity, and 6 km by gravity and pumping between the El Kebir wadi and the Boukhroufa dam [Zeid 1989]. Another gravity water supply system of 3.3 km stretches between the Boukhroufa and Boulatane wadi (Fig. 1).

Table 1. Morphometric characteristics of the Bouhaloufa watershed

Watershed characteristics	Values
Area	176.50 km^2
Perimeter	72.00 km
River length	26.50 km
Minimum altitude	85.00 m
Average altitude	370.00 m
Maximum altitude	946.00 m
Medium slope	3.0%
Drainage density	3.57
Torrentiality coefficient	24.10

Source: Ministry of Agriculture and Rural Development

Table 2. Annual average inputs of rivers

Wadis	Area [km^2]	[1]Rainfall [mm/an]	[2]Mobilizable contributions [hm]	Use
Boukhroufa	176.50	750	27.71 (30.71%)	Irrigation
Boulatane	105	865	20.00 (22.17%)	
El Kebir East	356	787	42.50 (47.11%)	

Source: [1]Ain Assel meteorological station data, [2] Water resources agency data

The Ministry of Agriculture and Rural Development (2022) determined that the basin's characteristics made the construction of the dam possible, however, the inter-basin water transfer system, which transports water from the Boulatane and Kebir-Est rivers, makes up for the river's limited water resources due to its small watershed (176.5 km^2). This allows for the mobilization of a 90 hm^3 total useable volume (Table 2). According to the Direction of Water Resources [2019], the Boukhroufa dam in the daïra of Boutheldja (El Tarf) was finished by the end of 2021, and its commissioning and technical tests were planned for 2023.

3.2. Site selection criteria

The proximity to the irrigation boundary certainly influences the choice of the site for the dam. In order to guarantee water drainage by gravity, the water intake is situated upstream of the irrigation perimeter [Zhao 2017].

The management decided to examine three supply sources for the dam – Boukhroufa, Boulatane, and Kebir-East wadis – in order to reach a maximum storage capacity of 125 hm^3 due to the area's advantageous morphometric characteristics (Fig. 1).

This construction will meet the irrigation water needs of agricultural land for a long time and support regional human development, but it may also have numerous unavoidable effects on the area's ecology, economy, and population [Wang 2005]. In addition to the regulation of natural flows that change with the seasons and climatic hazards, it also controls catastrophic droughts and floods, and adjusts them to the water demands of industry, agriculture, and drinking.

The majority of the selection criteria for the dam site concentrate on the municipality of Boutheldja and the irrigation perimeter, taking into account the fact that the primary economic potential of the El Tarf region is agriculture (71,000 ha of its 80,000 in total is arable land) [OECD 2017]. The irrigated perimeter of El Tarf will benefit the Bouteldja region, improving the agricultural labour in the area and creating new jobs with the increase of agricultural production [Mirande 2001].

3.3. Impact of dam construction

Dams are used to collect, store, and manage the water required to support many kinds of uses, including agriculture, industry, and people. Even though dams greatly help the society, they also have negative effects on the surrounding area [Acreman 2000]. These include relocation and resettlement, socioeconomic factors, environmental concerns, sedimentation issues. These hydraulic structures and the geological settings in which they were built are closely related. Therefore, it is imperative to thoroughly examine and mitigate all potential dangers associated with dams and reservoirs to the greatest possible extent [Parhizkar 2007]. Furthermore, building dams has long been recognized as an effective way to supply water for industrial, drinking, and agricultural uses as well as for flood control, hydroelectric energy production, and quality control [la Cecilia 2016]. It should be noted, nevertheless, that practically there are no dam without environmental problems. Therefore, structures associated with the development of water infrastructure on rivers may have a variety of effects on the environment.

