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Assessment of the Water Quality of Three Wetlands of Guerbes-Sanhadja Complex, a Ramsar Site in Skikda, Northeast of Algeria

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ABSTRACT

Pollution of wetlands is a major environmental issue worldwide, threatening ecosystem functioning and services to human. Unfortunately, protected areas such as Ramsar sites are no exception. In this study, an assessement was conducted for the water quality of three swamps in ecocomplex of Guerbes-Sanhadja wetlands (north-eastern Algeria) classified as Ramsar site since 2001, namely Garaet Hadj Tahar, Garaet Messaouassa and Garaet Ben M'Hamed. 108 sampling events were achieved during a year from January to December 2021. Moreover, ten physico-chemical factors were measured including temperature, pH, dissolved oxygen, EC, TDS, nitrite (NO_{2^-}), nitrate (NO_{3^-}), chloride (Cl^-), calcium ($Ca2^+$) and magnesium (Mg2+). The overall concentration of Cl^-, Ca2+ and Mg2+ at the study sites was extremely high. Cl^- exceeded 440mg/ l in Ben M'Hamed swamp, while Mg2+ and Ca2+ showed concentrations reaching up to 390 and 212mg/ l in Hadj-Tahar swamp, respectively. Nitrate levels were below 40mg/ l at the three sites, meaning they did not exceed the permissible limit for surface waters. Water quality in most of our samples of all three sites fall in the good to permissible categories for aquatic life. It was deduced that, a regular monitoring of water quality of these three swamps is essential to preserve and protect these sensitive ecosystems from pollution and other anthropogenic disturbances.

INTRODUCTION

The quality of surface water has deteriorated during the last decades worldwide. Surface water are complex ecosystems that provide many natural resources to humans and sustain their survival and socioeconomic activities **(Scanlon *et al*., 2007; Todd *et al*., 2012; John *et al*., 2014)**. However, multiple anthropogenic stressors such as climate change, precipitation, industrial activities, and intensive agriculture affect surface water quality, ecosystem functioning and services to human **(Zhao *et al*., 2011; Loucif *et al*.,**

2020; Loucif *et al*., 2024). Regular monitoring of surface water based on physicochemical and biological parameters is extremely important to assess the spatiotemporal variation in the health of the aquatic habitat **(Wu *et al*., 2017)**. Such understanding helps us establish protection plans that benefit both nature and people.

Wetlands are extremely biodiverse and productive ecosystems **(Whitten *et al*., 2002)**. They cover about 8–10 million km^2 globally, which represents only a small proportion (6%) of the total land surface **(Lehner & Döll, 2004)**. Studies have shown that wetlands could attenuate pollution from agricultural areas and urban sewage **(Díaz*et al*., 2012; Comín *et al*., 2014; Bateganya *et al*., 2015)**. Other studies have pointed out that the decline in water quality driven by human activities results in a decline in biodiversity, long-term habitat loss, and a socioeconomic decline among communities **(Zhao *et al*., 2011)**. Consequently, the increasing anthropogenic pressure on wetland ecosystem threatens the sustainability of these sensitive habitats and its related biodiversity and ecosystem services **(Hansson *et al*., 2005; Davidson *et al*., 2012)**.

Algeria harbors highly important, yet threatened wetlands of international importance **(Boulkhssaim, 2008; Khelifa *et al*., 2021; Khelifa *et al*., 2022a)**. Both lotic and lentic sites harbor sensitive endemic species and important populations for the Palearctic fauna and flora **(Seddik, 2010; Khelifa *et al*., 2016; Khelifa *et al*., 2022a)**. Algeria hosts 254 wetlands of international importance, such as Guerbes-Senhadja complex. This complex of wetlands includes a wide diversity of lentic and lotic habitats intermixed with agricultural lands and urban areas. The biodiversity in this wetland complex is very high, but relatively impacted by human exploitation of water (e.g., irrigation) **(Vela & Benhouhou, 2009)**.

