Assessment of surface Water Quality for Drinking and Irrigation Purposes in Two Dams in the Semi-Arid Region of Northeast Algeria

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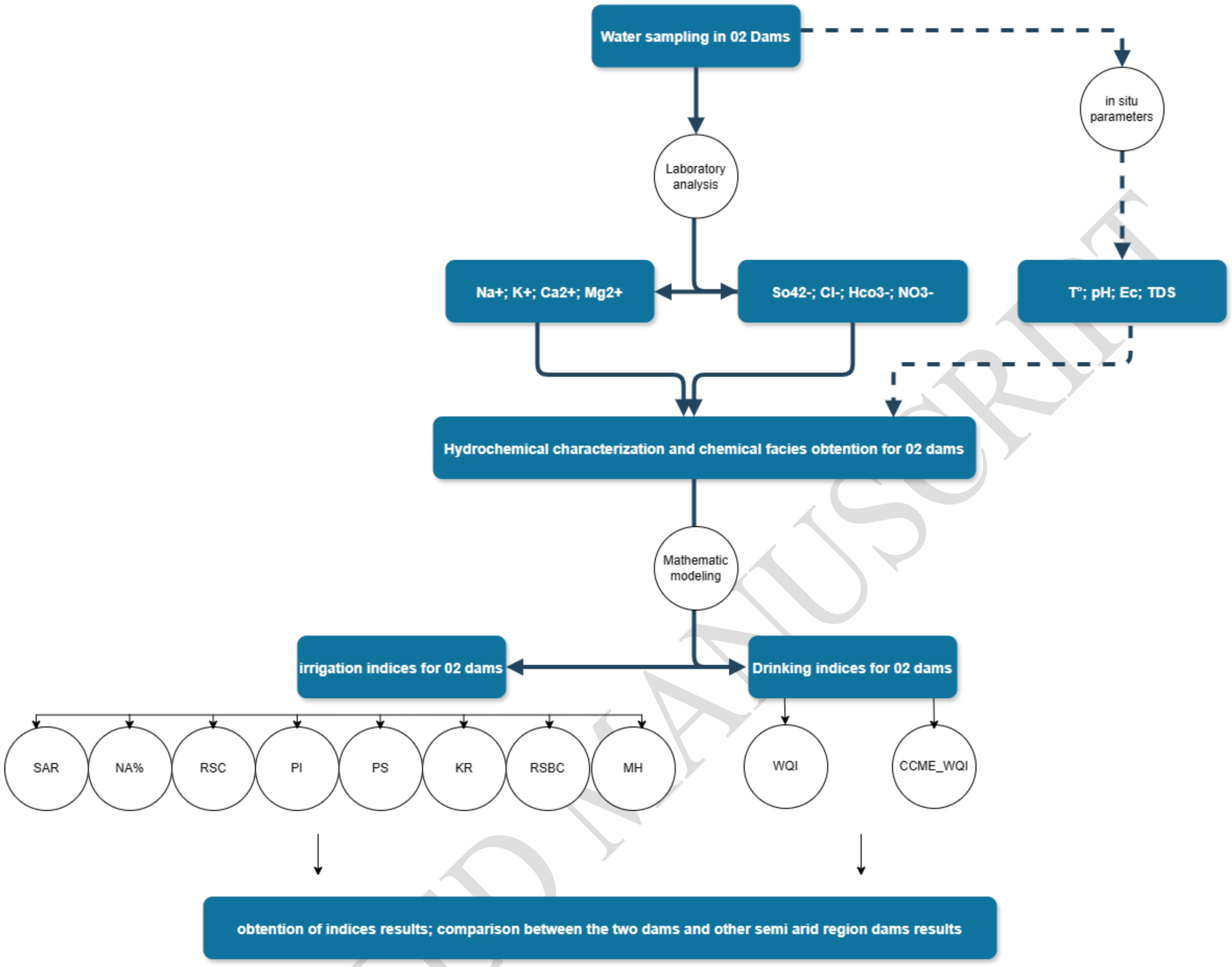
Graphical Abstract



Abstract

The quality of surface waters from the Timgad and Yabous dams in the semi-arid region of northeastern Algeria was assessed using physicochemical data collected monthly from collected monthly from May 2023 to April 2024. These data were analyzed to determine the suitability of the water from the two dams for consumption and irrigation. For drinking water evaluation, the Water Quality Index (WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) were employed.

The WQI results indicated that water from the Timgad dam was in the permissible class throughout the year (100%), while the Yabous dam consistently Yabous dam consistently presented a good quality class with (100%) of stations. However, the CCME-WQI classified the Timgad dam as marginal water category (100%) of sites, and the Yabous dam as Fair with Fair category with (100%) of year-round surveys. For irrigation purposes, the calculated values of indices such as Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%), Residual Sodium Carbonate (RSC), Permeability Index (PI), Potential Salinity (PS), Kelly's Ratio (KR), and Residual Sodium Bicarbonate (RSBC), indicated suitable irrigation classes for both dams. (100%) of the samples, except for the PS in the Timgad Dam. The Magnesium Hazard MH values were unsuitable for both dams throughout the year with (100%) of sampling points sampling points throughout the year in terms of irrigation. The results obtained during this investigation revealed that these two environments require integrated and rational management of water resources, particularly for the Timgad Dam.

Keywords: WQI-CCME, Drinking, SAR, RSC, Irrigation, Timgad Dam, Yabous Dam, semi-arid region, Algeria.

1. Introduction

Water isa pivotal resource essential for sustaining life and fostering economic progress, particularly in semi-arid regions where access to freshwater is limited (Li and Qian, 2018; Taş et *al*., 2019). Freshwater supports not only life but also ecological diversity and sustainable development (Taş et *al*., 2019).In these semi-arid areas, where water scarcity is exacerbated by declining precipitation and inadequate rainfall distribution, which often falls below 300 mm per year. The demand for water continues to rise alongside growing human populations (Isidoro and Aragüés, 2007; Awala, 2019; Hallouz, 2020) ;This situation poses significant challenges, particularly in ensuring sufficient water availability for various purposes, including agriculture and drinking (Isidoro and Aragüés, 2007). Consequently, Dams emerge as crucial water management structures in semi-arid and arid regions, providing storage and regulation mechanisms to mitigate the impacts of water scarcity (Khalaf, 2021; Yifru, 2021). However, their operations must be carefully managed to minimize downstream hydrological and environmental disruptions (Annys, 2020).

Furthermore, water quality degradation compounds the challenges faced in semi-arid regions, with pollutants originating from both natural sources and anthropogenic activities (Bouarroudj et *al*., 2019; Muhammad and Ullah, 2022). Human-driven factors such as urban expansion, agricultural practices, and industrial waste disposal contribute to water pollution, posing risks to both ecosystems and human health (Ouali et *al*., 2018; Islam et *al*., 2020).

Given these complexities, evaluating water quality becomes imperative for sustainable water resource management in semi-arid regions (Zhou et *al*., 2016; Snousy et *al*., 2021). Techniques like the Water Quality Index (WQI) offer effective tools for assessing water quality and guiding decision-making processes (Uddin et *al*., 2021). Additionally, various methodologies, including pollution indices and multivariate statistical analyses, aid in streamlining water quality assessments and informing management strategies (Varol, 2020; Liu et *al*., 2021); also it is crucial to assess water quality for irrigation purposes. Ramadhan et *al*., (2018) and Elsayed et *al.,* (2020) used water quality indices to evaluate if surface water was suitable for irrigation. Ramadhan studied the Khosar and Tigris rivers, while Elsayed focused on the Northern Nile Delta. Almeida (2007) introduced a quality profile for irrigation water based on various water quality indices, whereas Boyacioglu (2007) employed factor analysis to pinpoint the primary sources of water pollution in the Buyuk Menderes River Basin. The studies emphasize the potential of water quality indices and multivariate statistical techniques in evaluating surface water quality for irrigation; While Numerous researchers have assessed dams water quality in Algeria using various approaches. For instance, Bouderbala (2021) investigated the Oued Foda Dam, while Guenfoud et *al*., (2021) explored dams in Mascara. Gaagai et al (2020) investigated Babar's dam, and Soltani et *al*., (2020) examined the Beni Haroun dam. Their collective efforts shed light on the environmental health of these crucial water reservoirs, offering valuable insights for environmental management and protection. Previous studies have investigated the water quality of the Timgad dam, including those by Tiri et *al*., (2015), Bouslah et *al*., (2017), and Amrane et *al*., (2019). However, for the Yabous dam, this study represents the first investigation into its water quality, providing insights into both drinking and irrigation purposes.

in this study, we used the Water Quality Index (WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) to evaluate the suitability of water for drinking purposes in the region. This work applies indexed methods to assess the suitability of surface water from the Timgad and Yabous dams for irrigation based on physicochemical parameters. Water values, including irrigation indices such as SAR; Na%; RSC; PI; KR; MH; RSBC; and PS; are used to evaluate the suitability of irrigation for the two study dams in the absence of intense precipitation in the study area.

2. Materials and methods

2.1. Study area

The Koudiet M'douar dam lake is located 35 km from Batna and 7 km northeast of the historical site of Timgad (Roman ruins), with Lambert coordinates of 06° 24' E longitude and 35° 31' N latitude. This location defines a point on the dam where the elevation of the Oued coast is approximately 988 m above sea level. The Dam is part of the large water transfer system from the Beni Haroun dam, intended for the supply of drinking water and industrial water to the Batna willaya, as well as for the irrigation of agricultural lands in the plains of Batna and Chemora, and the supply of drinking water and industrial water to nearby cities. (Fig.01). The Tagharist dam is located in the northwestern part and adjacent to the commune of Tagharist known as Yabous, which is administratively under the jurisdiction of the Bouhmama district. It is bordered to the north by the Delâa mountain range and Djebel Es Sekkoum, to the south by Djebel Bou-Djeza, to the east by the commune of YABOUS and the CW45, and to the west by Foum Krazza and the commune of Foum Toub. It belongs to the Khenchela province and is situated at elevations between latitudes 1100 and 1200m above sea level. (Fig.01).

