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# The conception of GIS to evaluate the impact of anthropogenic activities on the quality of surface waters of the dams of the hydrographic region of Constantinois-Seybouse-Mellegue, Algeria

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**ABSTRACT**

A technique based on coupling the Geographic Information Systems with water quality assessment system was made and tested on superficial waters of the Constantinois-Seybouse-Mellegue hydrographic region. The adopted technique is based on the processing of the results of physico-chemical analysis realized in 15 different dams present in the region during the year 2016. A cartographic representation of the study area was carried out with elaboration of quality maps for each alteration. The results obtained allowed the elaboration of a global quality map which showed a very poor quality of water in the south of the studied area, which reflects a severe pollution in these regions, explained by the presence of fertilizers, the increase of temperature as well as the altitude, the high concentration of organic matter, the high concentration of carbon dioxide, the low level of oxygen and the low volume of dams. On the other hand, in the north of this area the map shows a good to moderate water quality which is explained by the implantation of these dams in the upstream of the agglomerations, the low temperature, the low altitude, the low concentration of organic matter, the high level of oxygen and the large volume of dams.

*Keywords:* Water quality; Hydrographic region; Geographic Information Systems; Dams; Global quality map; Good; Very poor; Pollution

## 1. Introduction

Water is a natural resource essential for the life of every ecosystem. Being aware of its quality allows to have a global vision of the risks to be able to assure the protection of the resources and to identity potential sources of the alteration of water quality [1], therefore the protection of water resources is one of the most important preoccupations of every environmental policy [2].

In Algeria, like the others countries in the world, the preservation of water resources has become a major priority, due to the rarity of this resource and the multiplication of the potential sources of pollution.

The increase of urban, agricultural, and industrial activities has contributed during the decades, to increase the potential of surface water contamination and, even underground water, thus a comprehension of the nature of wastewater is important to evaluate the effects of pollutants on

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aquatic life and human health [3]. Otherwise, the hydrographic region of Constantinois-Seybouse-Mellegue has known in the last decades an important demographic and industrial growth, which generates excessive consumption of this resource and makes water quality around watercourses and dams unpleasant [4]. Since then, a rational management of water is necessary to avoid new problems of contamination and to ensure a quality water supply.

For an integrated management of the resource, a better understanding of water properties is necessary.

The collected data should be managed, modified, then analyzed and represented as a map to facilitate the understanding and the communication [5]. Geographic Information Systems (GIS) are tools that allow this type of application [6].

In this context, the objective of the current work is to develop a technique of pairing GIS-WQES of the dams of the hydrographic region of Constantinois-Seybouse-Mellegue. Based on mapping and based on the integration the parameters of water quality. For each parameter, an indicator of weighting and of alteration have been calculated, alteration as a set of parameters of the same nature or the same disturbing effect. Every class of quality is defined as a set of threshold values for the different alterations. This approach has been studied and tested on surface water of the dams of the hydrographic region Constantinois-Seybouse-Mellegue.

### *1.1. Presentation of the studied area*

The study concerns the watersheds located in the north east of Algeria, located between 5° and 9°E longitude and 35° and 37°N latitude. This hydrographic region is limited from the north by the Mediterranean Sea, from the south by the watershed of the Sahara, from the west by the hydrographic region of the Algérois-Hodna-Soummam and from the east by the Tunisian border (Fig. 1).

This region extends over a surface of 4,3796 km$^2$, and it includes 43 sub-watersheds that form the five biggest watersheds (Table 1).

Watershed 03 of Constantine's coast is subdivided to 18 sub-watersheds; watershed number 07 of high plateaus of Constantine is subdivided to sub-watersheds. Watershed of Kebir-Rhumel subdivided to 07 watersheds, watershed of Medjerda is subdivided to 05, sub-watersheds, and watershed 14 of the Seybouse is subdivided to 06 sub-watersheds [4].

Highlighted by altimetry maps and the slope, established by the general direction of forests in 2010, the landform of the area of study is divided, to 4 zones according to an axis of north–south: zone of a weak altitude (0–400 m), zone of average altitude (400–800 m), zone of high altitude (800–1,200 m), zone of very high altitude (1,200–2,200 m) [7].

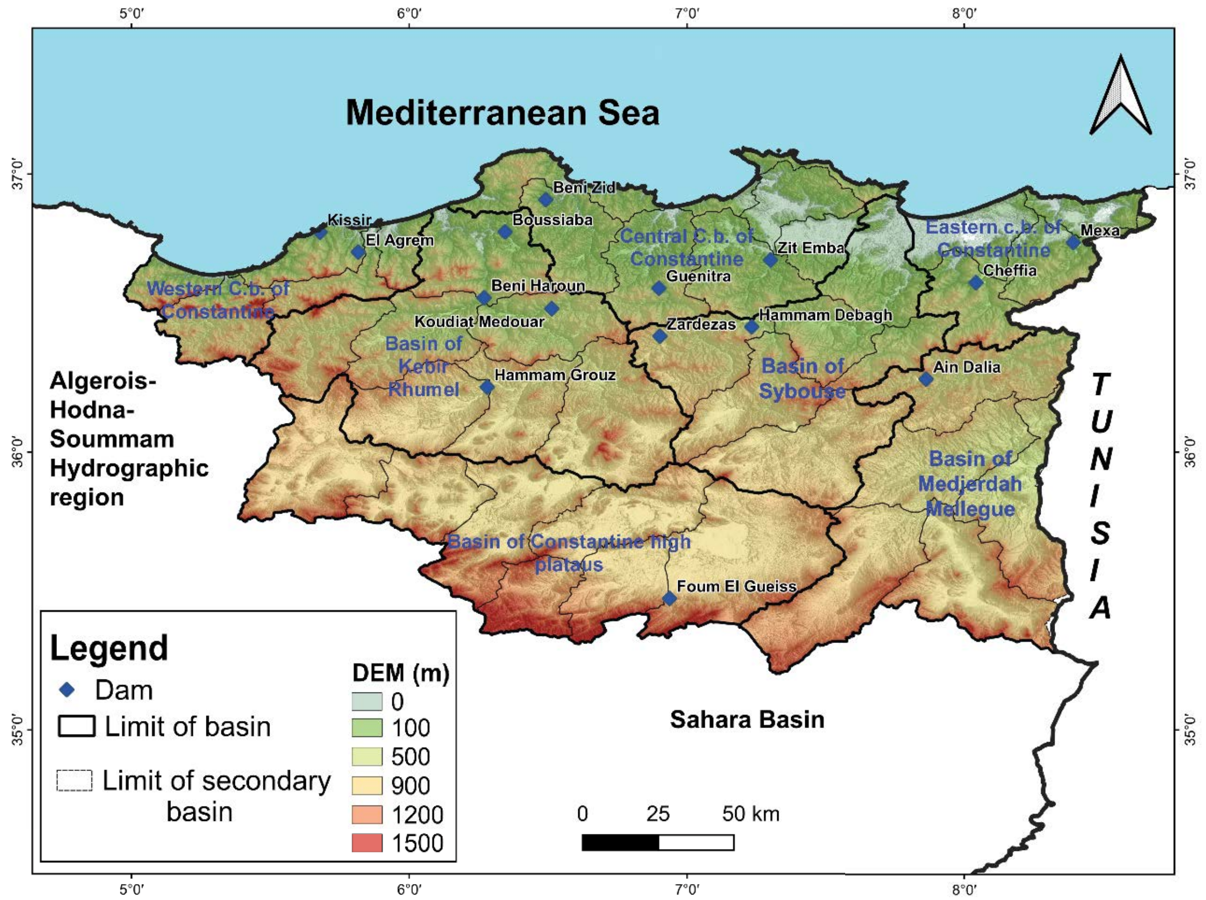


Fig. 1. Map of the geographical situation of the hydrographic region Constantinois-Seybouse-Mellegue.

Table 1
Location of dams

| Catchment code | Name catchment | Number of sub-catchment | Station | Dam | Sub-catchment code |
|---|---|---|---|---|---|
| | | | s1 | Cheffia | 0315 |
| | | | s8 | Mexa | 0316 |
| | | | s9 | Zit-Emba | 0311 |
| 03 | Basin of the Constantinois coastal | 18 | s3 | Guenitra | 0309 |
| | | | s6 | Benizid | 0307 |
| | | | s10 | El-Agrem | 0303 |
| | | | s14 | Kissir | 0303 |
| 07 | Basin of the high plateaus of Constantinois | 07 | s15 | Foum El Gueiss | 0707 |
| | | | s4 | Hammam Grouz | 1004 |
| 10 | Basin of the Kebir-Rhumel | 07 | s11 | Beni Haroun | 1007 |
| | | | s12 | Koudiat Medouar | 1006 |
| | | | s13 | Boussiaba | 1007 |
| 12 | Basin of the Medjerda | 05 | s7 | Ain Dalia | 1201 |
| 14 | Basin of the Seybouse | 06 | s5 | Hammam Debagh | 1403 |
| | | | s2 | Zardezas | 1403 |

Regarding the slopes, they are subdivided into four classes: class 1: 0% ≤ slope ≤ 5%; class 2: 5% ≤ slope ≤ 15%; class 3: 15% ≤ slope ≤ 35%; class 4: slope > 35%.