3.3.1. Impact on natural ecosystems

The Boukhroufa dam creates a barrier to longitudinal exchanges down the wadi. It modifies the downstream flow pattern towards the Kebir East wadi, influencing the nutrient and sediment regimes, as well as changing the temperature and chemical composition of the water. The dam's control of flow also affects the downstream river systems' natural processes – lowering flood peaks reduces the frequency, length, and depth of floodings. The shape of floodplains and channels is frequently altered by reduced flows and diminished sediment transfer [la Cecilia 2016]. A literature research on the watershed has been conducted in order to enable a sufficient examination of all the issues related to the catchment area under study, before any new data was

generated. It allowed for the identification of environmental problems that affect the watershed's water resources, such as the region's devastating floods. Identifying risks, mapping the affected areas, controlling urbanization, implementing the measures to reduce vulnerability, and forecasting floods are all part of the upstream component of risk prevention. The return periods of the catchment for this event are calculated to be 1000 years, 100 years, and 20 years – the duration of this interval determines how much human activity exacerbates the flows [ENHYD 1991]. The optimum flood flow is estimated to be 1015 m^3/s, 500 m^3/s, 260 m^3/s for return periods of 1000, 100 and 20 years respectively (Table 3).

Table 3. Frequency flood rates (Boukhroufa basin)

Return period [years]	Flows [m^3/s]	Volume [hm^3]
Millennium	1015	28,2
Centennial	500	18,2
Twentieth	260	11,6

Source: ENHYD, EDIIL [1991–1994]

These modifications, along with others, can have a direct and indirect impact on a wide range of factors that alter natural processes and, in turn, affect the ecological integrity of ecosystems [EDIIL 1994].

3.3.2. Impact on sediment transport

Dam construction acts as a barrier for movement of particles. As a result of sedimentation of materials in dam, dam construction causes relative reduction of the solid materials and river sediments. This can disturb the natural balance of sediment transmission potential at dam downstream and exacerbate the erosion in the downstream river [Pirestani and Shafghti 2009].

Many dams store practically the entire sediment load of the drainage basin [Richter 2010]. The shape of the channel, floodplain, and coastal delta is affected by the decrease in sediment load in rivers downstream of dams. This decrease tends to reduce the channel's capacity to move silt downstream of the dam, whereas flow management, which removes flood peaks, has the opposite effect. Usually, the first few kilometres downstream of a dam a greater erosion can be observed, since transported material is no longer replenished by material coming from upstream [Skaggs 1994]. However, because material entrained from tributaries and material mobilised below the dam cannot be carried through the channel system by the regulated flows, greater sedimentation (aggradation) may develop further downstream [Stevens 2000]. The application of empirical calculation techniques (Milikovsky-Drozd model) resulted in a stable input to the reservoir of 1.88 kg/m^3. Observations at the Ain Assel station give an almost identical result of 1.78 kg/m^3.

3.3.3. Impact on water quality

The construction of Boukhroufa dam has the potential to modify the concentrations and distribution of contaminants in the reservoir's waters by increasing the area of the reservoir, decreasing its diffusion, deepening it, and slowing the flow rate of its waters. Many nutrients, including nitrogen, phosphorus, and potassium, are stored in reservoirs, which favours the growth of algae. This could potentially lead to the eutrophication of a reservoir. Water quality will also be negatively impacted by irrigation development in the watershed [Webb 1994]. The reported nitrate ion concentrations, which range from 18 to 65.09 mg/L, are comparatively high and are the consequence of overuse of fertilizer, which eutrophises the environment (Table 4).