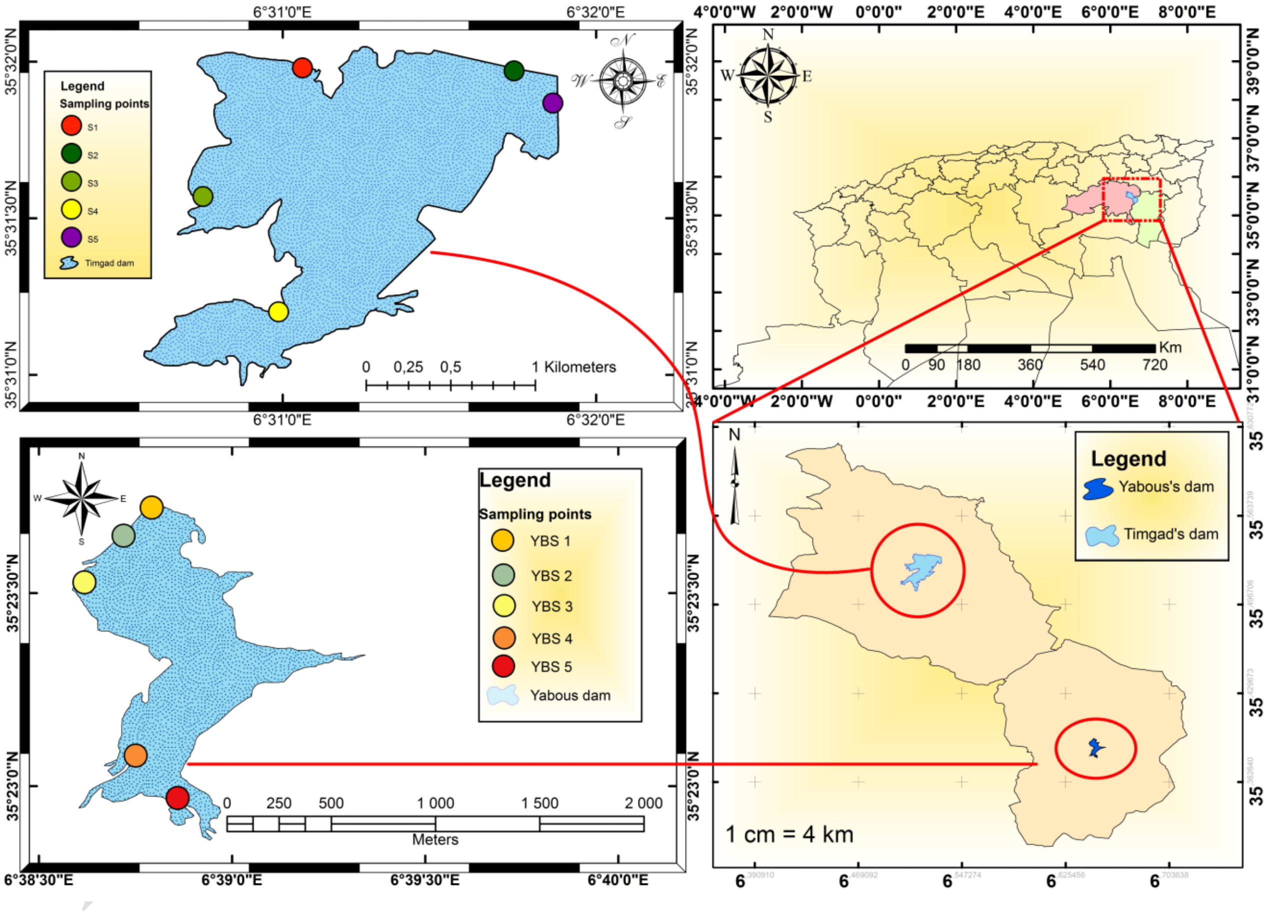


Figure 1. Location of the Koudiet M'douar and Tagharist dams, along with the sampling points (ArcGIS 10.8).

2.2. Sampling and analytical methods

Surface water samples were collected from May 2022 to April 2023 from 05 stations by dam representing the entire course of the stream. Figure 1 displays a map indicating the locations of these sampling stations. Using 1.5-liter sample bottles, water samples were extracted from a depth of 30 cm below the water surface. Samples intended for physicochemical analysis were stored in polyethylene bottles. They were transported to the laboratory in a cooler and maintained at a temperature of 4°C until analyses were conducted on the same day.

2.3. Physicochemical analysis

Temperature measurements were recorded in degrees Celsius (°C), while electrical conductivity (EC) was measured in microsiemens per centimeter ($\mu S\ cm^{-1}$). The pH level was determined on a dimensionless scale. Total Dissolved Solids (TDS) were quantified in milligrams per liter ($mg\ l^{-1}$), and salinity was expressed in practical salinity units (PSU). Dissolved oxygen (DO) levels were assessed in milligrams per liter (mg/L). All these measurements were taken using a high-precision multiparameter device WTW multi 3620 ids, ensuring accurate data collection.

In this scientific study, a comprehensive analysis of various chemical constituents was conducted using established methods. Nitrate (NO_3^-), sulfate (SO_4^{2-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), Bicarbonates (HCO_3^{-}, total hardness (TH), Magnesium (Mg^{2+} and chloride (Cl^-) were quantified and assessed in accordance with standard protocols as detailed in Aminot et *al.*, (2007) and Rodier (2009), Additionally, for the comparison between SAR versus EC and NA% versus EC, we utilized diagram software (v 8.43).

2.4. Water quality index

The Water Quality Index (WQI) was applied to enhance the assessment of water quality, providing an effective method for categorizing it in terms of suitability for drinking . The calculation of WQI involves considering ten water quality parameters (T, Ph, EC, Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-), with initial weight assignments (wi) based on their importance for overall drinking water quality according to WHO (2011) standards (Tab.1). Parameters such as Cl^-, NO_3^-, and SO_4^{2-} received a maximum weight of 5 due to their significant role in assessing water quality, while EC, pH, TH, TDS and Na^+ were assigned a weight of 4, Mg^{2+} and Ca^{2+} were assigned a value of 2 and finally the HCO_3^- and K^+ were assigned a minimum weight of 1 as it plays a relatively less crucial role (Vasanthavigar et *al*., 2010; Gibrilla et *al*., 2011; Srinivasamoorthy et *al*., 2011; Bouderbala, 2017).

In the second step, the relative weight (rWi) is calculated as follow: $rWi = \frac{wi}{\sum_{i=1}^{n} wi}$

In the formula, (rWi) represents the relative weight, (wi) denotes the weight assigned to each parameter, and (n) stands for the total number of parameters. The computed (rWi) values are specified in the table (1).

Moving on to the third step, a quality assessment scale (qi) is assigned to each parameter by dividing its concentration by the corresponding standard concentration, as per the guidelines outlined by WHO (2011). $qi = \frac{Ci}{Si} \times 100$

In this context, (qi) represents the quality index, (Ci) stands for the concentration of each chemical parameter in every water sample measured in mg l^{-1}, and (Si) denotes the allowable concentration of water for irrigation for each specific chemical parameter, also measured in mg l^{-1}.

Ultimately, in the process of computing the Water Quality Index (WQI), the initial determination involves obtaining (SLi) for each parameter. The cumulative sum of the (SLi) values then yields the Water Quality Index (WQI) for each respective sample. $SLi = rWi \times qi$

$$WQI = \sum SLi$$

The classification of the Water Quality Index (WQI) follows a methodology devised by Singh et *al*., (2011). According to this classification, a WQI less than 50 indicates excellent water quality, a WQI in the range of 50–100 signifies good water quality, a WQI within the range of 101–200 indicates poor water quality, a WQI falling between 200–300 implies very poor water quality and a WQI exceeding 300 denotes water unsuitable for drinking.

Table 1. Weight (wi) and the relative weight (rWi) of each chemical parameter.

Parameters	WHO (2011)	Weight (wi)	Relative Weight (rWi)
EC (μS cm^{-1})	500	4	0,097560976
pH	6.5-8.5	4	0,097560976
Cl^- (mg l^{-1})	250	5	0,12195122
SO_4^{2-} (mg l^{-1})	250	5	0,12195122
HCO_3^- (mg l^{-1})	300	1	0,024390244
Na^+ (mg l^{-1})	200	4	0,097560976
Ca^{2+} (mg l^{-1})	75	2	0,048780488
Mg^{2+} (mg l^{-1})	45	2	0,048780488
NO_3^- (mg l^{-1})	50	5	0,12195122
K^+ (mg l^{-1})	12	1	0,024390244
TH (mg l$^{-1)}$	300	4	0,097560976
TDS (mg l$^{-1)}$	500	4	0,097560976

2.5. CCME water quality index

The seasonal monitoring of our two dams enabled us to apply the CCME WQI. We used 10 parameters for calculating the CCME WQI: Electrical conductivity at 25°C, pH, Nitrate (NO_3^-), Chloride (Cl^-), Sulfate (SO_4^-), Bicarbonate (HCO_3^-), Calcium (Ca^{2+}), Sodium (Na^+), Potassium (K^+), and Magnesium (Mg^{2+}). The CCME-WQI method was utilized to assess the water quality of the two dams. The CCME-WQI method relies on three main elements: scope (F1), frequency (F2), and amplitude (F3) . These elements are determined as follows:

2.5.1. F1(Scope)

F1 represents the percentage of indicators that do not meet their standard values at least once during the evaluation period. The calculation can be determined using Equation:

$$F1 = \frac{Number\ of\ failed\ variables}{Total\ number\ of\ variables} \times 100$$

2.5.2. F2 (Frequency)

F2 indicates the proportion of monitoring quantity that surpasses the standard, serving as a metric for the frequency at which a water quality goal is not achieved. The calculation can be determined using Equation: $F2 = \frac{Number\ of\ failed\ test}{Total\ number\ of\ tests} \times 100$

2.5.3. F3 (Amplitude)

F3 represents the amplitude of how much the objectives are exceeded, indicating the extent to which failed test values fall short of meeting their objectives. (Guideline value). To calculate the F3, three steps are necessary.

Step 1: The difference between an individual concentration and the objective value, whether greater or lesser in the case of a minimum objective, is referred to as an excursion. Equation (7) was utilized to calculate the excursion when the test value should not surpass the objective. Equation (8) was utilized even though the test value had to be equal to or greater than the objective.

$$excursion\ i = \left(\frac{Failed\ test\ value\ i}{Objective\ i}\right) - 1 \qquad excursion\ i = \left(\frac{Objective\ i}{Failed\ test\ value\ i}\right) - 1$$

Step 2: involves calculating the total amount of non-compliance of individual tests, known as the normalized sum of excursions, using the following Equation. $nse = \frac{\sum_{i=0}^{n} excursion\ i}{Total\ number\ of\ tests}$

The amplitude (F3) is determined using an asymptotic function that scales the normalized sum of excursions from objectives to produce a value ranging from 0 to 100. In equation:

$$F3 = \frac{nse}{0.01nse + 0.01}$$

The CCME-WQI index is determined using Equation: $CCME - WQI = 100 - (\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732})$

The provided formulas yield a CCME-WQI value that falls within the range of 0 to 100. Water quality can be categorized into five groups according to the CCME-WQI values calculated previously, as shown in Table (2).

Table 2. Water quality status based on the CCME-WQI classification.

CCME-WQI	**95-100**	**80-94**	**65-79**	**45-64**	**0-44**
Water quality status	Excellent	Good	Fair	Marginal	Poor

2.6. Water quality for irrigation

The quality of irrigation water significantly impacts soil characteristics, consequently influencing agricultural yields. Understanding the water quality used for irrigation and its potential adverse effects on crop growth is essential. The water quality index serves as a tool to evaluate the overall quality of irrigation water, offering a comprehensive assessment of the combined influence of each water quality parameter's combined influence. The quality of irrigation water was assessed through the analysis of various parameters, including percentage of sodium (Na %), Sodium Absorption Ratio (SAR), magnesium hazard (MH), Kelly Ratio (KR), permeability index (PI), potential salinity (PS), residual sodium carbonate (RSC) and the Residual sodium bicarbonate (RSBC) (Asadi et *al*., 2020; Maman Hassan, and Firat Ersoy., 2022**).**

In this study, we aimed assessing water quality for irrigation by using the mentionned indices, the results were obtained by calculating the formulas in meq l^{-1}, equations in Table (03):

Table 3: classifications of the irrigation water quality indices

Classification pattern	Formula	Categories	Ranges	References
Percent Sodium (%Na)	$\%Na = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} * 100$	Excellent Good Permissible Doubtful Unsuitable	0 - 20 20 - 40 40 - 60 60 - 80 > 80	(Wilcox, 1955)
Sodium Absorption Ratio (SAR)	$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$	Excellent Good Doubtful Unsuitable	< 2 2 - 12 12 - 22 22 - 32 > 32	(Richard, 1954)
Permeability Index (PI)	$PI = \frac{Na^{+} + \sqrt{(HCO_3^{-})}}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100$	Suitable Unsuitable	< 75 ≥ 75	(Doneen, 1964)
Residual Sodium Carbonate (RSC) (meq l^{-1})	$RSC = (HCO_3^{-} + CO_3^{-}) - (Ca^{2+} + Mg^{2+})$	Permissible Unsuitable	< 1.25 ≥ 1.25	Richard.USDA, 1954
Magnesium hazard (MH)	$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100$	Permissible Unsuitable	< 50 ≥ 50	(Raghunath,1987)