Despite the immense ecological and socioeconomic importance of the Guerbes-Senhadja complex, the last one receives little research attention, particularly regarding water quality. To address this gap, we conducted a study focusing on the physicochemical characteristics of water in three swamps (Garaet Hadj Tahar, Garaet Messaouassa, and Garaet Ben M’Hamed) within this complex. This research is particularly urgent given the alarming rate of habitat degradation in wetlands across Algeria and North Africa, which demands increased scientific attention **(Khelifa *et al*., 2021a, 2021b, 2022)**. Therefore, the main objective of this study was to assess and document the current state of these critical ecosystems.

MATERIALS AND METHODS

1. Study area

This study was conducted in the Guerbes-Sanhadja wetland complex, the north-eastern part of Algeria (36 ° 46'371 N, 7 ° 8'7 25 E) (Fig. 1). This relatively large wetland complex covers an area of 42100 ha, and was listed as a Ramsar site in 2001. It encompasses about 10 water bodies of different sizes; the three largest being Garaet Hadj-Taher (120 ha), Garaet Beni M’Hamed (380 ha) and Garaet Messaoussa (250 ha)

(Fig. 1, Table 1). These sites have an average water depth of 0.8-1.0m **(Bara *et al.*, 2020)**. This eco-complex is situated in the sub-humid bioclimatic region **(Metallaoui & Houhamdi, 2010)**, with a mean annual rainfall of 700mm **(Hedjal*et al*., 2018)**.

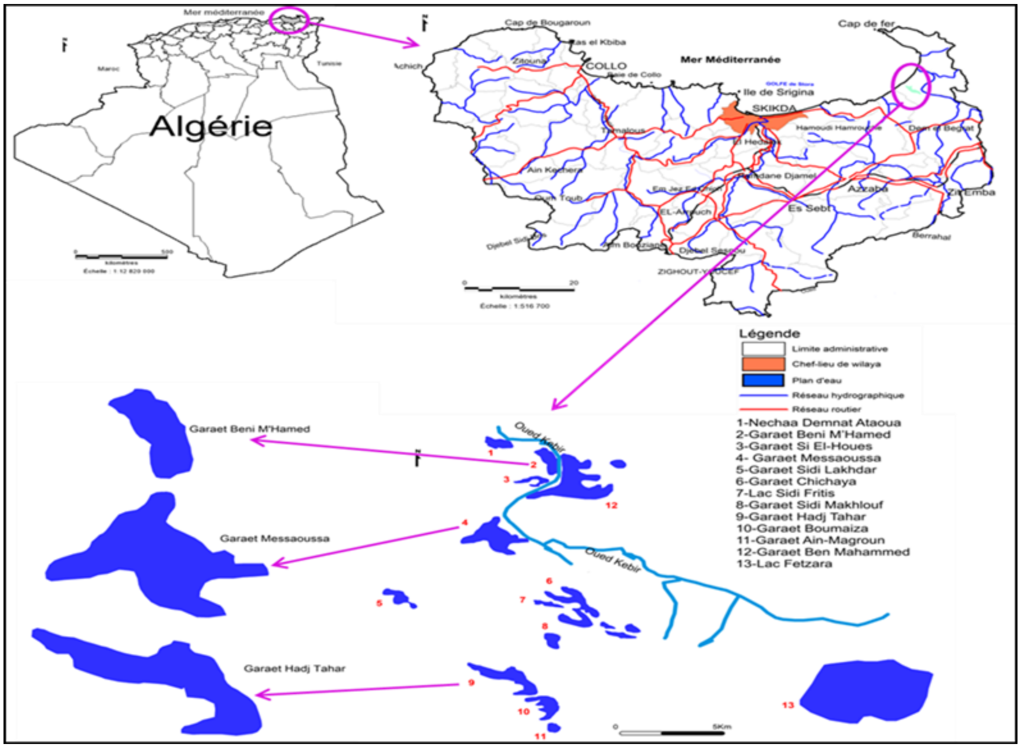

Fig. 1. Geographic location of the localities where sampling was conducted in three swamps in the ecocomplex of Guerbes-Sanhadja wetlands (2021)

Table 1. Average morpho-dynamic characteristics of the studied swamps

			Geographic coordinates	Fauna and flora	Water depth and nature of water	Status
Sampling points	Garaet Hadj-Taher	GHT1 GHT2 GHT3	36°51'50'' N ; 07°15'57' E	*Nymphaea alba*, *Typha angustifolia*, *Phragmitesaustralis*, *Scirpusmaritimus*, *S. lacustris*, *Iris pseudoacaurus*occupy 60 70% of the total area of the body of water; a rare pteridophyte (*Salvinianatans*) is also present.	Fresh water 0.8 and 1.20m	Ramsar