The target region of our study is arranged in parallel chains of gneiss and granite at the littoral strip of the Tellian Atlas (Jijel-Skikda-Annaba) and the marls which dominate the basin this formation is also found in the wilaya of Souk Ahras and south of Tébessa.

We can also find alluvium in Barika plains, high plains of Khenchela as well as Mahouna Cheham mountains (Guelma). Sandstones could be seen in the watershed of coastal Constantinois west and east. the flysch is dispersed in the coastal strip. The clay is found in the watershed of Seybouse, in high plateaus (high plains of El Madher-Chemora) and the north west of Medjerda basin [7].

The precipitations of the studied area decreases from north to south, where it has been noticed precipitations of 1,000 mm and more, in the western coastal strip. Recorded precipitations in the lower chain of Tellian Atlas goes between 600 and 800 mm, while high plateaus experience precipitation that does not exceed 500 mm. The exception is linked to Aures Massif where about 900 mm is recorded. For the Saharan plateau (Negrine), it rarely rains; it is estimated around 100 mm [8].

Hydrographic network of north east Algeria's watersheds is more advanced in the north than in the south. The type of coastal water streams that belongs to the three northern watersheds (03, 10 and 14) are exoreic, their flow is relatively provided by: Oued Mafragh, Kebir-Rhumel and Seybouse, these valleys start from Tellian Atlas mountain chain and lead to the Mediterranean Sea. The hydrographic network is extremely branched out and extremely strong in the south in the center, in the west and less strong in the east. We find free water plans in the watershed of coastal Constantinois (3) such as lake of Fetzara, Tonga and Oubeira.

There are also alluvial deposits in the plains of Barika, the high plains of Khenchela and the mountains of Mahouna and Wadicheham (Guelma). The sandstones can be seen in the west and east coastal Constantine watershed. The flysch disperse at the coastal strip. The clay of the eastern Constantine coasts and that of Kebir-Rhumel, clay is found at the watershed of Seybouse, at the high plateaus (high plains d'El Madher-Chemora) and the north east of Medjerda's watershed [7].

Precipitation in the study region decreases from north to south, where it is observed precipitations of the order of 1,000 mm and more, at the western coastal strip. The precipitation recorded in the inner chain of the Atlas Tellien fluctuate between 600 and 800 mm, while the high plateaus experience precipitation that does not exceed 500 mm. The exception is made for the Aures Massifs where nearly 900 mm are recorded. As for the Saharan plateau (Negrine), the precipitations are rare, they are estimated with 100 mm [8].

The hydrographic network of the watersheds of north-eastern Algeria is more advanced in the north than in the south. The coastal water stream belonging to the three northern watersheds (03, 10 and 14) are of the exoreic type, they have a relatively abundant flow: Wadi Mafraq, Kebir-Rhumel and Seybouse, these valleys were born in the chain of the mountains of the Atlas Tellien and flow into the Mediterranean Sea. The hydrographic stream system is quit ramified and very dense in the south, in the center, in the west and less dense in the east. There are open water plans in the coastal-Constantinois watershed (03) such as lakes of Fetzara, Tonga and Oubeira. There are also several dams that are being utilized in the south of the tell area. Small water streams are temporary. The Wadi Mellegue, which has its source in the Bentaleb Massifs and the high plains of Sedrata as well as the Wadi Medjerda which starts from the mountains of Souk-Ahras, flow into the Tunisian watersheds. The watersheds of Constantine's high plateaus are characterized by a branched and less dense hydrographic network with temporary flow, the main valleys of this watershed

Chemora and Boulfreiss. The Chemora Wadi ends after a distance of about 30 km, in the salt lakes of the high plains of Constantine. These are Sebkhet Djendli, Garâet Ank-Djemel, Garâet El-Tarf. The majority of water streams are made of dendrite [9].

## 2. Methodology

From a topographic map by digitalization, we could elaborate a certain number of information layers. In parallel, physico-chemical analysis are treated by an assessment system of water quality (WQAS). Afterward, everything is integrated in the GIS to finally elaborate the maps of the quality of each studied parameter and the map of the global quality.

### *2.1. Water quality assessment system*

This system is based on the notion of the weighted quality index which is calculated for each parameter.

Rule of calculation of the weighted index (WI):

The formula for calculating the weighted index is as follows [10].

$$\text{WIAP} = \text{Ii} + \left[\frac{(\text{Si} - \text{Ii})}{(\text{Ub} - \text{lb})}\right] \times (\text{Ub} - \text{Ap})$$

WIAP: weighted index of the analyzed parameter
– Ii: Inferior index
– Si: Superior index
– lu: lower bound
– Ub: Upper bound
– Ap: Analyzed parameter

Indeed, the values of the ranges set by the new grids (Table 2), to evaluate water quality are transformed into figures without units ranging from 0, for very poor quality, to 100 for excellent quality.

Water quality is assessed taking into consideration different types of pollution characterized by groups of parameters of the same nature or same effect on aquatic environments. The values of the parameters are obtained by the samples taken from the various dams in the region during the period from January 2016 to December of the same year. The index of a parameter is obtained by weighting and the index of an alteration is obtained by averaging the weighted values of the parameters characterizing the alteration (Fig. 2). Each quality class is defined by a set of threshold values that the various parameters of the various alterations must not exceed. To determine the global quality of the 15 dams and to develop the global quality map, we have adopted an approach that consists of determining the global quality by the lowest alteration index. The quality class obtained is that of the alteration with the lowest index.

### *2.2. GIS-WQAS-coupling*

In order to optimize the water quality assessment system, in the case of a large volume of data (higher number of measurement stations), we carried out a GIS-WQAS-coupling to assist us in making queries, as well as processing and analyzing the quality of water resources. A specific GIS application is offering a set of tools, in particular for data attachment and control, spatial analyzes and cartographic representations.

### *2.3. Creation of WQAS database*

The database is the set of variables studied from their design to the constituent elements of their cartographic

Table 2
Quality of the grid of surface waters

| Alteration | Quality class | Excellent | Good | Moderate | Poor | Very poor |
|---|---|---|---|---|---|---|
| | Index | 100 | 80 | 60 | 40 | 20 |
| | | 80 | 60 | 40 | 20 | 0 |
| Oxidizable and organic matter | | | | | | |
| $BOD_5$ (mg/L) | | <3 | 3–6 | 6–10 | 10–25 | >25 |
| COD (mg/L) | | <20 | 20–30 | 30–40 | 40–80 | >80 |
| OM (mg/L) | | <3 | 3–5 | 5–8 | 8–10 | >10 |
| Dissolved oxygen | | | | | | |
| DO (%) | | >90 | 90–70 | 70–50 | 50–30 | <30 |
| Nitrogenous matter | | | | | | |
| $NH_4$ (mg/L) | | <0.1 | 0.1–0.5 | 0.5–2 | 2–5 | >5 |
| $NO_2$ (mg/L) | | <0.03 | 0.03–0.1 | 0.1–0.5 | 0.5–1 | >1 |
| Phosphate matter | | | | | | |
| $PO_4^{-3}$ (mg/L) | | <0.1 | 0.1–0.5 | 0.5–1 | 1–2 | >2 |
| Nitrate | | | | | | |
| $NO_3$ (mg/L) | | <2 | 2–10 | 10–25 | 25–50 | >50 |