Kelly’s ratio (KR)	$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	Suitable Unsuitable	< 1 ≥ 1	(Kelley,1940 ; Kelley,1963)
Potential salinity (PS)	$PS = Cl^- + \sqrt{SO_4^{2-}}$	Excellent to good Good to Injurious Injurious to Unsatisfactor	< 3 3-5 > 5	(Doneen, 1964)
Residuel sodium bicarbonate (RSBC)	$RSBC = HCO_3^- - Ca^{2+}$	Non alkaline Normal Low alkalinity Medium Alkalinity High alkalinity Very high alkalinity	≤ 00 Equals 0 00 - 2.5 2.5 - 5 5 -10 > 10	(Gupta and Gupta, 1983)

3. Results and Discussion

3.1. Results

3.1.1. General hydrochemistry:

The hydrochemical analysis of water samples from Timgad Dam conducted between May 2022 and April 2023 revealed significant findings, summarized in Table 4. Electrical conductivity values varied across seasons, surpassing WHO 2011 standards consistently. In spring, conductivity averaged (1979.33 ± 355.18) µS cm^{-1}, decreasing in summer and autumn to (1337.13 ± 61.96) µS cm^{-1} and (1283.80 ± 30.30) µS cm^{-1}, respectively. Winter saw a slight increase to (1424.07 ± 19.63) µS cm^{-1}. These results contrast sharply with previous studies by Tiri (2015) and Bouslah (2017), reporting much lower values of (682.30) µS cm^{-1} and (1039) µS cm^{-1}, respectively.

pH values remained relatively stable throughout the year, ranging from (7.64 ± 0.09) in spring to (7.63 ± 0.05) in winter, within WHO 2011-accepted limits. This stability contrasts with Tiri (2015) and Bouslah (2017), who reported values of (7.50) and (8.09), respectively.Chloride concentrations showed significant variation, meeting the WHO 2011 standards at (193.33 ± 21.91) mg l^{-1}in the summer but surpassing them in other seasons, notably peaking at (358.55 ± 30.34) mg l^{-1}in winter. These results exceed those reported in previous studies by Tiri (2015) and Bouslah (2017), which found chloride levels of (22.40) mg $l^{-1}$and 90.04) mg l^{-1}, respectively. Sulfate concentrations exhibited relatively high values across all four seasons, with a peak value of (468.042) ± 170.49) mg l^{-1} recorded in spring. Subsequently, a decrease in these values was observed in the remaining three seasons, with values approaching (284.82 ± 29.49) mg l^{-1} in summer, (323.67 ± 11.95) mg l^{-1} in autumn, and (327.27 ± 10.44) mg l^{-1} in winter. These values consistently remained above the WHO 2011 standard. . Notably, there is a stark contrast in values compared to Tiri (2015) and Bouslah (2017), which reported notably lower sulfate levels of (119.80 mg $l^{-1}$and 244.81) mg l^{-1}, respectively. Magnesium concentrations in Timgad Dam consistently remained high across all seasons. The levels started at (122.31 ± 7.67) mg/l in spring, experienced a slight decrease to (102.23 ± 6.33) mg/l in summer, averaged (119.71 ± 4.86) mg/l in autumn, and slightly increased to (123.67 ± 14.58) mg/l in winter, surpassing the WHO 2011 standard of 45 mg/l. These levels exceeded those found in other studies, particularly those conducted by Tiri (2017) and Bouslah (2017), which reported values of 79.2 mg/l and 41.63 mg/l, respectively. Total Dissolved Solids (TDS) in Timgad Dam exceeded the WHO 2011 standard of 500 mg l^{-1}l, with values peaking at 1817.400 ± 405 mg l^{-1} in spring, decreasing to (1343.06 ± 73.75) mg l^{-1} in summer and (1284.53 ± 30.06) mg l^{-1} in autumn and slightly rising to (1428.13 ± 18.13) mg l^{-1} in winter. Nitrate, bicarbonate, calcium, potassium, and Total Hardness (TH) values all fell within the WHO 2011. Sodium concentrations are critical for evaluating water suitability for irrigation. While 95% of the samples met the WHO (2011) standards, station 5 recorded a value of 227.86 mg l^{-1}during the spring period, surpassing the standard. The average sodium concentration throughout the year was (161.79±21.63) mg l^{-1} . It is worth noting that previous research by Tiri (2015) reported sodium levels not exceeding 62.4 mg l^{-1}.

In Table 5, detailing the seasonal variations of physicochemical parameters in Yabous Dam, the values of electrical conductivity fluctuate slightly above or below the WHO 2011 standard. During summer, the average was below the standard at (493 ± 30.83) µs cm^{-1}, with stations 02 and 05 recording values below the norm at 458 µs cm^{-1} and 460 µs cm^{-1}, respectively. However, in autumn and winter, all five stations exceeded the standard, with values of (569.33 ± 26.95) µs cm^{-1} and (532.20 ± 7.72) µs cm^{-1}. In spring, the first sampling season in our study, the average was (524.33 ± 20.37) µs cm^{-1}, with station 02 recording a value of 491 µs cm^{-1}, which is below the norm. The pH values of Yabous Dam remained within the reference range provided by the WHO 2011 standard, decreasing from spring and summer to autumn and winter, with averages of (8.08 ± 0.10; 8.08 ± 0.04; 7.93 ± 0.05; and 7.96 ± 0.02), respectively. The Bicarbonate concentrations were elevated in summer and autumn, with values of (336.13 ± 43.67) mg l^{-1}and (305.90 ± 14.21) mg l^{-1}, except for station 02 in summer (284.50 mg l^{-1}) and stations 04 and 05 in autumn (288.81 mg l^{-1} and 292.88 mg l^{-1}, respectively). In spring and winter, the values were below the WHO 2011 standard, with concentrations of (83.86 ± 25.30) mg l^{-1} and (144 ± 15.38) mg l^{-1} , respectively. Magnesium concentrations throughout the year were high, starting at (77.41 ± 453) mg l^{-1} in spring, increasing to (95.19 ± 5.80) mg l^{-1} in summer, slightly decreasing to (92.47 ± 10.74) mg l^{-1} in autumn, and reaching the lowest value during winter at (72.23 ± 6.87) mg l^{-1}.

The total TDS values exhibited a consistent seasonal trend similar to electrical conductivity, showing elevations in spring, autumn, and winter, with averages of (527.53 ± 23.94) mg l^{-1}. However, station 02 recorded a value below the standard at 485 mg l^{-1}, while the highest value was (569.53 ± 27.13) mg l^{-1}. In summer, TDS levels met the WHO 2011 standard, with an average of (494.20 ± 29.19) mg l^{-1} , with stations 02 and 05 reported values below the norm at (485.33 mg l^{-1} and 466.68) mg l^{-1}, respectively. Directly comparing the values obtained from Yabous Dam with those from other studies on dams in the semi-arid region may not be entirely appropriate. This is due to the unique microclimate of Yabous Dam, stemming from its mountainous location within the semi-arid region. Nevertheless, the water quality parameters from Yabous Dam are notably superior to those reported in studies conducted by Soltani (2020) on Beni Haroun Dam and Gaagai (2020) on Babar Dam, emphasizing the favorable conditions present in Yabous Dam.

Table 4. seasonal variation of the hydrochemistry of Timgad's dam (period from May 2022 to April 2023) and WHO (2011) standards.

	Parameters	T°C	EC 25°C	pH	NO_3^-	Cl^-	SO_4^-	HCO_3^-	Ca^{2+}	Na^+	K^+	Mg^{2+}	TH	TDS
	WHO	**30**	**500**	**6.5 - 8.5**	**50**	**250**	**250**	**300**	**75**	**200**	**12**	**45**	**300**	**500**
SPRING	**SPR_TMG 1**	22.00	2140.00	7.68	0.10	289.92	264.35	130.17	42.17	169.10	4.54	119.11	52.00	1390.67
	SPR_TMG 2	18.33	2115.00	7.67	0.19	266.25	384.78	117.97	39.13	175.36	3.36	116.51	50.67	1366.00
	SPR_TMG 3	21.67	2216.33	7.47	0.07	455.58	504.04	105.76	36.08	189.33	2.78	131.51	56.67	2206.33
	SPR_TMG 4	20.67	1351.00	7.68	0.15	372.75	461.11	113.90	38.11	180.06	3.62	129.51	56.00	2047.67
	SPR_TMG 5	18.67	2076.33	7.62	0.08	307.67	725.93	113.90	39.13	227.86	4.32	114.91	50.00	2076.33
	Min	18.33	1351.00	7.47	0.07	266.25	264.35	105.76	36.08	169.10	2.78	114.91	50.00	1366.00
	Max	22.00	2216.33	7.68	0.19	455.58	725.93	130.17	42.17	227.86	4.54	131.51	56.67	2206.33
	Mean	20.27	1979.73	7.62	0.12	338.43	468.04	116.34	38.92	188.34	3.73	122.31	53.07	1817.40
	SD	1.69	355.18	0.09	0.05	76.51	170.49	8.91	2.20	23.29	0.72	7.67	3.08	405.34
SUMMER	SUM_TMG 1	24.00	1425.00	7.73	0.84	191.58	255.88	243.39	26.95	152.15	11.24	113.31	48.33	1456.00
	SUM_TMG 2	23.67	1368.33	7.84	0.17	165.67	263.20	272.54	24.93	150.98	7.85	97.71	41.67	1368.00
	SUM_TMG 3	20.00	1278.00	7.83	0.17	183.42	277.35	248.13	23.91	143.74	6.82	100.31	42.67	1277.33
	SUM_TMG 4	21.33	1333.33	7.77	0.18	201.17	299.10	235.93	27.97	146.87	8.66	101.11	43.33	1334.00
	SUM_TMG 5	24.00	1281.00	7.67	0.92	224.83	328.56	219.66	23.91	143.35	11.24	98.71	42.00	1280.00
	Min	20.00	1278.00	7.67	0.17	165.67	255.88	219.66	23.91	143.35	6.82	97.71	41.67	1277.33
	Max	24.00	1425.00	7.84	0.92	224.83	328.56	272.54	27.97	152.15	11.24	113.31	48.33	1456.00
	Mean	22.60	1337.13	7.77	0.46	193.33	284.82	243.93	25.53	147.42	9.16	102.23	43.60	1343.07
	SD	1.83	61.96	0.07	0.39	21.91	29.49	19.30	1.84	4.04	2.01	6.33	2.72	73.75
AUTUMN	**AUT_TMG 1**	16.33	1310.33	7.67	0.80	372.75	325.38	166.78	36.08	153.91	8.41	117.11	50.67	1310.67
	AUT_TMG 2	14.33	1317.00	7.53	0.70	289.92	328.75	187.12	37.10	150.00	8.19	117.71	51.00	1317.33
	AUT_TMG 3	14.00	1265.67	7.40	0.78	360.92	332.99	191.19	37.10	161.35	7.38	116.11	50.33	1266.00
	AUT_TMG 4	19.00	1281.33	7.50	1.01	337.25	328.37	215.59	37.10	156.26	8.39	128.11	55.33	1283.00
	AUT_TMG 5	16.33	1244.67	7.57	0.68	307.67	302.86	199.32	32.03	157.83	7.79	119.51	51.33	1245.67
	Min	14.00	1244.67	7.40	0.68	289.92	302.86	166.78	32.03	150.00	7.38	116.11	50.33	1245.67
	Max	19.00	1317.00	7.67	1.01	372.75	332.99	215.59	37.10	161.35	8.41	128.11	55.33	1317.33
	Mean	16.00	1283.80	7.53	0.80	333.70	323.67	192.00	35.88	155.87	8.03	119.71	51.73	1284.53
	SD	2.00	30.30	0.10	0.13	34.90	11.95	17.82	2.20	4.25	0.44	4.86	2.05	30.06
WINTER	**WNT_TMG 1**	11.00	1434.33	7.57	0.43	372.75	340.40	207.46	38.11	166.82	4.28	113.51	49.33	1437.67
	WNT_TMG 2	10.67	1425.00	7.61	0.80	372.75	325.67	195.25	32.03	119.30	3.23	145.91	62.33	1426.33
	WNT_TMG 3	11.33	1430.67	7.62	0.62	313.58	334.14	134.24	39.13	164.67	3.45	115.71	50.33	1425.67
	WNT_TMG 4	11.00	1440.00	7.64	0.43	390.50	314.31	199.32	38.11	164.87	3.83	131.11	56.67	1450.00
	WNT_TMG 5	12.67	1390.33	7.70	0.56	343.17	321.82	162.71	37.10	161.93	3.92	112.11	48.67	1401.00
	Min	10.67	1390.33	7.57	0.43	313.58	314.31	134.24	32.03	119.30	3.23	112.11	48.67	1401.00
	Max	12.67	1440.00	7.70	0.80	390.50	340.40	207.46	39.13	166.82	4.28	145.91	62.33	1450.00
	Mean	11.33	1424.07	7.63	0.57	358.55	327.27	179.80	36.90	155.52	3.74	123.67	53.47	1428.13
	SD	0.78	19.63	0.04	0.15	30.34	10.24	30.63	2.81	20.32	0.41	14.58	5.89	18.13