Sampling points				*Fuligulenyroca ,Aythyanyroca, Fuligulemilouin,Aythyafe-rina and Fuligulemorillon ,Aythyafuligul*. Red List of the IUCN : White-headed Duck *Oxyuraleucocephala*, Marbled Duck *Marmaronettaangustirostris*		
	Garaet Beni M'Hamed M'Hamed	GBM1 GBM2 GBM3	36°57' N ; 7°16'E	*Nymphaea alba, Typha angustifolia, Phragmites australis, Scirpusmariti-mus,*	Slate water Don't exceed 60 cm	Ramsar
	Garaet Messaouassa	GM1 GM2 GM3	36°52'N 07°15'E	More than 90% of water surface covered by helophytes which are:*Nymphaea alba, Typhaangustipholia, Phragmitesaustralis, Scirpusmaritimus, S. lacustris, Iris pseudoacaurus*and*Alnusglutinosa.* It is wintering and breeding ground for many water bird species of international importance including White-headed Duck*Oxyuraleucocephala*andFuligulenyroca*Aythyanyroca*	Fresh water Between 1 and 2.3 m	Ramsar

2. Sampling

In each of the three swamps, we measured 10 physic-chemical parameters monthly between January and December 2021. These measurements were carried out within 48h on three replicated water samples collected at 30cm depth from each site. A 2m-long PVC pole was used to collect the water samples. Water temperature (°C), conductivity (µS), dissolved oxygen (mg/l), pH, and TDS were measured *in situ* using field multiprobes (340I- /SET WTW Serial Number 03240020) at mid-water depth for each sampling site. Our water samples were preserved in prerinsed 1-L polypropylene, acid-washed sampling bottles at 4°C in darkness. Table (2) exhibits the measurements of water quality parameters based on standard methods established for surface water monitoring NF T90-014/1952, EDTA (NF T90-003/1984) **(Rejsek, 2002)**.

Table 2. Water quality parameters and their associated abbreviations, units, and analytical methods used

Parameter	Instrument/ Determination method
Temperature (°C) Potential hydrogen Dissolved oxygen (mg/l) Electrical conductivity (µS/cm) Total dissolved solid (mg/l)	(340I- /SET WTW Serial Number 03240020)
Chloride (Cl^-) (mg/l)	Nitration : (NF T90-014/1952)
Calcium (mg/l) Magnesium (mg/l)	Titrimetric method :EDTA (NF T90-003/1984)
Nitrite (mg/l) Nitrate (mg/l)	Spectrophotometer **(Rejsek, 2002)**

3. Multivariate statistical analyses

The statistical analysis and mathematical computations of water quality variables were performed using the software STATISTICA package for Windows version (7) and Microsoft Excel. The minimum and the maximum values were determined for all parameters studied. A principal component analysis (PCA) was conducted to determine the degree of similarity between the three sites based on these nine variables: pH, EC, TDS, NO_2^-, NO_3^-, Cl^-, Ca^{2+} and Mg^{2+}. A biplot of PCA based on correlation matrix was performed to compare the quality of water among all study sites.

RESULTS AND DISCUSSION

1. Temperature

Water temperatures in the three wetlands ranged between 15 and 25°C (Fig. 2). The highest temperatures were recorded in May, while the lowest temperatures were in January. The recorded temperatures are lower compared to the maximum permissible limit (25°C) of the World Health Organization **(WHO, 2004)**. According to the water quality assessment grid **(Monod, 1989)**, the observed thermal values indicate a good water quality. The collection of data on water temperature is crucial because this factor governs almost all physical, chemical and biological reactions **(Chapman *et al*., 1996)**.