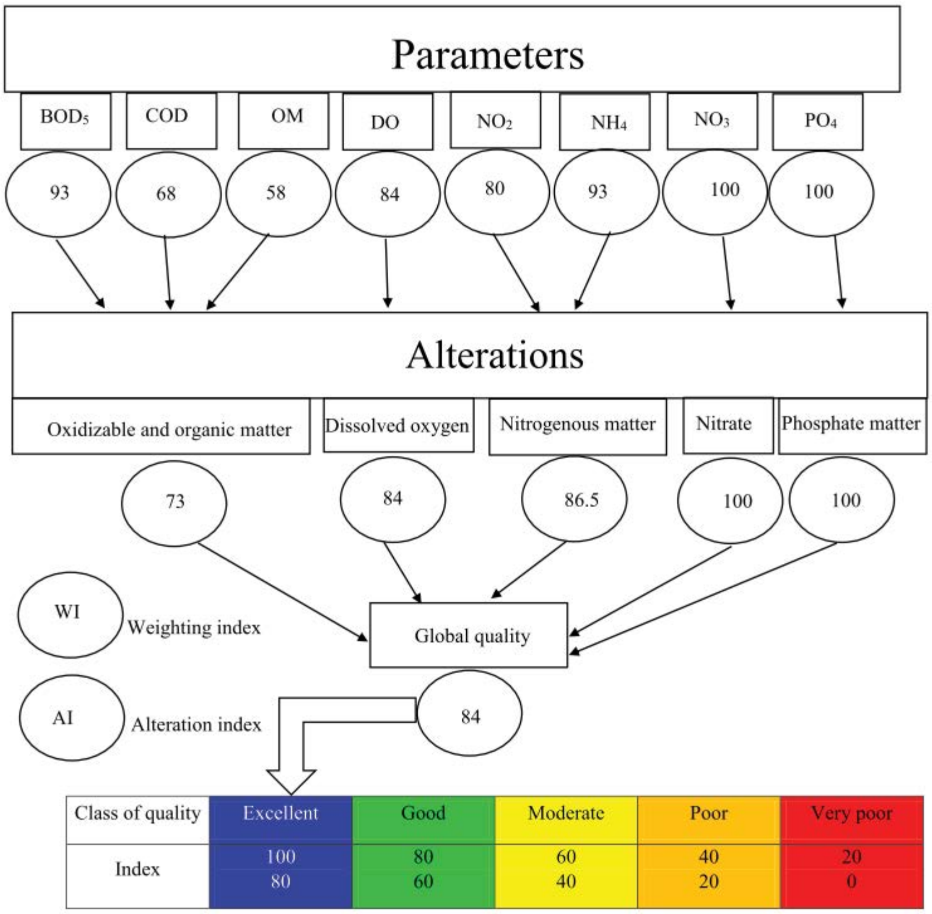


Fig. 2. Diagram showing global quality of a station from the water quality assessment system and measured values.

representation. In order to control the spatial evolution of the water quality of the dams in the Constantinois-Seybouse-Mellegue hydrographic region, 15 water sampling points were chosen according to the importance, the use and the capacity of the dam.

The data related to the attribute table related to the different localities of the sampling dams and their geographic coordinates from station s1 to s15 (Table 2).

To these localities, we attribute the indices of alteration of the physico-chemical parameters. The database integrates both spatial and attributes components of surface water quality data, namely vegetation, habitation, and valleys.

### 2.4. Integration of a DBF in QGIS

Data of alteration indexes are assembled in an Excel table; this table is then transformed into a DBF file that can be read by the QGIS 3.16 software.

### 2.5. Queries

This functionality allows identifying geographic and attributing entities that respond to one or more criteria. With GIS, the system is interrogated by asking a question or a series of questions. It then displays the data that relates to our query as a new topic [6].

### 2.6. Attribute selections

The questions addressed are based on the construction of a logical sentence or SQL (structural query language) queries which selects all the graphic objects that meet the defined criteria in this expression. The result can be graphically visualized and in the associated table. It is possible to make more complex queries (multi-criteria) with logical operators such as and/or. Example: selection of stations with very poor quality.

### 2.7. Spatial selections

Topologic queries are constructed to meet spatial criteria. These questions are answered by a spatial operator based on notions of proximity (“distant from”, “included in”, “contains”). It is possible to make queries of one or more layers. Example: select patches of vegetation that are crossed by rivers.

## 3. Results and discussion

Water quality assessment system method is primarily designed to precisely identify the major types of water quality degradation in order to target pollution fighting programs. In our study, we calculated the weighted index for each parameter as well as the alteration index for the concerning alteration.

In this case the alteration assembles the parameters of the same nature or with the same effect on the aquatic environment. The results obtained for the weighting and alteration indexes are grouped in Table 3 for all the studied dams.

### *3.1. Water quality evaluation*

In order to enhance the results and highlight the evolution of water quality in the Constantinois-Seybouse-Mellegue hydrographic region in 15 dams, we have elaborated several quality maps. The data used for the production of these maps have been gathered and therefore, the maps represent a general quality of the hydrographic region during the period of 2016.

Since the dam mainly represents the point of accumulation of a large amount of water from watersheds, the geostatistic analysis allowed us to understand the spatial (geographic) relationship between the surface waters of the region studied. Concerning the study of this relationship we used the geostatistic analysis by the method IDW (inverse distance weighting) using the software QGIS version 3.16. The inverse distance weighting (IDW) tool uses an interpolation method that estimates cell values by averaging the values of sample points in the vicinity of each processing cell. The closer a point is to the center of the cell being analyzed, the more weight it has on the average calculation procedure.

### *3.2. Organic and oxidizable matter*

#### *3.2.1. Biological oxygen demand (alteration 1)*

The biological oxygen demand allows the evaluation of biodegradable organic matter in waters [11]. More specifically; this parameter measures the quantity of oxygen necessary for the destruction of organic matter thanks to the phenomena of aerobic oxidation. Biological oxygen demand ($BOD_5$) is an interesting parameter for the evaluation of water quality, in pure water it is less than 1 mg/L of $O_2$, and when it exceeds 9 mg/L the water is considered to be polluted [12].

According to the results of Fig. 3, we note a dominance of the excellent quality which represents 80% of the samples. While the good quality represents 7% of the samples and the moderate quality represents 13% of the samples. In addition, the weighted indices allow us to see that 12 dams such as (s1, s3, s5, s6, s7, s8, s9, s10, s11, s12, s13, s14) represents excellent quality with values that fluctuate between 93 and 87, this is explained by the low concentration of $BOD_5$ which is less than 3 mg/L at these dams; a single s2 dam represents good quality with a weighted index of 80, this is due to the slight increase in $BOD_5$ which is 3 mg/L. Finally, two dams such as s4 and s15 indicate moderate quality with weighting indices of 55 and 60, respectively, this situation is due to the increase in the concentration of $BOD_5$ (6 and 7 mg/L).

The distribution map of the $BOD_5$ weighting indices shows a low spatial variability in the Seybouse-Mellegue-Constantine hydrographic region, it illustrates an increase

Table 3
Results of the index weights and alterations

| Alterations \ Stations | s1 | s2 | s3 | s4 | s5 | s6 | s7 | s8 | s9 | s10 | s11 | s12 | s13 | s14 | s15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biological oxygen demand | 93 | 80 | 93 | 60 | 93 | 87 | 93 | 87 | 87 | 93 | 87 | 87 | 93 | 93 | 55 |
| Chemical oxygen demand | 81 | 50 | 68 | 33,5 | 68 | 68 | 68 | 68 | 50 | 68 | 68 | 68 | 81 | 68 | 33,5 |
| Organic matter | 67 | 29 | 66 | 8 | 57 | 75 | 71 | 72 | 55 | 57 | 57 | 47 | 75 | 58 | 3 |
| Dissolved oxygen | 98.5 | 68 | 69 | 73 | 92 | 62 | 71 | 99 | 95.5 | 90 | 86 | 61 | 98 | 84 | 33 |
| Nitrite | 85 | 72 | 68 | 30.5 | 55 | 75.5 | 81 | 59 | 76 | 100 | 53 | 63 | 83 | 100 | 58 |
| Ammonium | 93 | 78 | 87 | 68 | 80 | 96 | 93 | 93 | 89 | 93 | 80 | 89 | 93 | 93 | 74.5 |
| Phosphate | 93 | 95.5 | 100 | 80 | 84.5 | 95.5 | 95.5 | 91 | 100 | 91 | 87 | 100 | 100 | 100 | 91 |
| Nitrate | 90 | 100 | 75 | 100 | 67.5 | 80 | 67.5 | 77.5 | 90 | 100 | 77.5 | 100 | 100 | 80 | 100 |
| Global quality | Good | Poor | Good | Very Poor | Moderate | Good | Good | Moderate | Moderate | Moderate | Moderate | Moderate | Good | Moderate | Very Poor |