Electrical conductivity: µs cm^{-1}. NO_3^-; Cl^-; SO_4^{2-}; HCO_3^-; Ca^{2+}; Na^+; K^+; Mg^{2+}; TH; TDS: Mg l^{-1}. SPR: Spring; SUM: Summer; AUT: Autumn; WNT: Winter; TMG: Timgad dam.

Table 5. seasonal variation of the hydrochemistry of Yabous's dam (period from May 2022 to April 2023) and WHO (2011) standards.

	Parameters	**T°C**	**EC25°C**	**pH**	**NO_3^-**	**Cl^-**	**SO_4^{2-}**	**HCO_3^-**	**Ca^{2+}**	**Na^+**	**K^+**	**Mg^{2+}**	**TDS**	**TH**
	WHO	**30**	**500**	**6.5 - 8.5**	**50**	**250**	**250**	**300**	**75**	**200**	**12**	**45**	**500**	**300**
SPRING	**SPR_YBS 1**	21.67	520.33	7.97	0.53	59.17	154.23	146.44	18.84	28.17	1.59	72.51	541.00	30.67
	SPR_YBS 2	19.67	490.67	8.09	0.05	47.33	245.87	170.85	16.81	30.71	0.80	82.94	485.00	35.00
	SPR_YBS 3	20.00	532.00	8.21	0.26	59.17	224.12	203.39	19.85	26.80	1.03	72.93	533.67	31.00
	SPR_YBS 4	20.33	540.33	8.17	0.35	47.33	145.95	191.19	17.82	28.17	2.06	79.54	538.33	33.67
	SPR_YBS 5	20.33	538.33	7.99	0.58	62.58	221.40	207.46	19.85	27.58	1.48	79.14	539.67	33.67
	Min	19.67	490.67	7.97	0.05	47.33	145.95	146.44	16.81	26.80	0.80	72.51	485.00	30.67
	Max	21.67	540.33	8.21	0.58	62.58	245.87	207.46	19.85	30.71	2.06	82.94	541.00	35.00
	Mean	20.40	524.33	8.09	0.35	55.12	198.32	183.86	18.64	28.29	1.39	77.41	527.53	32.80
	SD	0.76	20.37	0.11	0.22	7.24	45.13	25.31	1.32	1.47	0.49	4.53	23.94	1.88
SUMMER	**SUM_YBS 1**	23.67	516.67	8.07	0.57	65.08	165.01	305.08	8.69	30.32	3.53	92.59	516.67	38.67
	SUM_YBS 2	24.33	458.33	8.13	0.09	76.92	141.43	284.75	10.72	31.52	1.50	95.37	458.33	27.33
	SUM_YBS 3	25.00	518.00	8.10	0.38	76.92	161.16	378.30	15.80	32.86	5.20	101.73	518.00	42.67
	SUM_YBS 4	25.33	511.67	8.03	0.35	71.00	163.19	383.05	15.80	34.04	4.30	99.33	511.33	33.33
	SUM_YBS 5	25.33	460.33	8.07	0.64	79.75	147.21	329.49	11.74	28.17	2.76	86.95	466.67	36.33
	Min	23.67	458.33	8.03	0.09	65.08	141.43	284.75	8.69	28.17	1.50	86.95	458.33	27.33
	Max	25.33	518.00	8.13	0.64	79.75	165.01	383.05	15.80	34.04	5.20	101.73	518.00	42.67
	Mean	24.73	493.00	8.08	0.41	73.93	155.60	336.13	12.55	31.38	3.46	95.19	494.20	35.67
	SD	0.72	30.83	0.04	0.22	5.89	10.59	43.67	3.16	2.28	1.42	5.80	29.19	5.77
AUTUMN	**AUT_YBS 1**	16.00	532.33	7.88	0.37	71.00	177.72	313.22	21.88	76.08	2.55	96.71	532.33	49.33
	AUT_YBS 2	16.33	548.67	7.89	0.57	106.50	178.49	321.36	22.90	30.71	2.59	90.11	548.67	38.33
	AUT_YBS 3	16.00	588.00	7.99	0.40	76.92	160.10	313.22	19.85	27.78	2.06	83.51	588.00	35.33
	AUT_YBS 4	15.00	589.67	7.95	0.48	76.92	163.28	288.81	17.82	28.76	2.36	83.11	589.67	35.00
	AUT_YBS 5	15.67	588.00	7.97	0.49	88.75	153.08	292.88	20.87	28.56	2.14	108.91	589.00	46.00
	Min	15.00	532.33	7.88	0.37	71.00	153.08	288.81	17.82	27.78	2.06	83.11	532.33	35.00
	Max	16.33	589.67	7.99	0.57	106.50	178.49	321.36	22.90	76.08	2.59	108.91	589.67	49.33
	Mean	15.80	569.33	7.93	0.46	84.02	166.54	305.90	20.66	38.38	2.34	92.47	569.53	40.80
	SD	0.51	26.96	0.05	0.08	14.13	11.19	14.21	1.95	21.10	0.24	10.74	27.13	6.51
WINTER	**WNT_YBS 1**	13.33	530.33	8.00	0.58	71.00	126.51	146.44	15.80	36.77	1.05	67.51	558.00	28.33
	WNT_YBS 2	11.67	532.67	7.96	0.08	59.17	134.60	150.51	15.80	28.76	0.90	67.51	540.67	28.33
	WNT_YBS 3	12.00	523.67	7.93	0.09	71.00	121.99	146.44	15.80	26.80	0.84	66.71	527.33	28.00
	WNT_YBS 4	10.33	532.33	7.96	0.23	76.92	140.56	117.97	15.80	28.17	0.86	78.71	531.00	33.00
	WNT_YBS 5	11.67	545.00	7.97	0.11	73.25	136.42	158.64	17.82	28.36	0.78	80.71	543.67	34.00
	Min	10.33	523.67	7.93	0.08	59.17	121.99	117.97	15.80	26.80	0.78	66.71	527.33	28.00
	Max	13.33	545.00	8.00	0.58	76.92	140.56	158.64	17.82	36.77	1.05	80.71	558.00	34.00
	Mean	11.80	532.80	7.97	0.22	70.27	132.02	144.00	16.20	29.77	0.89	72.23	540.13	30.33

		SD	1.07	7.72	0.03	0.21	6.66	7.58	15.38	0.91	3.98	0.10	6.87	12.03	2.92

Electrical conductivity: µs cm-1. NO3-; Cl-; SO42-; HCO3-; Ca2+; Na+; K+; Mg2+; TH; TDS: Mg l^{-1}*. SPR: Spring; SUM: Summer; AUT: Autumn; WNT: Winter; YBS: Yabous dam.*

In our study we used the Piper-Hill diagram to assess the hydrogeochemical facies of the water in Timgad dam and its tributaries, as proposed by Piper (1944). Figure 2 shows the prevalence of a chloride and sulfate of calcium and magnesium facies during different seasons, with a notable shift towards the boundary of sodium and potassium chloride facies. This highlights the complex interactions between water and geological formations, particularly the dissolution of evaporitic gypsum formations from the Upper Miocene in the study area. . This indicates a significant change in the dam's facies when comparing it to the study of Tiri 2015. For the Yabous Dam, the chemical facies shown in Figure 2 indicate, indicates two chemical facies in the sample which are sulferous magnesium during spring season and magnesium bicarbonate throughout the three other seasons summer, autumn and winter.

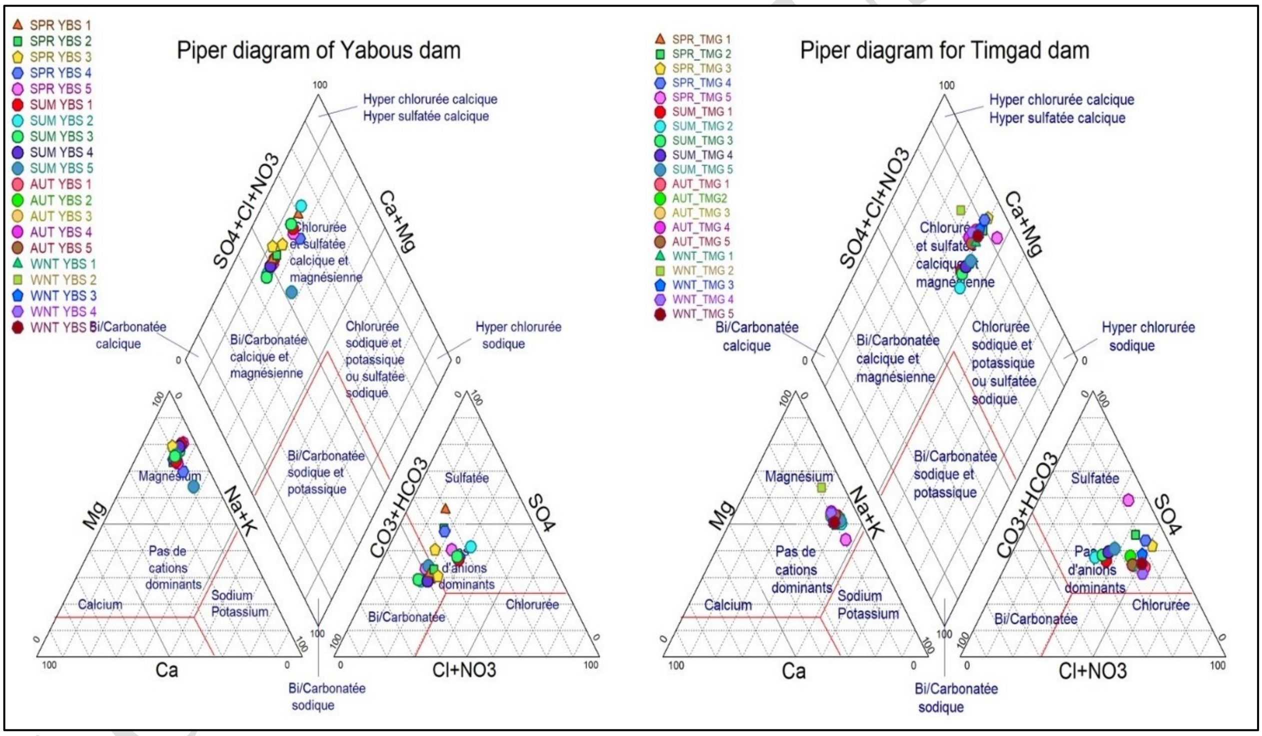


Figure 02. Piper diagram for Timgad and Yabous dams (period from May 2022 to April 2023). SPR: Spring stations. SUM: Summer stations. AUT: Autumn stations.WNT: Winter stations; TMG: Timgad dam stations; YBS: Yabous dam stations.