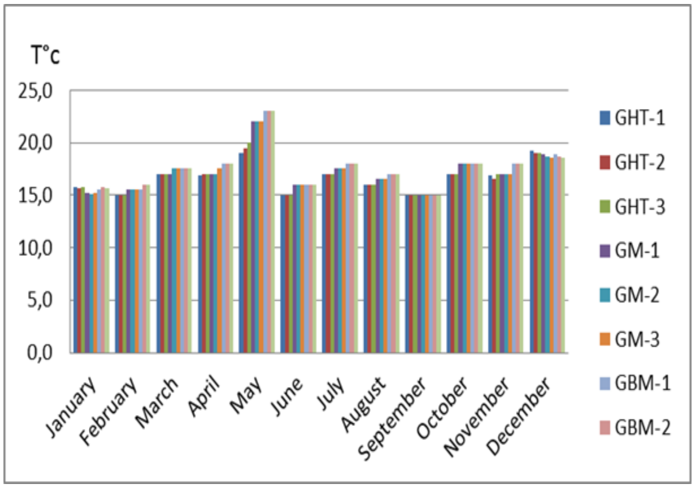

Fig. 2. Spatiotemporal variation of water temperature (°C) in three sampling locations within three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher ,GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

2. pH

Our pH values ranged between 6 and 9.4 (Fig. 3), and thus are within the normal limits. All these values of pH indicate a neutral to alkaline medium throughout the study period and in three wetlands. In fact, in surface water, pH values varied between 6 and 8.5 **(Chapman *et al*., 1996)** while in warm waters, it fluctuates between 5 and 9 **(HCEFLCD, 2007)**. pH decreases in the presence of high levels of organic matter and increases during low water periods, especially when evaporation is high **(Meybeck*et al*., 1996)**. The decline in pH results from bacterial activity which decomposes the organic substances **(Neal *et al*., 2000a)**.

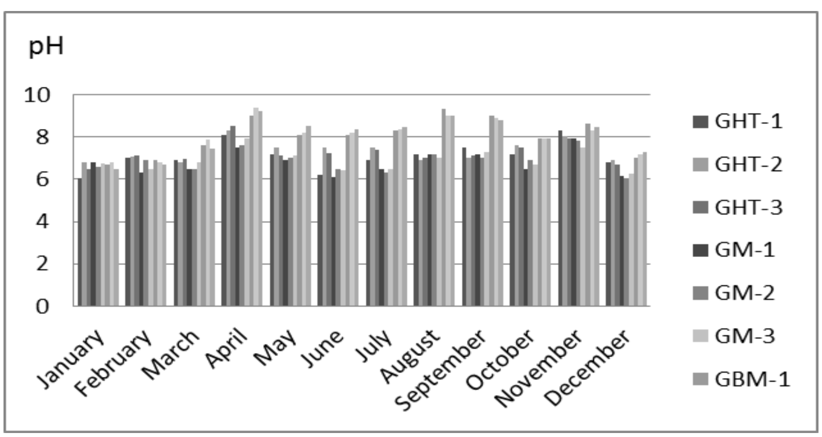

Fig. 3. Spatiotemporal variation of pH in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher, GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

4. Electrical conductivity (EC*)*

EC reached a maximum of 2330µS/ cm at Garaet Hadj-Taher, however BenM'Hamed and Messaouassa reached 1798 and 943µS/ cm, respectively, during the dry period (Fig. 4). Based on the river water quality assessment grid **(Monod, 1989)**, the water of the Hadj-Tahar swamp showed high levels of EC. In general, a high conductivity reflects either abnormal pH or more often high salinity. A decrease in water flow which favors the predominance of highly mineralized discharges and the acceleration of the bacterial process of mineralization of organic matter are usually due to the increase in the mineralization in the summer season **(Silva & Sacomani, 2001)**.