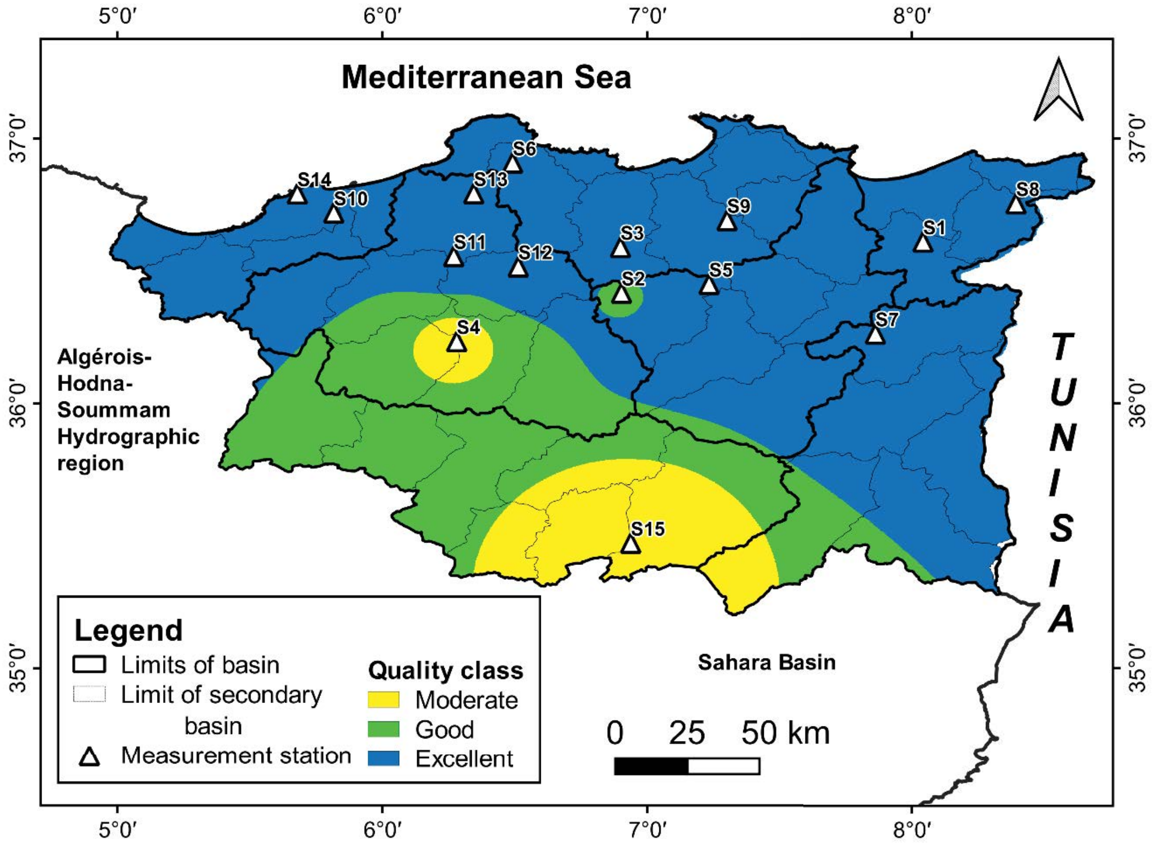


Fig. 3. Quality map for biological oxygen demand alteration.

in the indices in the north, north east, east and north west of the study area, which reflects the excellent and good quality of the waters at the level of the dams, on the other hand we note that the distribution of the indices is descending from the north to the south, south east and south west sides, which shows the moderate quality of the waters at the level of the dams. This situation is explained by the high concentration of organic matter and the low concentration of dissolved oxygen.

### 3.2.2. Chemical oxygen demand (alteration 2)

The chemical oxygen demand makes it possible to assess the concentration of organic or mineral matter, dissolved or suspended in the water, through the quantity oxygen necessary for their total chemical oxidation [13,14].

The results given in Fig. 4 indicate that 13.33% of the samples show excellent quality, 60% show good quality, 13.33% show moderate quality and 13.33% show poor quality. In two dams s1 and s13 the calculated weighting index is 81 this is due to the low concentration of chemical oxygen demand (COD) which is 18 mg/L which reflects the excellent quality, in 09 dams such as (s3, s5, s6, s7, s8, s10, s11, s12, s14) we see that the weighting index is 68 this is explained by the slight increase in the COD which is 26 mg/L from which good water quality. For dams s2 and s9 the weighting index is 50, the decrease in this index is due to the increase in COD which reached 35 mg/L and finally for dams s4, s15 the quality is poor given the low result of the weighted index which is 33.5, this situation is explained by the high concentration of COD which is 53 mg/L.

The spatial distribution map of the COD weighting indices in the Constantine-Seybouse-Mellegue hydrographic region shows an increase to the north east and north west of the study area, which reflects the excellent and good water quality in the dams, and a slight decrease in the north and in the center of the study area explained by the poor quality of the dam waters. On the other hand, we note that the distribution of the indices is decreasing from the north to the south, south east and south west, which shows the poor quality of the water in the dams. This situation is explained by the high concentration of organic matter.

### 3.2.3. Organic matter (alteration 3)

Organic matter in surface waters includes living or dead, animal or plant cells and all molecules resulting from the decomposition of these cells [15]. It comes from the degradation of plant debris on the soil by microorganisms [16]. Organic matter is a major element of natural and anthropogenic environments that is naturally present in water, but on the other hand, anthropogenic organic matter, depending on its nature and concentration, can be very harmful and can destroy the natural balance of aquatic ecosystems [15–17].

The numerical results of the weighted organic matter index calculated are summarized in Fig. 5, from the

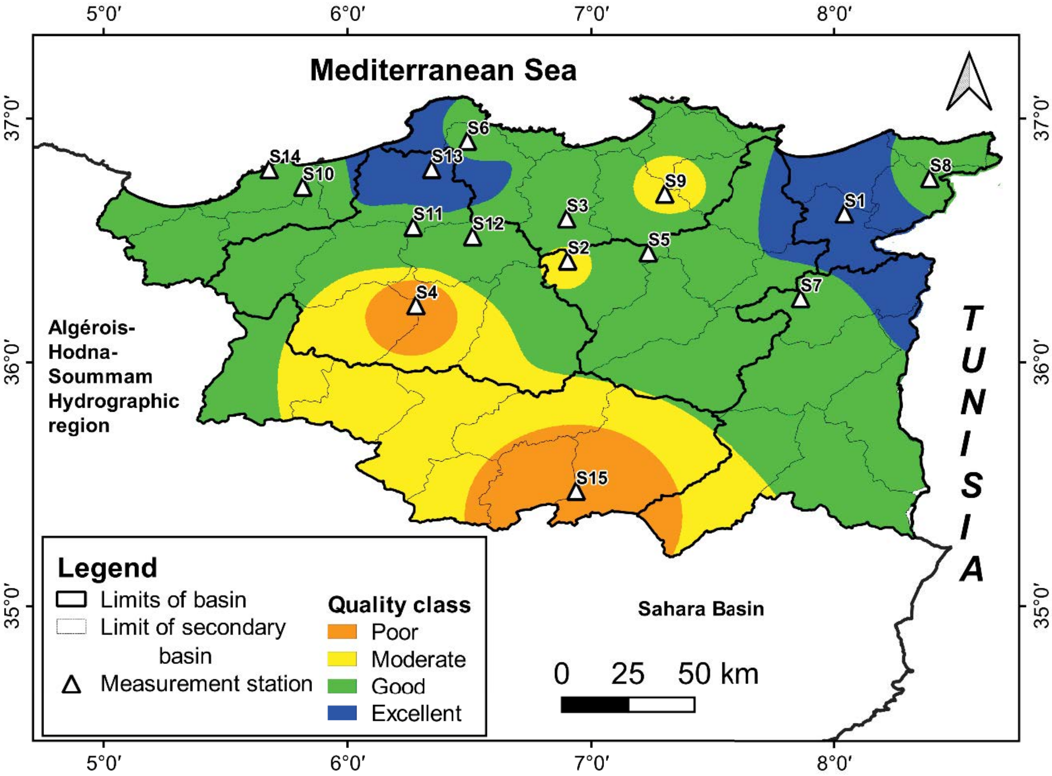


Fig. 4. Quality map for biological oxygen demand alteration.