3.1.2. Water quality for drinking purposes:

3.1.2.1. Water quality index

The range of values observed for the Water Quality Index (WQI) for Timgad dam, as illustrated in Figure 3, spanned from 110.91 to 180.84. According to the criteria established by Singh et al. (2011), these values were classified as permissible for human consumption in all seasons. Moreover, Bouslah et al. (2017) identified two categories of WQI in their study of the same dam, based on the classifications outlined by Brown et al. (1972), Chatterji and Raziuddin (2002), and Denbath et al. (2017): a) unfit for human consumption and b) very poor, highlighting the severity of water quality degradation. In the context of Yabous Dam, as illustrated in Figure 3, the Water Quality Index (WQI) values were observed to range between 54.33 and 66.72. According to the criteria delineated by Singh et al. (2011), these values signify a classification of "Good" for human consumption in all seasons.

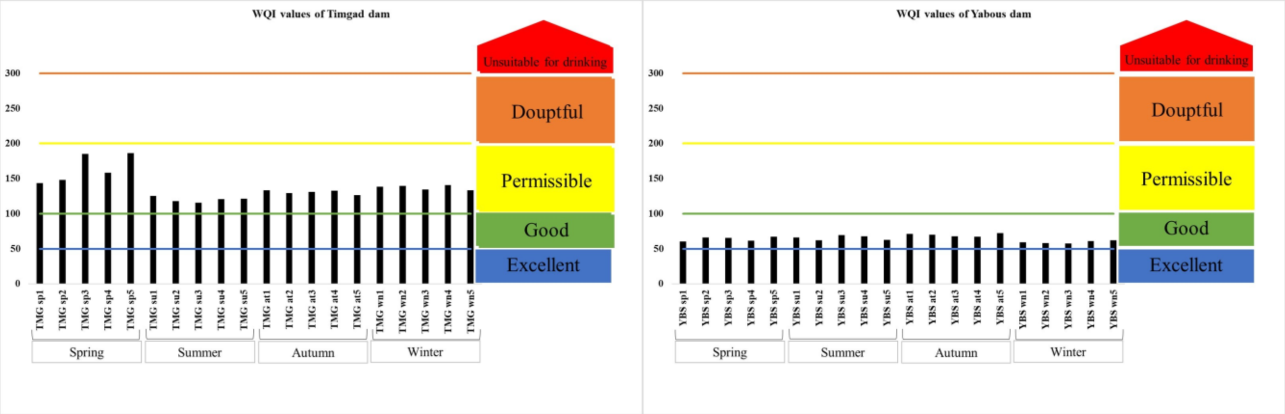


Figure 03: Seasonal variation of WQI in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.2.2. CCME-Water quality index:

The CCME WQI was applied for the first time to both dams after a year-long physicochemical characterization, which is a prerequisite for implementing the CCME WQI. According to Figure 04, Timgad Dam recorded a minimum value of (52.28 ± 2.11) in station 05 and a maximum of (57.14 ± 2.11), with an annual average of (56.02 ± 2.11). These values fall into the "Marginal" class according to the CCME WQI classification in Table 02, indicating conditions that are frequently threatened or impaired, and often depart from natural or desirable levels. The Yabous Dam, shown in Figure 04, had favorable hydrochemistry. Station 01 recorded a minimum value of (68.77 ± 1.12), while station 02 had a maximum value of (71.72 ± 1.12). The average value was (69.81 ± 1.12). The values in Table 02 are categorized as "Fair," suggesting that the waters are occasionally at risk or compromised, and conditions may deviate from natural or desirable levels.

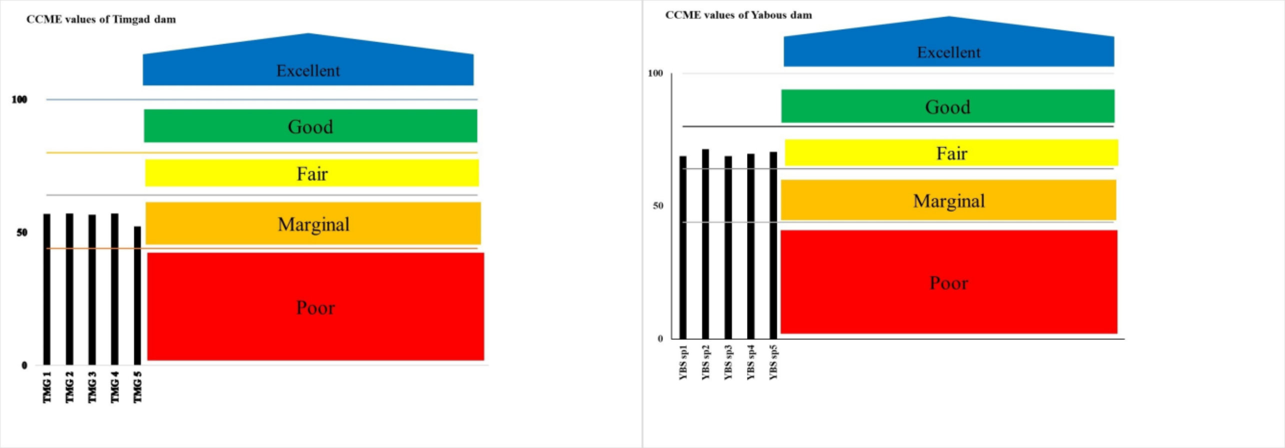


Figure 04: Seasonal variation of CCME-WQI in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3. Water quality for irrigation purpose

This study assessed the suitability of water quality for irrigation by evaluating parameters such as sodium hazard (Na %), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), magnesium hazard (MAR), permeability index (PI), residual sodium bicarbonate (RSBC), Kelly ratio (KR), and potential salinity (PS).

3.1.3.1. Sodium hazard (Na%) and sodium adsorption ration (SAR):

It is essential to bear in mind that all concentrations are expressed in milliequivalents per liter (meq l^{-1}) when assessing water quality indices for irrigation based on the observed chemical compositions in aquatic ecosystems. The SAR results are presented in Figure 05 to assess the impact of sodium risk concerning calcium and magnesium concentrations in the Timgad study area dam. The SAR values ranged from 01.98 to 04.18, with an average of 2.95. According to the classification by Richards (1954) in Table 03, most samples were deemed suitable for irrigation, except for station 02 during winter sampling, which had a SAR value of 01.98, classified as excellent for irrigation. In the Yabous dam, as shown in Figure 05, SAR values ranged from 0.55 to 1.55, with an average of 0.70, indicating an excellent classification for 100% of the samples in all seasons according to Richards (1954) in Table 02.Figure 6 displays the classification of percentage sodium according to Wilcox (1955), which was applied to the Timgad Dam. The %Na results ranged from 27.69 to 49.49, with an average of 38,57, indicating 75% of samples collected throughout the year are classified as good for irrigation purposes and 15% of samples were classified as permissible during summer sampling.

For Yabous Dam, as shown in Figure 6, the values of Na% ranged between 11.36 and 26.93, with an average of 15.36. We observe that 90% of the samples were classified as excellent, while 10% were classified as good, specifically at station 01 in autumn and winter samples, according to Wilcox's (1955) classification. Upon analyzing the plots of SAR versus Electrical Conductivity (EC) for Timgad Dam on Richard's diagram (Figure 7), it was observed that 100% of the samples fell within the class C3-S1 category, as delineated by Richard's diagram. Similarly, when examining the plots of Sodium Adsorption Percentage (Na%) versus EC on Wilcox's diagram (Figure 08), it was noted that all samples except those from the spring season were situated in class 02 (considered good), while the spring samples were located in class 03 (deemed doubtful) of Wilcox's diagram. Consequently, these findings indicate that the samples are suitable for plants with a high salt tolerance but may possess limited suitability for irrigation, particularly in soils with restricted drainage. For yabous dam and upon analyzing the plots of SAR versus Electrical Conductivity (EC) on Richard's diagrams (Figure 07), it was observed that 100% of the samples fell within the class C2-S1 category, as specified by Richard's diagram. Similarly, when examining the plots of Na% versus EC on Wilcox's diagram (Figure 08), it was noted that all samples were situated in class 01 (considered excellent). Consequently, these findings suggest that the water is of good to medium quality and should be used cautiously for poorly drained soils and sensitive plants.

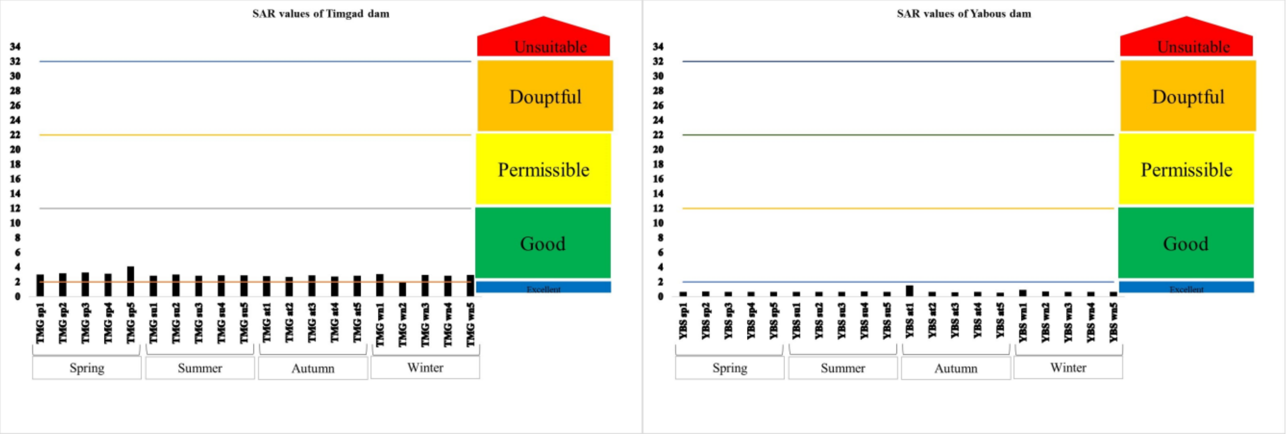


Figure 05: Seasonal variation of SAR in Timgad dam and Yabous dam (period from May 2022 to April 2023).