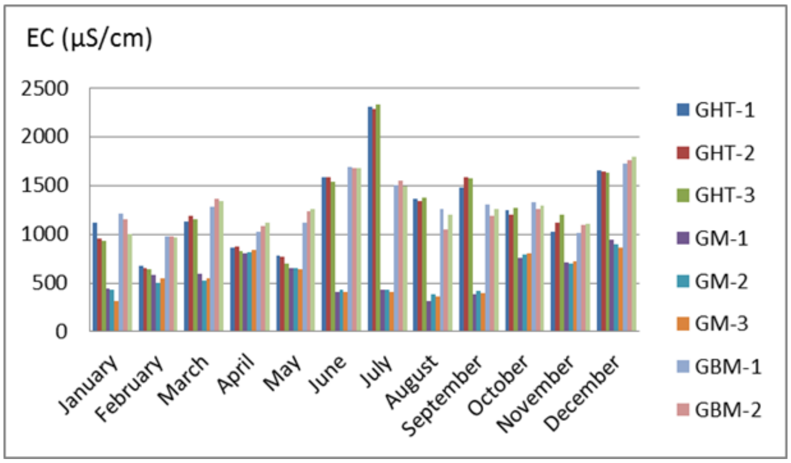

Fig. 4. Spatiotemporal variation of electrical conductivity in the water of three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher, GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

5. Total dissolved solids (TDS)

TDS values fluctuated between 592.18mg/ l at Ben M'Hamed in August and 1491.2mg/ l at Hadj-Tahar swamps in July (Fig. 5). TDS values in lakes and streams are typically found to be in the range of 50 to 250mg/ l. In areas of especially hard water or high salinity, TDS values may be as high as 500mg/ l (**Bhateria& Jain, 2016**). Higher values of TDS in our samples might be ascribed to domestic discharges from urban areas, as well as agricultural and other human activities (**WHO, 2004**). There is also the possibility that the values could be related to the type of soil through which water flows (**Karthik *et al*., 2019**). Higher TDS values can be toxic to aquatic life.

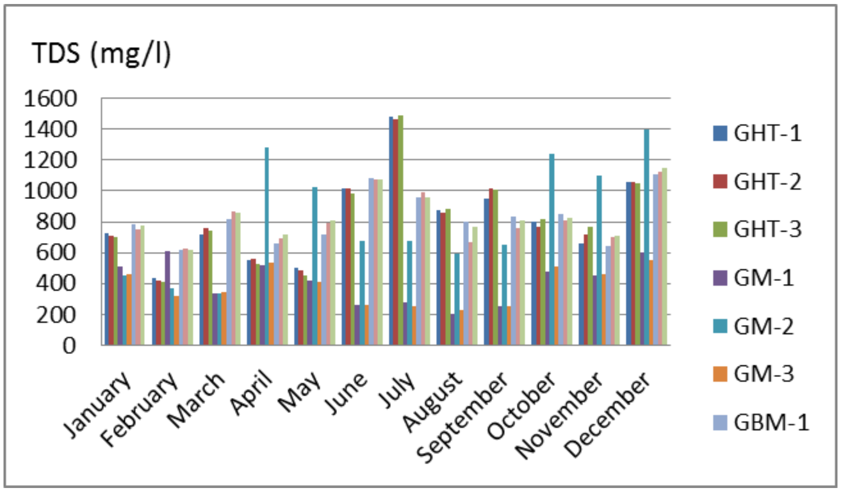

Fig. 5. Spatiotemporal variation of TDS in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher , GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

6. Dissolved oxygen (DO)

Average DO contents varied from 5.2 to 8.7mg/ l (Fig. 6). DO influences dominant physical and biological processes in freshwater systems **(Trivedi & Goel, 1986)**. The levels of DO are often affected by higher temperatures and higher rates of decomposition of organic matter. Industrial activities might have greatly contributed to the decreasing of DO level. However, the recorded levels of DO in this study are within the permissible limit established by Adour Garonne basin agency **(Monod, 1989)**. These concentrations reflect a normal water quality in our three wetlands.

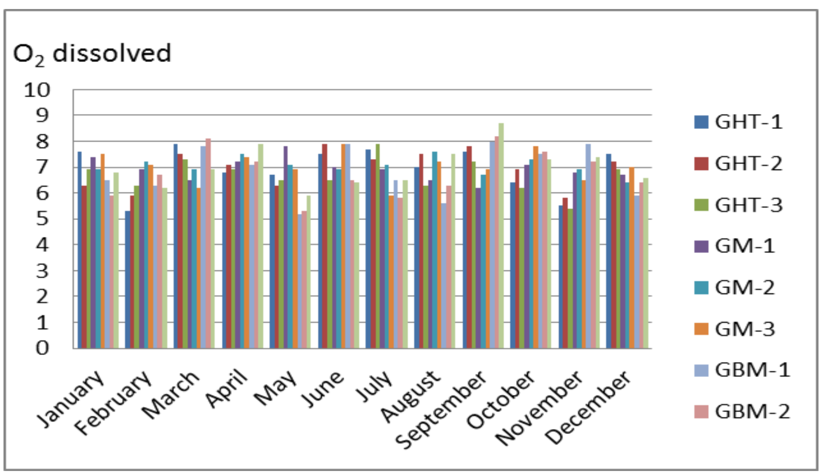

Fig. 6. Spatiotemporal variation of dissolved oxygen in water of three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher, GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