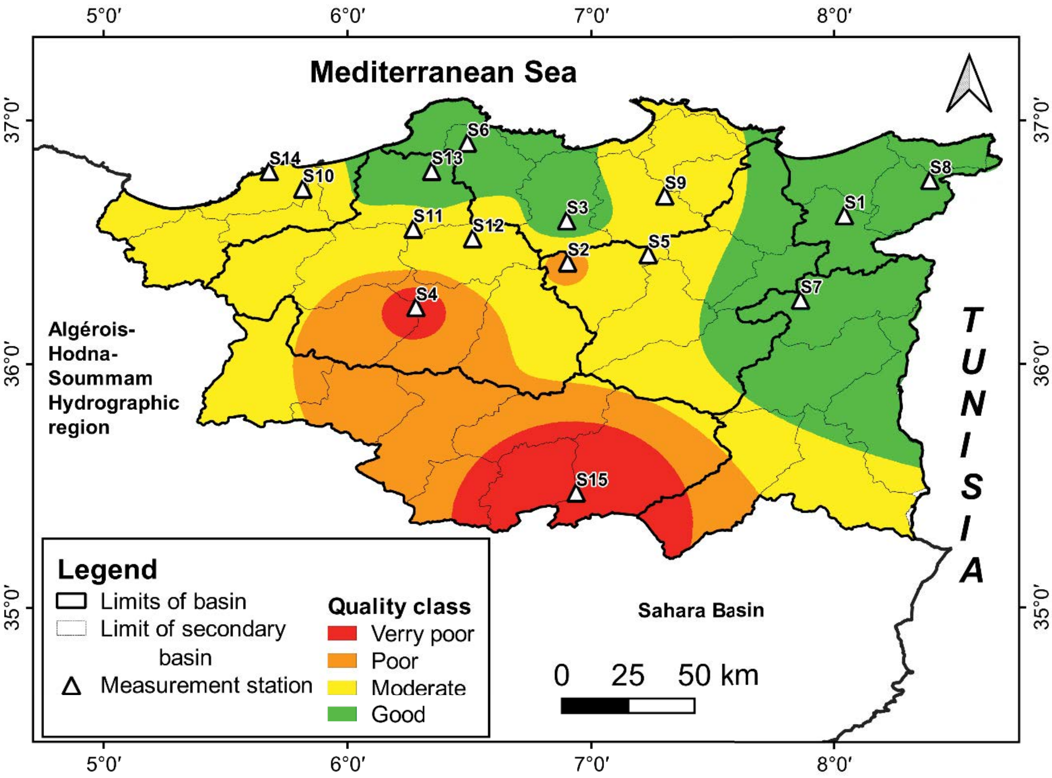


Fig. 5. Quality map for organic matter alteration.

results, it can be seen that the water quality of the different stations varies from one dam to another. According to the results shown, we notice a dominance of good and moderate quality with 40% of the samples for each, 7% of the samples are characterized by poor quality and 13% of the samples represent very poor quality. For which is of good and moderate quality the stopping marked by this aptitude are respectively (s1, s3, s6, s7, s8, s13) and (s5, s9, s10, s11, s12, s14), this is explained by the calculated values of the weighting index which oscillate respectively between 67 to 75 and 47 to 58 due to the increase in the concentrations of organic matter (OM), the latest fluctuates between 3.5 and 4.3 mg/L, which reflects the good water quality thus between 5.4 and 5.8 mg/L which reflects the average quality. A single s2 dam of poor quality with a calculated weighting index equal to 29, this state is explained by the high concentration of OM which is 9.1 mg/L. Two dams such as s4, s15 have very poor quality with weighting indices of 8 and 3, this situation is due to the very high concentration of OM which is 14.1 and 15.2 mg/L.

The distribution map of the weighting indices of the OM shows great spatial variability in the Constantine-Seybouse-Mellegue hydrographic region, it illustrates an increase of the indices to the north east of the study area, which reflects the good quality of the waters in the dams, and a slight decrease in indices in the north and north west of the study area explained by the poor quality of dam's waters. On the other hand, we note that the distribution of the indices is decreasing from the north towards the center, south, south east and south west side, which shows the very poor quality of the waters in the dams. This situation is explained by the high concentration of organic matter.

### *3.2.4. Dissolved oxygen (alteration 4)*

It is an important variable in the ecology of the environments studied. It is essential for the respiration of living heterotrophic organisms. The concentration of gaseous oxygen found in dissolved state in water is expressed in mg/L. Dissolved oxygen comes mainly from the atmosphere and from the photosynthetic activity of algae and aquatic plants [18].

Available dissolved oxygen is limited by oxygen solubility (maximum 9 mg/L at 20°C) [19]. It depends on many factors such as water temperature, the level of dissolved elements in the environment, as well as the partial pressure of oxygen in the atmosphere [20]. In addition, the presence of large quantities of organic matter in water, often of anthropogenic origin, can cause a deficit of dissolved oxygen in the aquatic environment [21]. This is linked to the consumption of oxygen in the environment by microorganisms that degrade organic matter [22].

The oxygen content provides information on the health of water streams and allows, among other things, to assess the quality of fish habitats [23].

The numeric results of the weighted dissolved oxygen saturation index calculated are summarized in Fig. 6, from

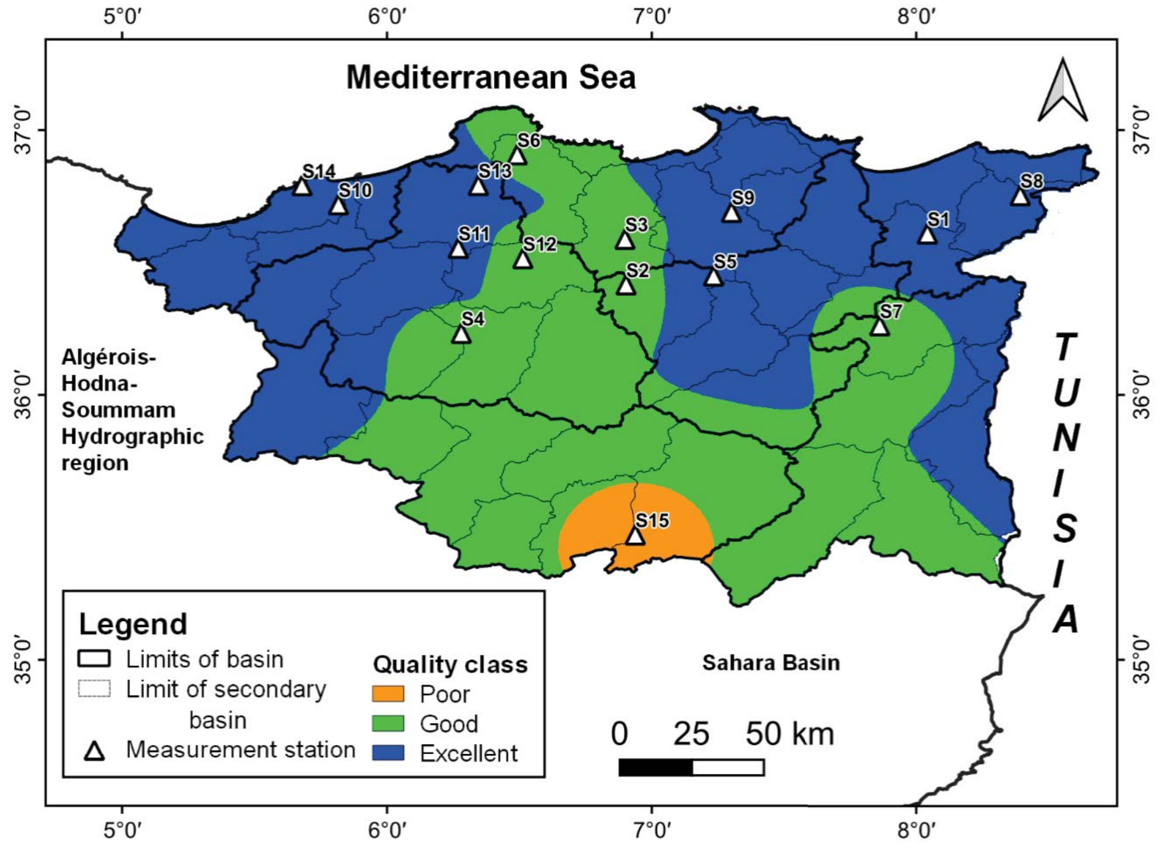


Fig. 6. Quality map for dissolved oxygen alteration.

the results it can be seen that the water quality of the different stations varies from one dam to another; the dissolved oxygen saturation mainly represents excellent to good qualities, with respectively 53% and 40% of the dams. This is due to the high concentration of oxygen saturation which exceeds 90% in 08 such dams as (s1, s5, s8, s9, s10, s11, s13 and s14), the weighting index calculated is between 99 and 84, which reflects the excellent quality of these dams. And a lower concentration of oxygen saturation which oscillates between 70% and 90% at the level of the 06 remaining dams (s2, s3, s4, s6, s7, s12) for which we found a weighting index calculated between 73 and 61 which reflects the good quality of these dams. A remarkable decrease in oxygen saturation at station s15 with a value of 37.08%, the calculated weighted index is 33 and it reflects poor quality, this is explained by the high concentration of organic matter responsible for oxygen consumption.