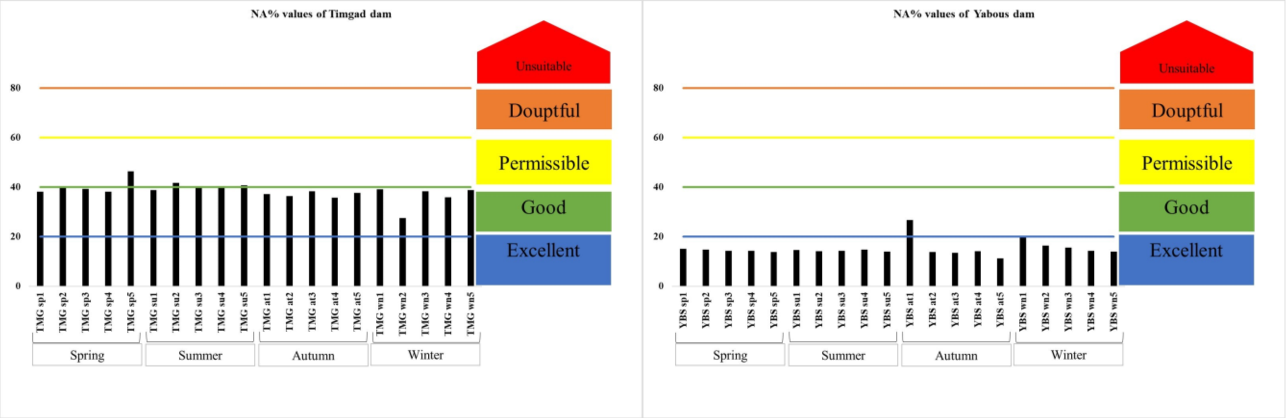


Figure 06: Seasonal variation of Na% in Timgad dam and Yabous dam (period from May 2022 to April 2023).

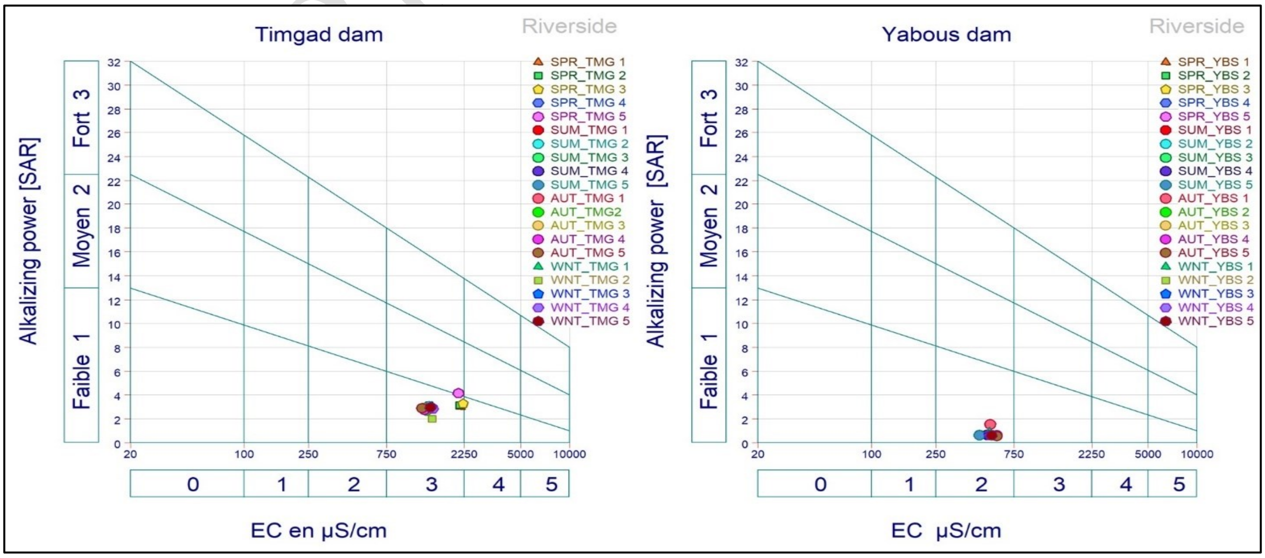


Figure 07: Plots of values of Sodium Adsorption Ratio (SAR) versus Electrical Conductivity (EC) for Timgad and Yabous dams (period from May 2022 to April 2023).

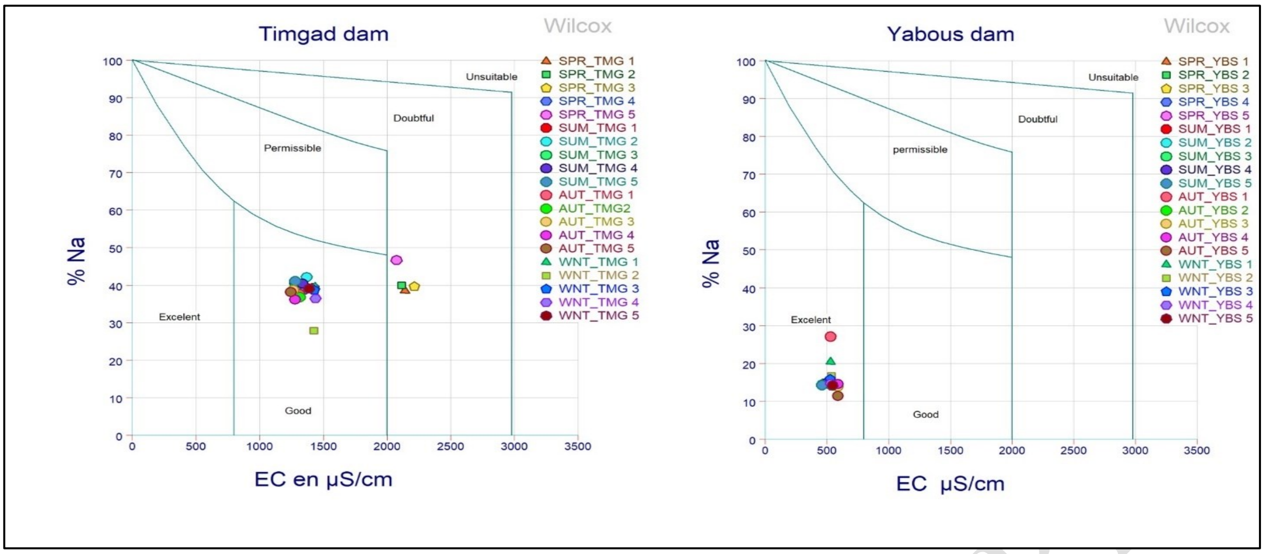


Figure 08: Plots of values of Sodium Adsorption Ratio (SAR) versus Electrical Conductivity (EC) for Timgad and Yabous dams (period from May 2022 to April 2023).

3.1.3.2. The Residual Sodium Carbonate (RSC)

The Residual Sodium Carbonate (RSC) is a crucial indicator for assessing the surplus alkalinity in water. Elevated levels of carbonate/bicarbonate in irrigation water can lead to the precipitation of calcium and magnesium, resulting in water with high concentrations of these elements. An excess of sodium bicarbonate and carbonate can have adverse effects on the physical properties of soil, leading to the dissolution of organic matter and potential challenges for plant growth (Bauder et *al*., 2011; Bouderbala, 2021). In our study of dams, Figure 9 illustrates the variation of RSC values. For the Timgad Dam, the minimum value was -11.03 meq l^{-1} recorded at station 03 during spring sampling, while the maximum value of -4.92 meq l^{-1} was observed at station 02 during summer sampling, with an average of -8.86 meq l^{-1} . Based on the classification provided in Table 03, the dam consistently falls within the "permissible" class for irrigation purposes across all seasons. Similarly, for the Yabous Dam, the minimum value of -5.42 meq l^{-1} was recorded at station 04 during winter sampling, while the maximum value of -2.43 meq l^{-1} was observed at station 05 during summer sampling, with an average of -3.90 meq l^{-1} . According to the classification in Table 03, the dam is also classified as "permissible" for irrigation purposes in all seasons.

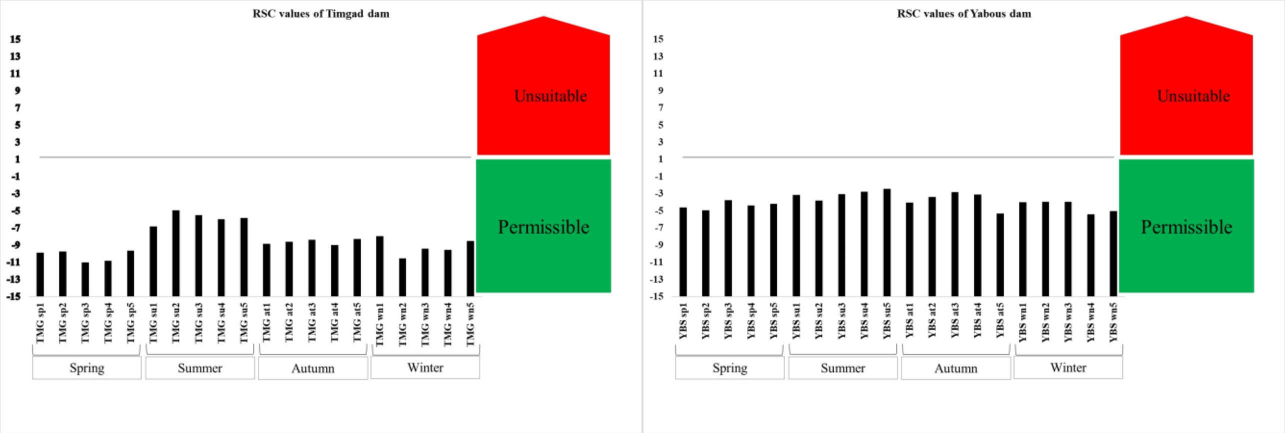


Figure 09: Seasonal variation of RSC in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3.3. Permeability index (PI):

Donnen (1964) developed a Permeability Index (PI) to evaluate the suitability of water for irrigation, a crucial indicator for this purpose. According to Figure 10, PI values at Timgad Dam range from 36.82% and 54.40% across stations 02 during winter and summer, with an annual average of 47.47%. These values consistently place the water within the "suitable" classification according to Donnen's (1964) Table 03, across all seasons and stations. Similarly, Yabous Dam also falls within the "suitable" class for irrigation, with values ranging from a minimum of 30.22% at station 05 in autumn to a maximum of 44.73% at station 01, also in autumn, and an average of 43.30%.

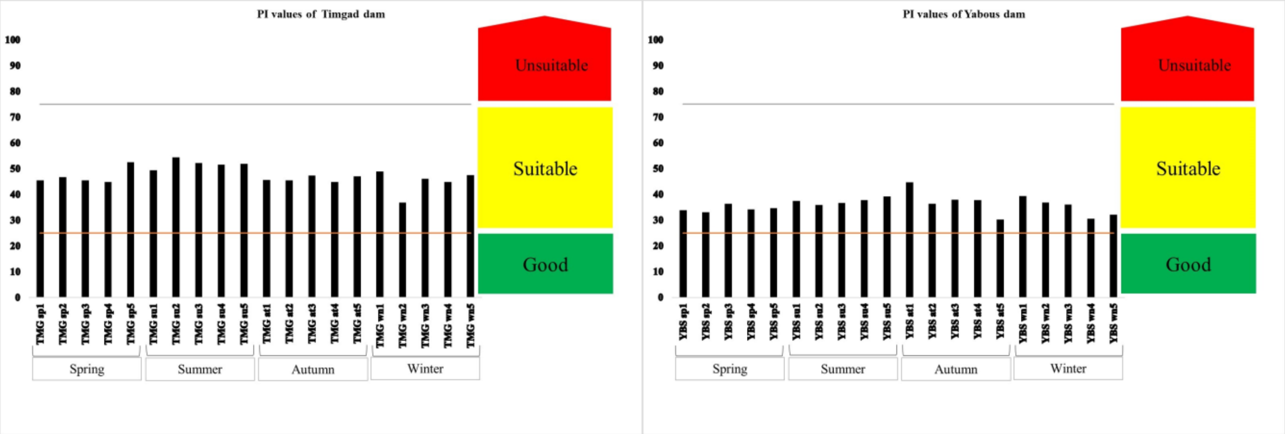


Figure 10: Seasonal variation of PI in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3.4. Potential salinity (PS):

The Potential Salinity Index evaluates water quality based on chloride (Cl^-) and sulfate (SO_4^{2-}) concentrations. In the present study, illustrated in Figure 11, samples from Timgad Dam exhibited values ranging between 7.42 and 18.12, with a mean value of 12.30. According to the classification in Table 03, these values indicate that the water from Timgad Dam is unsuitable throughout the year. In contrast, Yabous Dam consistently showed a classification of "good" throughout the year, except at station 04 during spring sampling, where it was classified as "excellent" with a value of 2.86, the minimum recorded. The maximum Potential Salinity Index value recorded for Yabous Dam was 4.87, with an average of 3.70.