Table 4. Statistical data of physicochemical parameters in Boukhroufa wadi

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4	Cl^{-}	NO_3	PO_4	NO_2	NH_4	EC	Turb	TDS
Max	180	212	87.8	1.23	672.23	376.8	205.65	65.09	0.28	1.33	2.03	1100	29	704
Min	100	135	63.78	0.55	432.81	145	162.66	18	0.01	0.06	0.45	798	18.56	510.72
Average	146.87	173.6	72.99	1.09	560.52	259.2	194.57	35.03	0.05	0.63	1.14	962	22.45	615.68
SD	28.03	27.09	8.27	0.34	88.08	76.81	15.68	16.46	0.10	0.43	0.59	105.4	3.51	62.51

Discharges of domestic and agricultural wastewater disrupt the balance of surface water due to large nutrient quantities that lead to excessive algae growth and oxygen depletion in in the wadi. Uncontrolled discharge of wastewater and excessive use of fertilizers in the study basin have significantly affected the surface water resources of most of the wadi and its tributaries, causing more or less significant damage in downstream and upstream.

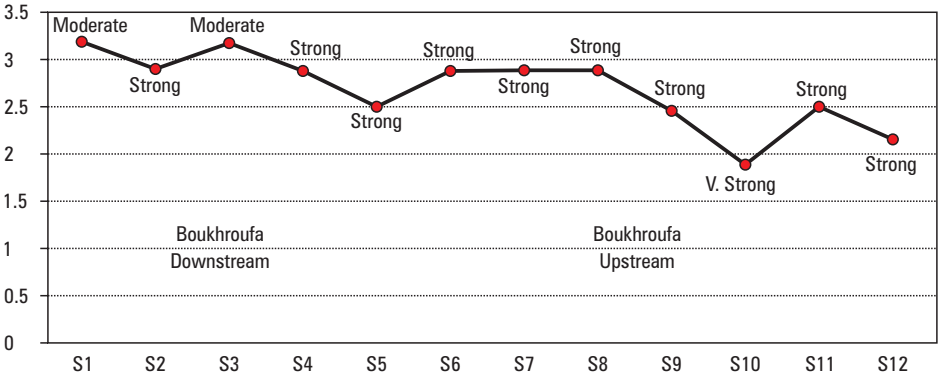
A statistical tool is used to determine the organic pollution index [Leclercq and Maquet 1987], which is defined by the number of organic ions such as NH_4, PO_4 and NO_2, and allows he water to be classified on a scale with 5 pollution levels. The classification is based on the changes caused by the pollutants (Table 5). To assess the water quality, samples were collected at 12 sampling points along the Boukhroufa wadi.

Table 5. Grading of the organic pollution index

Classes	Class 5	Class 4	Class 3	Class 2	Class 1
NH_4 (mg /l)	< 0.1	0.1–0.9	1.0–2.4	2.5–6	> 6
NO_2 (µg /l)	< 6	6–10	11–50	51–150	> 150
PO_4 (µg/l)	< 16	16–75	76–250	251–900	> 900
OPI	5–4.6	4.5–4	3.9–3	2.9–2	1.9–1
Pollution level	None	Low	Moderate	Strong	Very strong

Source: Leclercq and Marquet [1987]

According to the data, more than 16% of the total samples were moderately polluted, while 75% of the samples were strongly. The remaining 8% of samples were classified at very strong pollution levels (Fig. 2).



Source: Leclercq and Marquet [1987]

Fig. 2. Computed values of organic contamination indexes

The ammonium levels in the Boukhroufa wadi indicate insufficient decomposition of organic matter. The presence of phosphates in the wadi, originating from fertilisers, poses a threat to the receiving environment as it consumes a substantial quantity of oxygen and promotes algal growth. The organic pollution index varies across the wadi, from upstream to downstream, due to variations in urban and agricultural runoff in the studied reservoir. The most significant deterioration in the wadi's water quality occurs downstream rather than upstream.

3.3.4. Impact on geological environment

After the water has been stored, the increased water load of the reservoir and the water permeation pressure can change the stress state of the rock mass, causing significant stress at certain locations and ultimately triggering an earthquake. The assessment of the reservoir (earthquake duration, magnitude, epicentre location, etc.), the survey of the geological conditions of the collapse area, the analysis and assessment of the tendency and causes of induced earthquakes and slope failures, and the proposal of project safety measures are the main impacts on environmental geology [Kondolf 2007].