The spatial distribution map of the $O_2$ weighting indices in Seybouse-Mellegue-Constantine hydrographic region shows an increase in the indices to the north east and north west of the study area, which reflects the excellent water quality in the dams, and a slight decrease in the indices in the centre, north, north west and south west of the study area explained by the good quality of dam water. On the other hand, we note that the distribution of the indices is decreasing from the north to the south side, which shows the poor quality of the water in the dams. This situation is explained by the low concentration of oxygen which is related to the increase in temperature and altitude as well as the decrease in pressure in this region.

*3.2.5. Nitrite (alteration 5)*

Nitrites come either from the incomplete oxidation of organic nitrogen or from a reduction of nitrates. The main sources of pollution are the use of fertilizers, the manufacture of explosives, the chemical and food industry. The nitrate content of water is generally higher than that of nitrite. A high concentration of nitrites indicates bacteriological pollution as a result of ammonia oxidation [24].

Fig. 7 illustrates a dominance of excellent and good quality with 33% of the samples for each, 27% of the samples are characterized by moderate quality and 7% of the samples represent poor quality. For which is of excellent and good quality the dams marked by this ability are respectively (s1, s7, s10, s13, s14) and (s2, s3, s6, s9, s12), this is explained by the calculated value the weighting index which oscillates respectively between 81 to 100 and 63 to 76, due to the low concentration of nitrites which fluctuates between 0 and 0.028 mg/L which reflects the excellent quality of water thus between 0.044 and 0.089 mg/L which reflects the good quality. Four dams such as s5, s8, s11, s15 have an moderate quality with weighting indices from 59 to 53, this situation is due to the slight increase in the concentration of nitrites which varies from 0.126 to 0.235 mg/L. A single s4 dam of poor quality with a calculated weighting index equal

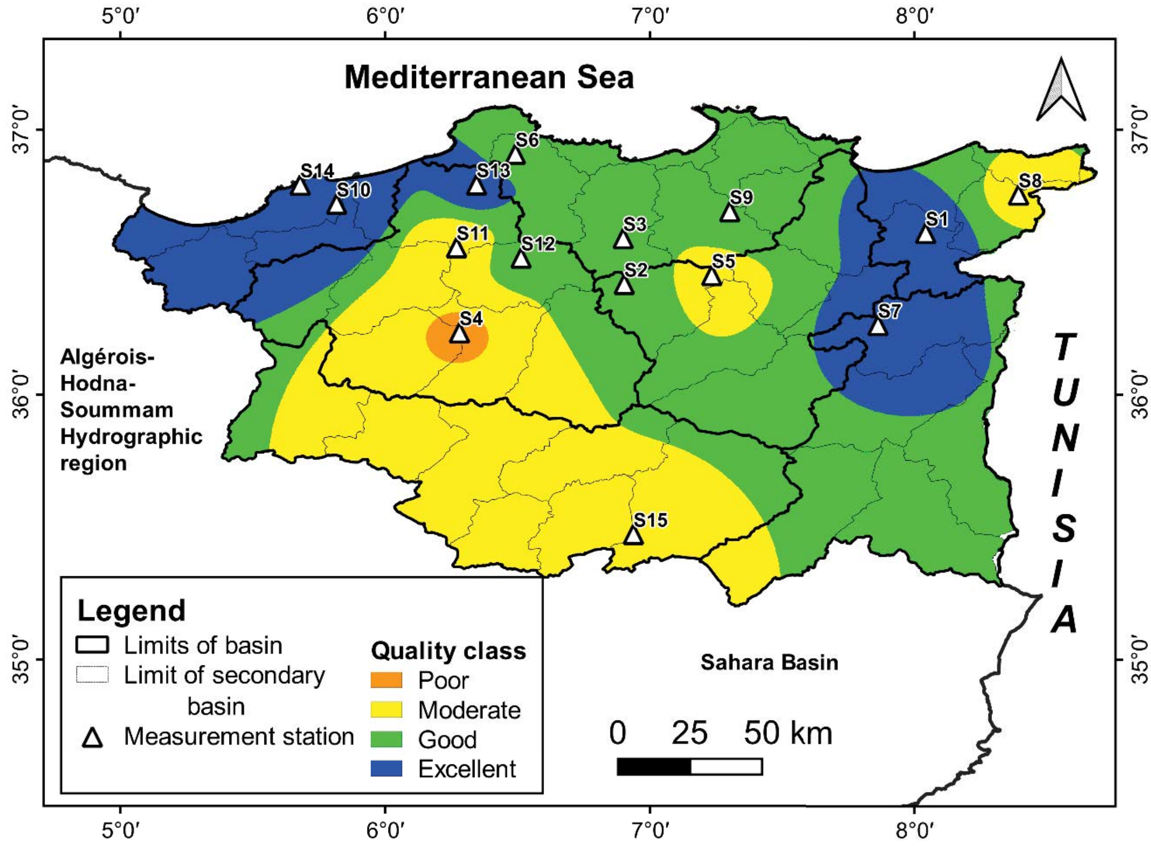


Fig. 7. Quality map for nitrite alteration.

to 30.5, this state is explained by the high concentration of nitrites which is 0.736 mg/L.

The distribution map of $NO_2$ weighting indices in the Constantine-Seybouse-Mellegue hydrographic region shows indices that fluctuate between excellent, good and moderate water quality in the north, north east, north west and south east of the area of study, and a decrease in the indices in the south west of the study area explained by the poor quality of the dam waters from which we note that the spatial distribution of the indices is decreasing from east to West. This situation is explained by the presence of the detergent factory (Henckel) in this region.

*3.2.6. Ammonium (alteration 6)*

Ammoniacal nitrogen is one of the links in the complex nitrogen cycle in its primitive state. It is a gas soluble in water. It exists in small proportion, less than 0.1 mg/L in natural waters. It is a good indicator of the pollution of water streams by urban effluents. In surface waters, it comes from nitrogenous organic matter and gaseous exchanges between the water and the atmosphere [25]. Its presence in high levels indicates recent pollution, and low levels indicate old pollution [26]. The high $CO_2$ content and the low oxygen content increase the ammonium concentration in the water [27].

From Fig. 8 we can see that the majority of the samples with a percentage of 67% have excellent quality and 33% of the samples show good quality. 10 dams such as (s1, s3, s6, s7, s8, s9, s10, s12, s13, s14) represent an excellent quality due to the high weighting index which varies from 87 to 96 because of the very low ammonium concentration which oscillates between 0.02 and 0.06 mg/L. Five dams such as (s2, s4, s5, s11, s15) are marked by a good quality due to the slight decrease in the weighting index which fluctuates from 74.5 to 80 due to a slight increase in the ammonium concentration which varies from 0.09 to 0.34 mg/L.

The distribution map of the $NH_4$ weighting indices in the Constantine-Seybouse-Mellegue hydrographic region shows an ascending spatial evolution of the indices from south to north, and from west to east. This situation is explained by the high $CO_2$ content from the various industrial units, and the low dissolved oxygen content in these regions.

*3.2.7. Phosphate (alteration 7)*

Phosphate ions contained in surface water or in groundwater can be of a natural origin: decomposition of organic matter, leaching of minerals or also due to industrial discharges (agri-food, …, etc.), fertilizers (pesticides, …, etc.) and (polyphosphate from detergents) [28].

From Fig. 9 we can see that almost all the samples with a percentage of 93% have excellent quality and 7% of the samples show good quality. 14 dams such as (s1, s2, s4, s5, s6, s7, s8, s9, s10, s11, s12, s13, s14, s15) represent an excellent quality due to the high weighting index which varies from 84.5 to 100 because of the very low phosphate concentration