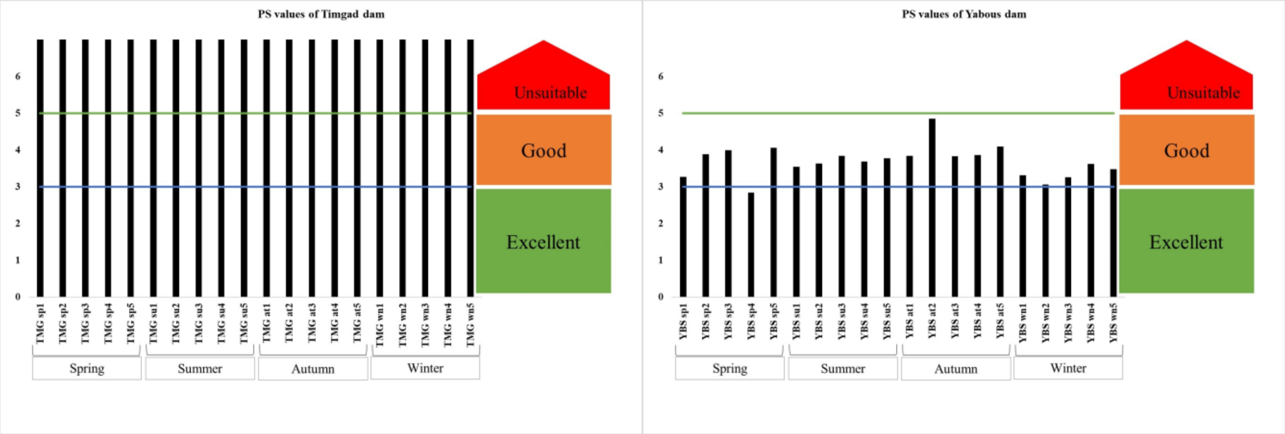


Figure 11: Seasonal variation of PS in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3.5. Kelly's Ratio (KR):

The Kelly's Ratio (KR) is a crucial parameter for assessing water intended for irrigation. For Timgad Dam, KR values range between 0.38 and 0.86, with a mean of 0.62. According to Kelley's classification from 1964, as depicted in Figure 12, the water from Timgad Dam consistently falls within the "suitable" class for irrigation throughout the year. Similarly, after analyzing KR data for Yabous Dam, we found values ranging from 0.12 to 0.36, with a mean of 0.18. According to Kelley's classification in Table 02, these values also belong to the "suitable" class for irrigation across all four seasons of the year.

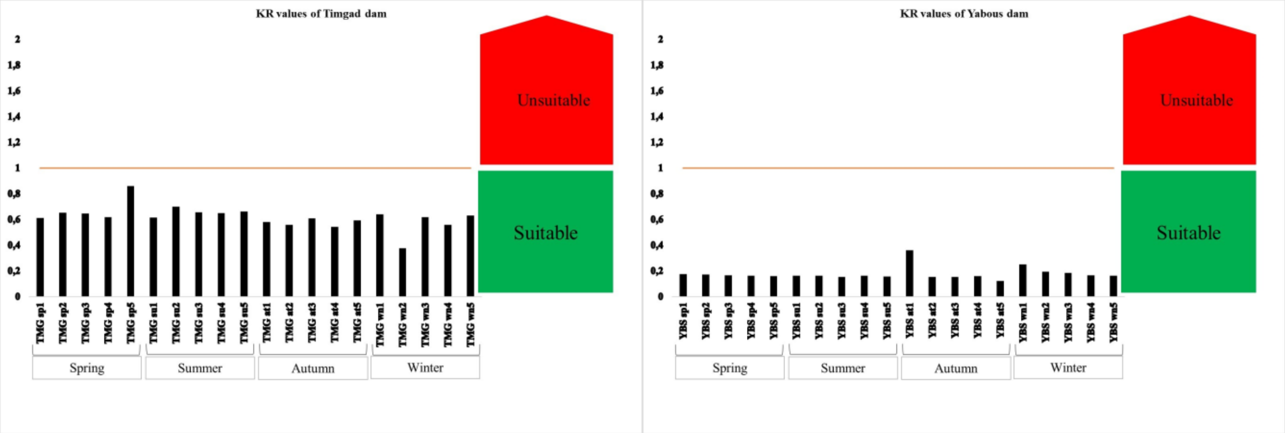


Figure 12: Seasonal variation of KR in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3.6. Residual sodium bicarbonate (RSBC):

The Residual Sodium Bicarbonate (RSBC) was evaluated by Gupta in 1983 (Prasad et *al.,*2001*)* to assess suitability for irrigation. In our study, diverse results were obtained in figure (13). For Timgad Dam, RSBC values range between -0.09 and 3.22, with a mean of 1.28. Spring samples mostly exhibited non-alkaline class, except for station 01 which showed low alkalinity. Alkalinity increased in summer, with stations 01, 02, and 03 reaching medium alkalinity class, while stations 04 and 05 remained in the low alkalinity class. In autumn and winter, all stations reverted to low alkalinity class. These classifications are according to Gupta's 1983 classification in Table (03). Yabous Dam exhibited three alkalinity classes, with RSBC ranging between 1.14 and 5.59, and a mean of 3.12. Spring samples showed low alkalinity, but increased to medium alkalinity in summer, with stations 01, 02, and 05, while stations 03 and 04 reached high alkalinity class. Autumn showed relative stability in alkalinity, with all stations classified as medium alkalinity, which decreased in winter, with all stations reverting to low alkalinity class according to Gupta's 1983 classification in Table (03).

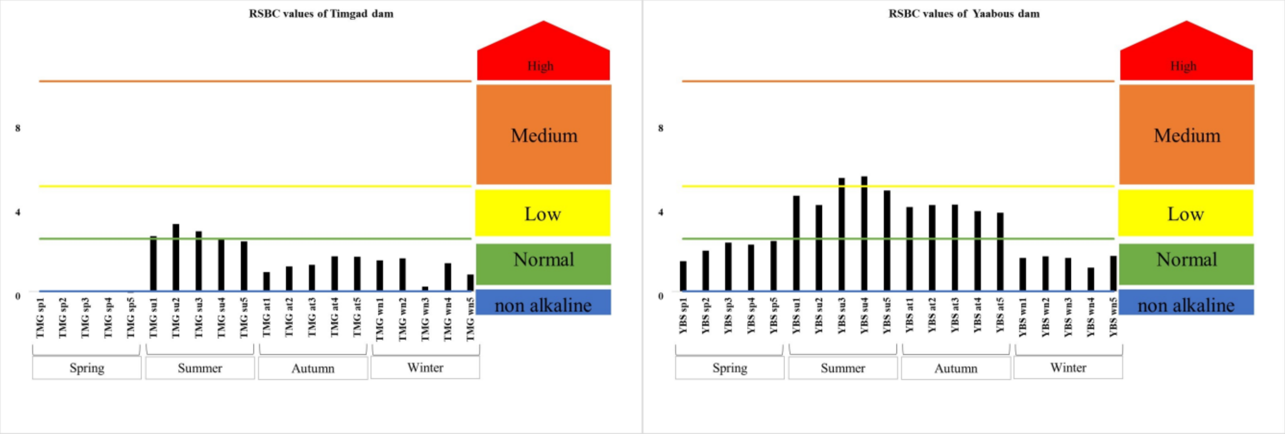


Figure 13: Seasonal variation of RSBC in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.1.3.7. Magnesium Hazard (MH):

Raghunath (1987) first introduced the concept of magnesium hazard, highlighting the substantial influence of magnesium in irrigation. According to Figure 14, our study consistently shows that the dams assessed are classified as unsuitable for irrigation purposes throughout the year. The Timgad Dam, for instance, displayed recorded values ranging from a minimum of 82.48 to a maximum of 88.36, all falling within the unsuitable category for irrigation. Similarly, the Yabous Dam recorded values within the unsuitable classification for irrigation purposes throughout the year, with a minimum of 85.96 and a maximum of 94.6.

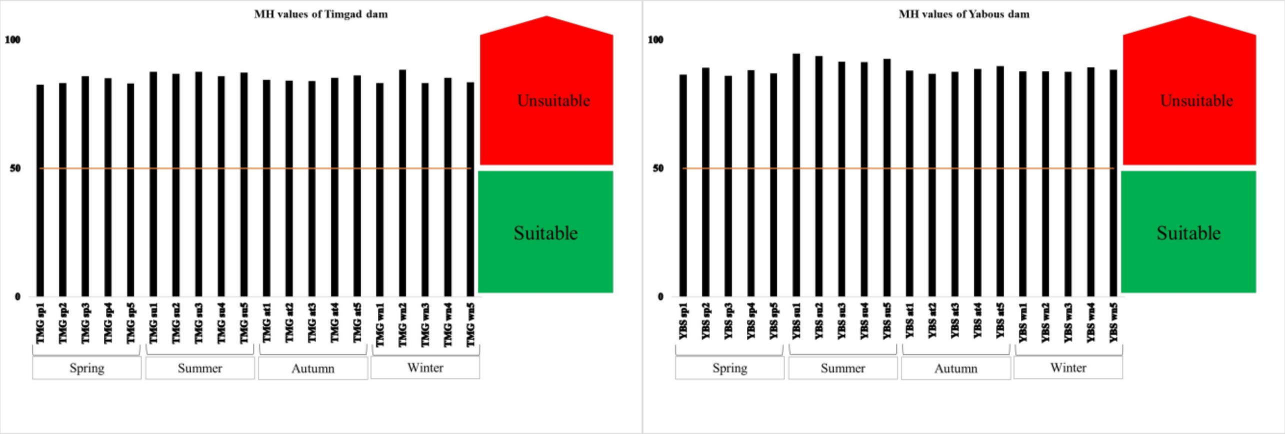


Figure 14: Seasonal variation of MH in Timgad dam and Yabous dam (period from May 2022 to April 2023).