Some earthquakes are attributed to dam construction, because changes in land slope and topography and accumulation of sediments behind the dam reduce the content of sediment in the river channel, and erosion of the river bed is one of the most important factors threatening the environment [Şahin and Kurum 2002]. These earthquakes occur due to the heavy weight of the dam water and the disturbed pressure balance in various layers of the earth [Kondolf 2007].

3.3.5. Impact on ecological heritage

The richness and variety of water resources and vegetation in the study area create all kinds of ecological niches, enabling the installation of a diverse faunal procession that supports the preservation of the ecological equilibrium [Tealdi 2011]. As a privileged site for wintering waterfowl and migratory birds, the El Taref wetland has a fauna characteristic of a Mediterranean region, and the Bouhaloufa dam may help to preserve unique sites (Table 6). Reduced concentration of the nutrients downstream of the dam and its impact on the plant and animal community of the area, the water temperature, the distribution of salt, and oxygen may be altered by the formation of the reservoirs, leading to the production of new species and serious changes will occur in the water quality [Acreman 2000].

Table 6. Wildlife in the study area

Avifauna	Raptors	Mammals
White stork	Osprey	Barbary deer
Black stork	Marsh harrier	Monk seal
European shag	Griffon vulture	Otter
Black-winged stilt	Black kite	Lynx
Flamingo	Bald eagle	Porcupine
Greylag goose	Greater spotted eagle	Weasel
Poule sultane	Falcon	Mongoose
Marbled teal	Red-footed falcon	Wild boar
Sterne hansel	Rock falcon	Jackal
Grand cerneran	Sparrowhawk	Fox

Source: El Tarf Forests Conservation Agency data

To improve the environmental status, the definition of the ecological boundaries of the dam project and preparation of comprehensive management plans is necessary. Conducting scientific studies to identify plant and animal species in the region is an imperative operation.

Table 7. A summary of the downstream and upstream effects of building a dam

Upstream impacts	Downstream impacts
Soil erosion and reservoir sedimentation	Removed silt from downstream flows decrease of silt's fertilizing properties
Reduced storage capacity	Reduction in natural floods
Decrease in power	Changes in water temperature
Lower water quality	Changes in productivity

Chemical changes in water	Water quality downstream is altered chemically.
Loss of productivity	Loss of access to resources
Changes in flow rates	Loss of habitats and species, Ecological disturbance

5. Conclusions

The benefits of dams include storing water in times of its abundance and providing it in times of its scarcity, managing extreme droughts and floods, regulating natural resources that vary with the seasons and climate, responding to the need for water for industrial, alimentary and agricultural uses.

On the other hand, laws intended to mitigate the effects of development projects bear the responsibility of limiting the harm to the environment caused by these works. Due to the significance of their size or potential impact on the environment, environmental studies are now required before beginning any construction or remodelling of the projects that could affect the environment.

The artificial resources in Algeria are still heavily dependent on precipitation, because, due to the frequent dry periods that cause water shortages, eolian erosion, loss of plant cover and demographic pressure, the arable land continues to shrink and lose fertility. A significant retention development program has been initiated in order to protect the major infrastructure while also mobilising local water resources, such as the Boukhroufa dam.

The RAMSAR has classified the area where the dam and the irrigable perimeters are located as wetlands, and it is imperative to preserve the delicate environmental balance within these areas. The dam storage capacity is 120 hm^3, which must be guaranteed by the water resources transferred from the nearby Boulatane and Kebir East hydrographic network. In fact, there could be a number of negative impacts in the near future that will be caused by the construction site, as the project is being carried out. The way these developments operate will bring about changes in the medium and long terms (transport, water management, environmental changes, etc.). In this situation, complementary observations (weather, hydrology, piezometry, soil, water, etc.) of the site are required. This will make it possible to monitor the receiving environment's absorption capacity and to prevent irreversible effects.

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