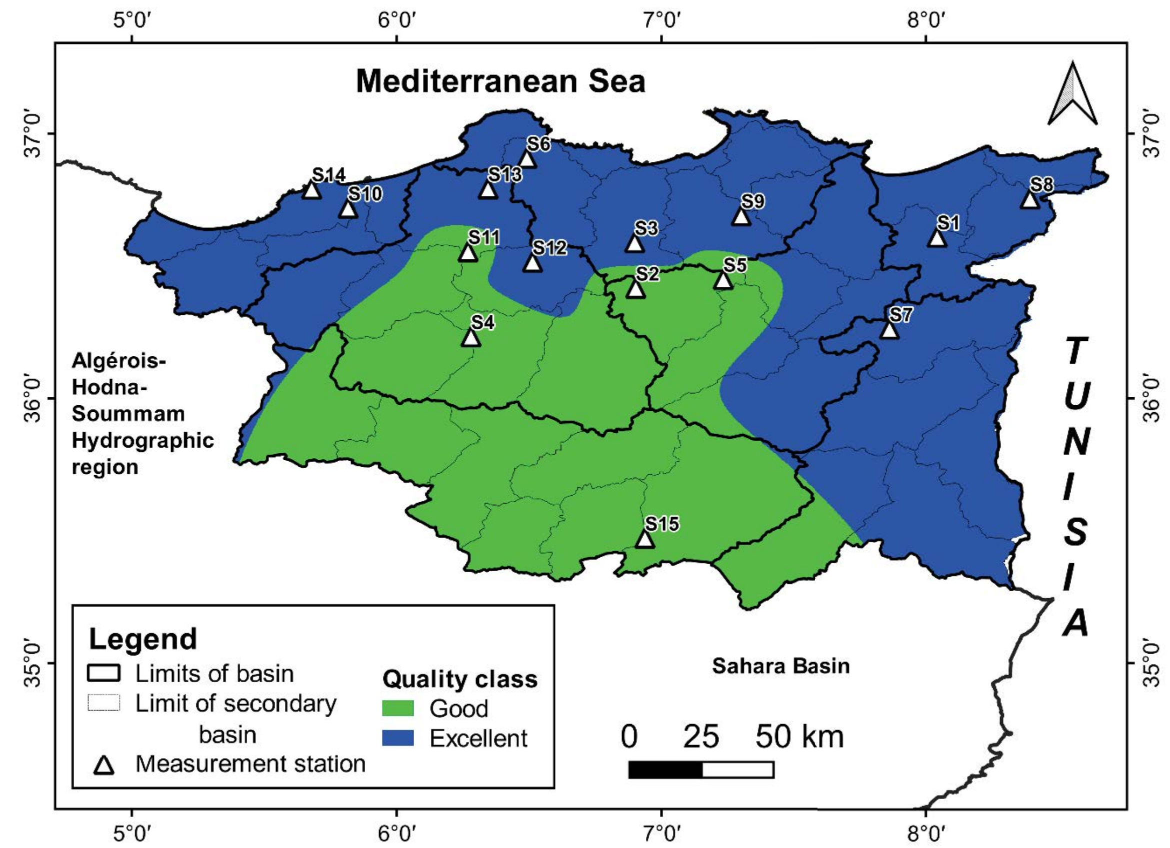


Fig. 8. Quality map for ammonium alteration.

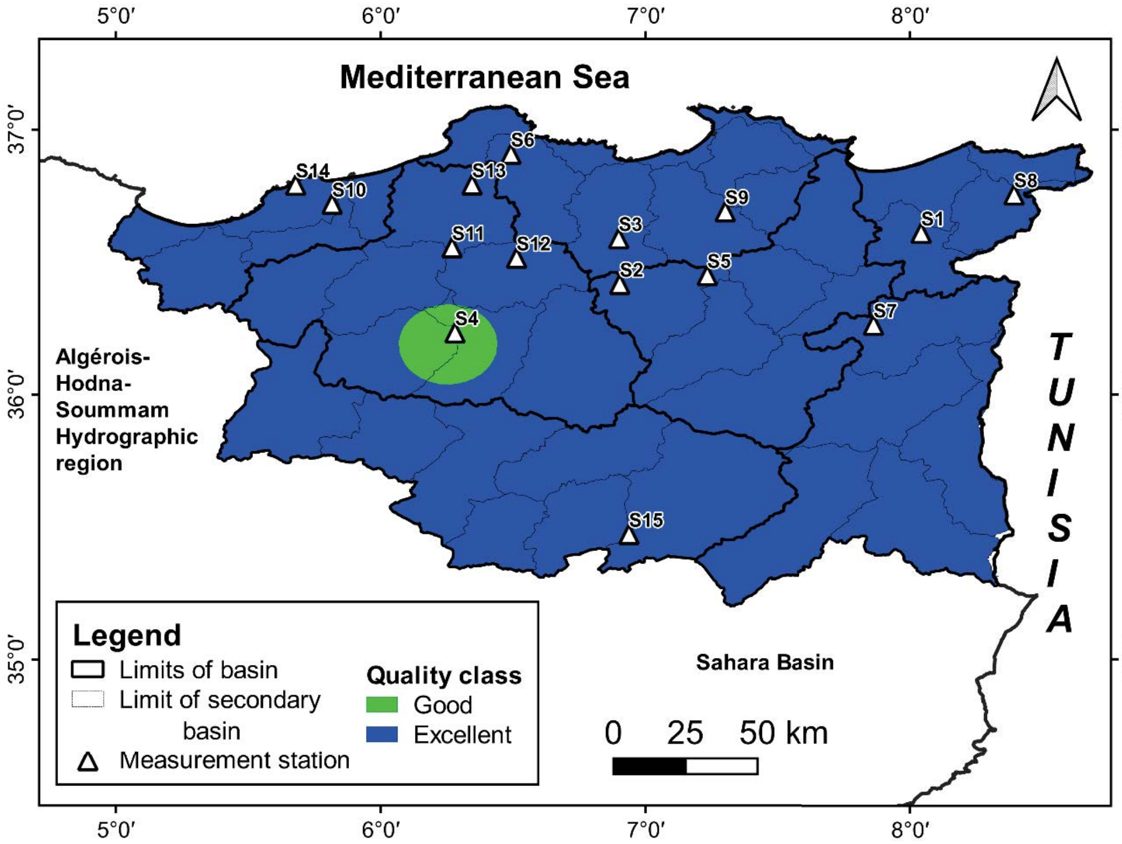


Fig. 9. Quality map for phosphate alteration.

which fluctuates between 0 and 0.07 mg/L. A single s3 dam marked by good quality due to the slight decrease in the weighting index which is 80 due to the slight increase in the phosphate concentration which is 0.1 mg/L.

The map of distribution of $PO_4$ weighting indices in the Constantine-Seybouse-Mellegue hydrographic region shows a spatial stabilization of the indices, which reflects the excellent quality of the dam waters with the exception of the west side where there is a slight decrease in the weighted index showing good water quality. This situation is explained by the high concentration of organic matter, the presence of the industrial unit and the low volume of water from the dam in this region.

### 3.2.8. Nitrate (alteration 8)

Present at a natural and soluble state in soil, nitrates penetrates in the soil and groundwater and flow into water streams. However, they have also been brought in synthetically by fertilizers [25] and they present one of the factors responsible for degradation of water quality. Nitrates are also the final phase of nitrification and represent the most oxidized form of nitrogen present in water [29].

From Fig. 10 we notice that 53% of the samples show excellent quality and 47% of the samples show good quality. Eight dams such as (s1, s2, s4, s9, s10, s12, s13, s15) represent an excellent quality due to the high weighting index which varies from 90 to 100 because of the very low nitrate concentration which oscillates between 0 and 1 mg/L. Seven dams are marked by good quality such as (s3, s5, s6, s7, 8, s11, s14) due to the slight decrease in the weighting index which fluctuates from 67.5 to 80 due to slight increase in the nitrate concentration which varies from 2 to 7 mg/L.

The distribution map of $NO_3$ weighting indices in the Constantine-Seybouse-Mellegue hydrographic region shows a first spatial similarity of the indices to the west and south of the study area, which reflects the excellent quality of the dam waters, and a second spatial similarity to the east and north which reflects the good quality of the dam waters. This situation is explained by the presence of fertilizers on agricultural lands in these regions.

### 3.2.9. Global quality map

Water quality assessment system allowed us to make an evaluation of the global water quality at each dam taking into consideration eight alterations. The results of the calculation of the global weighted index are summarized in Fig. 11.