3.2. Discussion:

The hydrochemistry of both dams reveals that the conductivity values exceed the WHO 2011 standard of 500 µS cm^{-1} , particularly in Timgad Dam, This increase is primarily due to significant evaporation throughout the study period, concentrating ions in the remaining reservoir water. Moreover, substantial salt input from Timgad city's wastewater and effluents from a nearby brick factory via two rivers, notably affecting stations 03 and 04, contributes to these elevated values. A comparative study by Alsubih et al. (2022) in Saudi Arabia, focusing on semi-arid region dams, reported values ranging from 649 µS cm-1 to 2340 µS cm^{-1}, underscoring the natural and anthropogenic influences on Timgad's conductivity levels, corroborated by previous research (Tiri, 2015; Bouslah, 2017) which reported lower values of 682.3 µS cm^{-1} and 1039 µS cm^{-1} respectively. In contrast, Yabous Dam shows a slight increase in electrical conductivity attributed solely to a decline in the reservoir's water level over the year. Yabous Dam's values stand out compared to Merouche's (2019) study on seven semi-arid region dams, which reported values between 700 µS cm^{-1} and 1200 µS cm^{-1}. Total dissolved solids (TDS) values closely mirror electrical conductivity values for both dams. The rising temperatures associated with climate change have further exacerbated salt concentrations in dam waters, compounded by wastewater and brick factory effluent inputs, particularly evident for Timgad Dam. These findings align with similar studies on semi-arid region dams, such as Alsubih et al. (2022) and Bouderbala (2021). Notably, de Oliveira et *al*., (2020) reported TDS values below the WHO 2011 standard, similar to Yabous Dam's values, as well as in Sidi M'hamed Bentiba Dam evaluated by Merouche et *al*., (2019) where TDS was measured at 398 mg l^{-1}. Chloride levels have shown a relative increase in Timgad Dam compared to previous studies by Tiri (2015) and Bouslah (2017) studies, attributed to the urban expansion of Timgad city directly discharging into the dam, including a gas station situated alongside a river flowing towards station 04 of the dam. High chloride levels are typical for the Timgad region due to gypsum dissolution (Alexakis, 2011; Bouaroudj et *al*., 2019). However, chloride values in Yabous Dam remain within the WHO 2011 standard. High sulfate values in Timgad Dam result from geological elements and gypsum presence, suspected to be exacerbated by brick factory cooling and washing water containing sulfur-containing materials. High bicarbonate concentrations in Yabous Dam, especially noted during summer sampling, primarily stem from the geological formations in the region, which include limestone, marl, and sandstone. These formations release various forms of bicarbonate into the water, such as calcium bicarbonate. Despite these geological influences, the dam's bicarbonate values align with those observed in studies conducted in semi-arid regions, such as de Oliveira et al. (2020) and Bouderbala (2021). Previous research on magnesium concentrations in semi-arid regions has shown similarities to those found in our study's dams. Alsubih et al. (2022) reported a maximum of 153 mg l^{-1} in Saudi Arabia, de Oliveira et al. (2020) found up to 111.09 mg l^{-1} in Brazil, and Merouche et al. (2019) reported values up to 150 mg l^{-1}. In Timgad Dam, elevated magnesium levels are attributed to discharge from brick factory effluents, exceeding the WHO 2011 standard. Conversely, in Yabous Dam, magnesium carbonate release from geological sources remains the primary contributor to the dam's magnesium levels.

The Water Quality Index (WQI) for the two study dams was determined using the weighted arithmetic index method proposed by Horton (1965), a widely used approach in water quality assessment (Chauhan and Singh, 2010; Chowdhury et *al.*,2012; Ewaid and Abed., 2017; Ibrahim (2019); kalagbor et *al.*,2019; Imneisi and Aydin., 2016; Rao et *al.*, 2010). Our study's findings suggest an improvement in the water quality of Timgad Dam compared to seasonal results obtained by Bouslah et *al.*, (2017) . Their study identified two categories of WQI: unfit for human consumption and very poor, indicating severe degradation in water quality Results for Timgad dam indicates the important role of the wastewater treatment station planted near the river that carries sewage from the city of Timgad to the dam.

In contrast, the initial study of Yabous Dam revealed a "good" classification, which is notably exceptional compared to other dams in semi-arid regions. For example, Abualhaija and Mohammad (2021) reported poor quality classes in Jordan, and Molekoa et *al.*, (2022) observed poor quality in the dry season in southern Africa. Yabous Dam benefits from its location in a mountainous area with a unique microclimate, which receives precipitation and snow, hereby helping to maintain diluted concentrations of various elements in its waters.

Soltani et *al*., (2020) evaluated Beni Haroun Dam, the largest dam in Algeria, using the CCME-WQI for the period 2000-2010, resulting in a poor-quality classification. Comparatively, the CCME-WQI results for our study dams are not far from those of Beni Haroun Dam, Timgad Dam was classified as marginal and Yabous Dam as fair, which are currently satisfactory results.

The significant elevation difference between Yabous Dam and Yabous City makes it highly improbable for city wastewater to flow into the dam. The dam is situated at an elevation ranging between 1190 m and 1216 m above sea level, juxtaposed with the altitude of Yabous City, which spans from 1118 m to 1180 m above sea level. This significant difference in elevation renders it improbable for wastewater from the city to flow into the dam, Additionally, the dam is surrounded by forested areas and is located at a considerable distance from agricultural activities, which further supports its water quality. The elevation of dams plays a critical role in water quality dynamics, as evidenced by various studies.While dams can improve water quality in urbanized watersheds (Shahady, 2021), they may degrade it, especially in agricultural areas susceptible to eutrophication and contaminant accumulation (Zubala, 2009; Jaguś, 2011). Furthermore, the release of cooler, oxygen-depleted deep water by dams in low-latitude areas can harm downstream ecosystems (Winton, 2019). These findings emphasize the need to protect our study dams, especially Timgad Dam, which is susceptible to poor classification at any moment, as seen in similar studies in semi-arid regions (Sirunda et *al*., 2022).

The evaluation of surface water suitability from the Timgad and Yabous dams for irrigation depends on various factors, including the ionic concentrations in the water, soil characteristics, and the growth stage of plant species (Ghazaryan and Chen ., 2016; Bouderbala, 2021). The accumulation of salts in soil can lead to decreased osmotic pressure within plant cells, hindering water uptake and resulting in reduced plant growth and agricultural yields. It is crucial for farmers to adhere to recommended irrigation practices to mitigate soil salinity and maintain soil productivity (Ayres and Westcot., 1999; Bouderbala, 2017; Bouderbala, 2021).

Research findings indicate that the magnesium hazard for both dams renders them unsuitable for irrigation,primarily due to the significant contribution of geological factors leading to increased magnesium concentrations, as confirmed by Gupta (2012) and Khan et *al*.,2022. Rock weathering was identified as the primary process determining the presence of ions in water, with calcium and bicarbonates being the most prevalent (Sun, 2013). The presence of heavy metals in water was linked to geological factors, resulting in higher concentrations in finer sediment fractions. These studies underscore the substantial influence of geology on the ionic composition of water in dams, further exacerbated by industrial brick production in the Timgad basin and wastewater discharge from the city, which increase sulfate and chloride concentrations, thereby making the dam's potential salinity unsuitable for irrigation.

However, other irrigation indices and parameters exhibited satisfactory values compatible with studies conducted on dams in semi-arid regions worldwide, such as the Sitios Novos Dam in Brazil (De Oliveira et *al*., 2020), the Asir region dams in Saudi Arabia (Alsubih et *al*., 2022), and other dams in Algeria's semi-arid regions like Oued El Fodda in chlef region (Bouderbala, 2021);Beni Haroun dam by Soltani et *al*., 2020 and merouche et *al*.,2019 which increase sulfate and chloride concentrations, thereby making the dam's potential salinity unsuitable for irrigation. For Timgad Dam, classified as C3S1 on the SAR (Sodium Adsorption Ratio) versus electrical conductivity plot, specialized management practices for salinity control may be necessary even with adequate drainage. These practices should prioritize selecting plant varieties with high salt tolerance. This recommendation finds support in previous studies by Richard (1954), Balba (1995), Sallam and Elsayed (2018), and Bouderbala (2021), emphasizing the importance of integrating salinity management strategies into agricultural practices.

The initial study of the Yabous Dam revealed good to excellent values, attributed in part to its location in a mountainous area with significant slopes, minimizing water contact time with geological structures and traversed soils, as supported by Kim (2013) and Jódar (2020). Kim's research indicates higher levels of anions and cations due to prolonged water retention periods in mountainous regions, while studies by Lee (2005) and Kelley (2007) highlight challenges in water management in specific regions. Lee's study on the Unmun Dam in Korea emphasizes a strong hydraulic connection between the reservoir and the dam's interior, while Kelley's research on the Mosul Dam underscores the dam's impact on subsurface dissolution rates. These findings underscore how water interaction with geological features in mountainous regions is influenced by factors such as water residence time, hydraulic connectivity, and the presence of dams.

3. Conclusion

Timgad and Yabous dams are located in a semi-arid region of northeastern Algeria, playing a critical role in meeting the region's water demands for drinking and irrigation. This study employed a comprehensive research methodology to enhance understanding of dam water hydrochemistry in arid and semi-arid regions globally. The findings indicate that Timgad Dam consistently exhibits a chemical composition dominated by sodium and potassium chloride, as well as sodium and potassium sulfate throughout the year. High values were recorded for electrical conductivity (EC), total dissolved solids (TDS), chloride (Cl^-), sulfate (SO_4^{2-}), and magnesium ($Mg^{2+).}$ Notable concentrations of sodium have been observed, all of which comply with the WHO 2011 standards. The Water Quality Index (WQI) categorizes the dam water as suitable for drinking purposes year-round.Moreover, it is classified as good for Sodium Adsorption Ratio (SAR) and Sodium Percentage (Na%) for irrigation purposes, except during the summer season when SAR values are permissible. However, high concentrations of :Cl^- and So_4^{2-} contributed in the unsuitable classe for the PS index, Mg^{2+} results in an unsuitable classification for the Magnesium Hazard (MH) index throughout the year. The Residual Sodium Bicarbonate Concentration (RSBC) varied, showing non-alkaline conditions in spring, medium alkalinity in summer, and low alkalinity in autumn and winter. Other indices exhibited positive results for Timgad Dam.

Yabous Dam, studied for the first time, exhibits a chemical composition dominated by magnesium sulfates and magnesium bicarbonates year-round.Overall hydrochemistry approaches perfection, with a slight elevation in EC values and significant levels of magnesium, while all other parameters comply perfectly with WHO 2011 standards.The dam water is classified as good according to the WQI for drinking purposes, and it is rated excellent for SAR and Na%, except for 10% of the stations classified as good in terms of Na%. In the rsc index all stations recorded the classe permissible across the year ; the class good was obtained in PS index across all seasons and suitable classifications for the PI and KR indices at all stations year-round. In mater of alkalinity ; the recorded RSBC for this dam is low alkalinity in spring ; medium alkalinity in summer and autumn except for station 03 and 04 during summer were withing the high alkalinity values and low alkalinity in winter.

Generally, the results indicate satisfactory water quality for both Yabous and Timgad dams. Yabous Dam shows superior water quality for both drinking and irrigation purposes compared to Timgad Dam. However, despite these satisfactory findings, safeguarding these crucial infrastructures is essential. Given the threats posed by various wastewater sources and climate change impacts, several remedial measures are proposed. Firstly, reactivating the currently inactive wastewater treatment station at Timgad Dam is recommended to mitigate contaminant influx. Secondly, implementation of best agricultural practices to reduce agricultural runoff into the dam reservoirs is crucial. Additionally, constructing retention ponds, vegetated swales, and permeable pavements can intercept and treat stormwater runoff before it reaches the dams, focusing particularly on sources such as brick factories and gas stations that impact Timgad Dam.

These interventions collectively aim to address the identified sources of pollution in the dams and contribute to the protection and preservation of water quality in the dams.

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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".

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