The results shown in Fig. 11 indicate that five dams (s1, s3, s6, s7, s13) are characterized by good quality. Indeed, during the quality monitoring period in 2016, good quality represents 33% of the samples. This situation is explained by the low concentration of the various parameters responsible for the alteration of water quality and the high saturation in dissolved oxygen, and consequently a good

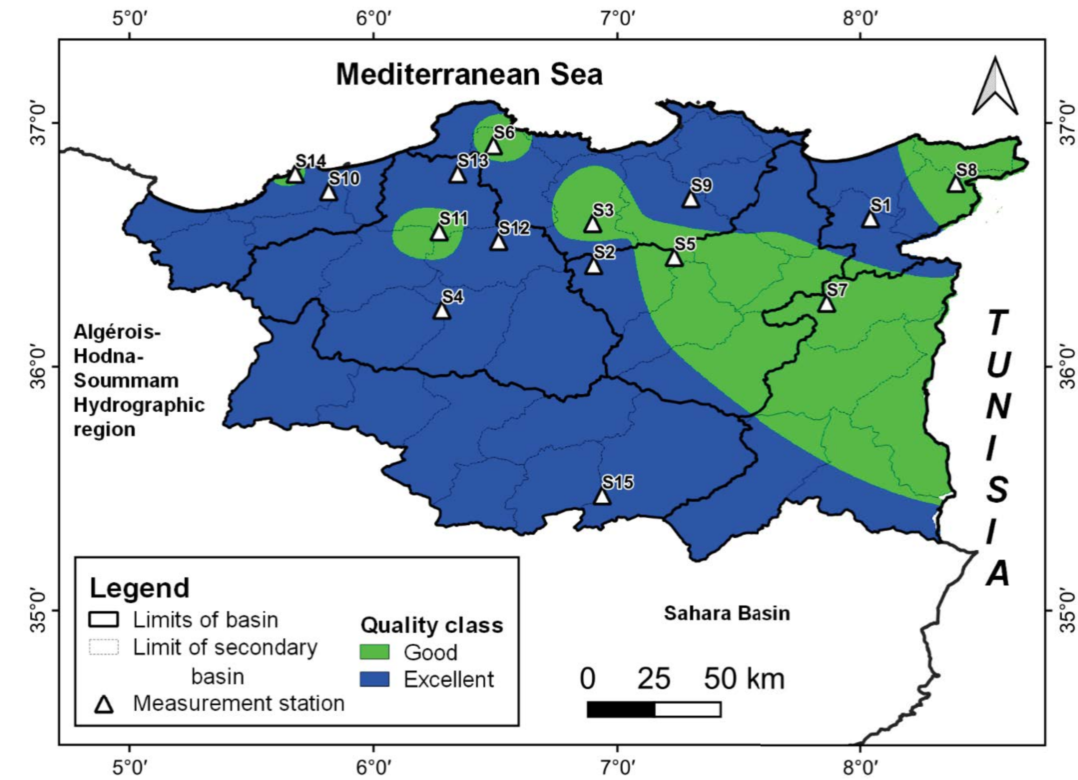


Fig. 10. Quality map for nitrate alteration.

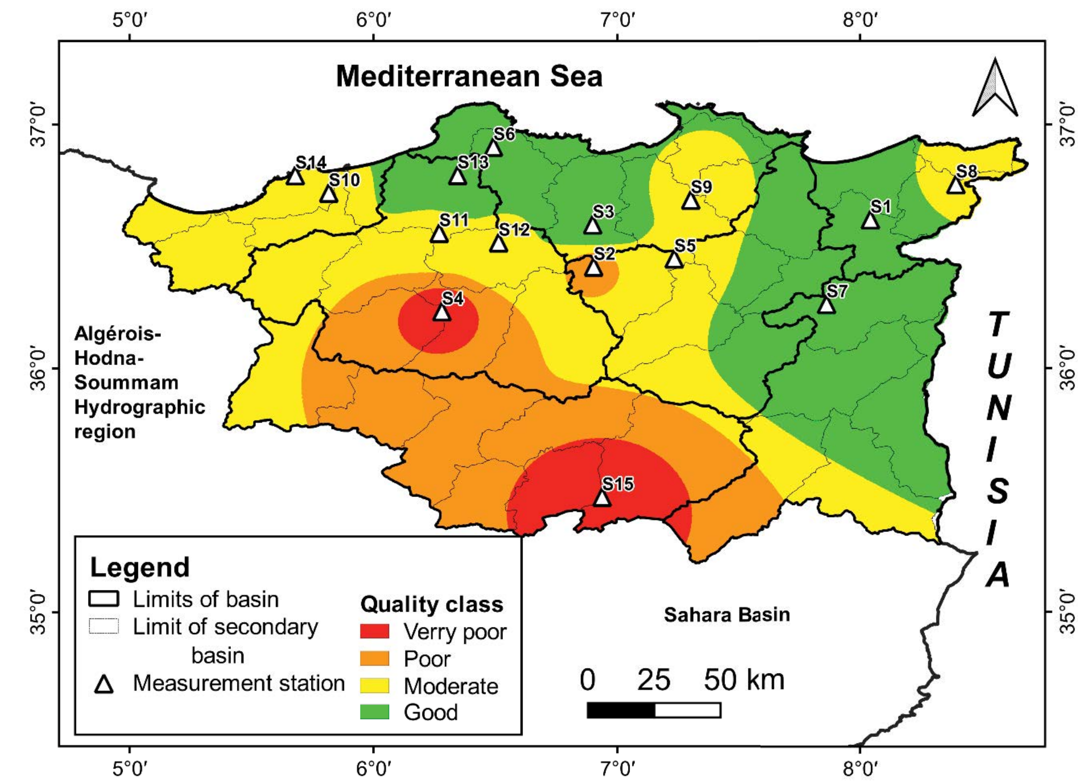


Fig. 11. Map of the global quality.

result of the global weighting index which varies from 80 to 60.

Seven dams (s5, s8, s9, s10, s11, s12, s14) are characterized by an moderate quality. Indeed, during the quality monitoring period in 2016, the moderate quality represents 47% of the samples. This situation is explained by the slight increase in the concentrations of the various parameters responsible for the alteration of water quality such as organic matter, nitrites and the chemical oxygen demand, and consequently an average result of the weighting index overall which varies from 60 to 40.

A single dam s2 characterized by poor quality. Indeed, during the quality monitoring period in 2016, poor quality represents 7% of the samples. This situation is explained by the slight and the strong increase in the concentrations of the various parameters responsible for the alteration of the quality of the waters such as the chemical oxygen demand and the organic matter, respectively, consequently a low result of global weighting index which varies from 40 to 20.

Two dams (s4, s15) are characterized by very poor quality. Indeed, during the quality monitoring period in 2016, very poor quality represents 13% of the samples. This situation is explained by the slight, strong and very strong increase in the concentrations of the various parameters responsible for the alteration of water quality such as biological oxygen demand and nitrites, chemical oxygen demand, organic matter, and a strong decrease in oxygen saturation, consequently a very low result of the global weighting index which varies from 20 to 0.

The map of the global quality in Constantine-Seybouse-Mellegue hydrographic region shows very poor water quality in the south of the studied area, which reflects severe pollution at the level of these regions, explained by the presence of fertilizers, the increase of temperature as well as altitude, the high concentration of organic matter, the high concentration of carbon dioxide, the low early oxygen and the low volume of dams. On the other hand, in the north of this zone, there is good to poor water quality, which is explained by the installation of these dams in the upstream of the agglomerations, the low temperature, the low altitude, low concentration of organic matter, the strong early oxygen and the large volume of the dams.

## 4. Conclusion

It can be concluded that the Constantine-Seybouse-Mellegue hydrographic region encompasses five large watersheds, these watersheds do not represent the same quality, in fact the two watersheds such as the coastal Constantine (east, center, west) and the Medjerda are characterized by a good to moderate quality with global weighted indices vary from 62 to 47, while the Seybouse watershed has moderate to poor quality with low weighted indices fluctuating between 55 and 29. The Kebir-Rhumel watershed is characterized by good quality; moderate and very poor with weighting indices which oscillate between 75 and 8, and finally the Constantine watershed of the high plateaus presents a very poor quality with a weighted index of 3.

The parameters responsible for the deterioration of the quality differ from one watershed to another, in fact the watersheds which present good quality dams such as (s1, s3, s6, s7, s13) are characterized by the presence of low rates of alteration parameters and water volumes vary from 117 to 37 $hm^3$, this state is mainly linked to urbanization and the existence of great hydro-agricultural potential in the Constantine watersheds.

However, the watersheds which show dams of moderate quality such as (s5, s8, s9, s10, s11, s12, s14), are distinct by the presence of more or less high rates of organic matter and nitrites as well as a reduction in volumes of water which oscillate between 77 and 21 $hm^3$. This situation is due to strong urbanization, large industrial units in the central Constantine coastal watershed and the existence of the cement company at the Kebir-Rhumel watershed, and the great hydro-agricultural potential in the Constantine watersheds, Kebir-Rhumel and Seybouse watershed.

At the Seybouse watershed, the s2 dam presents a poor quality characterized by a more or less high rate of chemical oxygen demand as well as organic matter and a decrease in the volume of water which is 4.5 $hm^3$. This is explained by the high rate of urbanization and the existence of the petrochemical complex in this area.

At the Kebir-Rhumel watershed and the Constantine watershed of the high plateaus, the dams (s4, s15) present a very poor quality, this alteration is due to the high concentration of organic matter and the low volume of water which is 0.3 $hm^3$. This state is explained by the urbanization and the existence of the detergents factory (Henckel) at the level of the Kebir-Rhumel watershed.

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