7. Nitrate and nitrite

Figs. (7, 8) show the changes of nitrate and nitrite concentration throughout the months of the year of study. Slight monthly variations in nitrate concentration at the three studied swamps appeared to range from 37mg/ l during summer at Ben M'Hamed and Messaouassa swamps to 8mg/ l during winter season at Hadj-Tahar swamp. The high concentration of nitrate during the dry period may be due to microbial use as well as to the varying agricultural run-off from agricultural farm in the vicinity of the study wetlands **(WHO, 2004)**. This pollution can lead to the eutrophication of these aquatic environments, resulting in a decline in water quality and a loss of biodiversity. However, the highest values of nitrite were recorded at Garaet Hadj-Tahar with 0.34mg/ l (Fig. 8) to a lesser degree at Ben M'Hamed and Messaouassa swamps with 0.2 and 0.14mg/ l, respectively. According to the Algerian norms recommended by the National Agency for Hydric Resources (ANRH) grid, these values indicate excellent to good water quality. Our results thus indicate that the recorded levels of nitrite do not present any risk to aquatic life at our three wetlands.

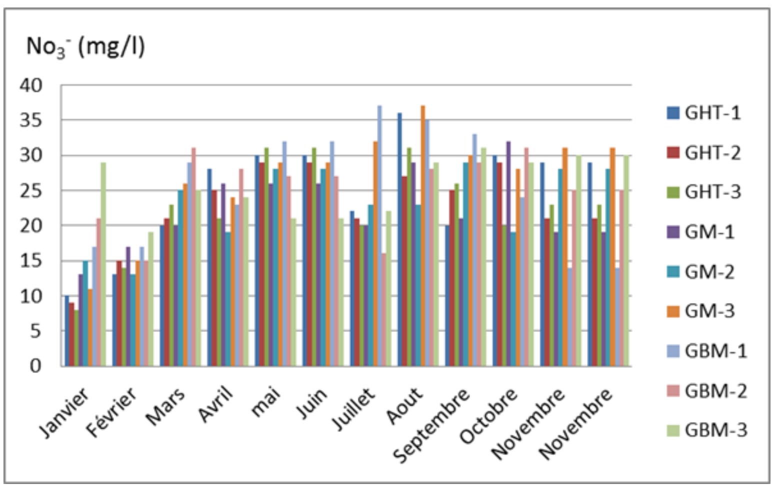

Fig. 7. Spatiotemporal variation of nitrate in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher , GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

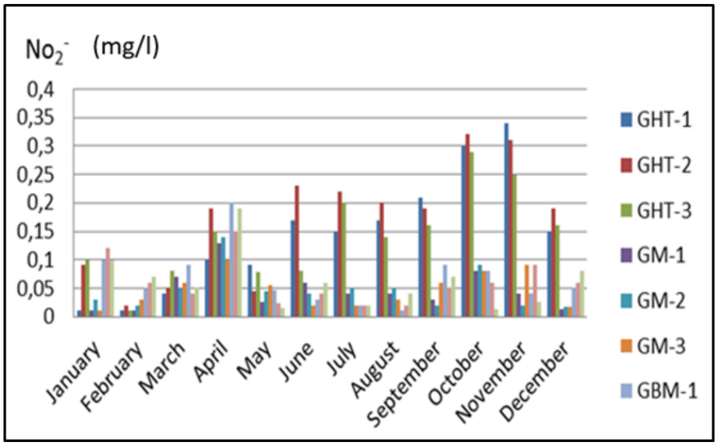

Fig. 8. Spatiotemporal variation of nitrite in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher ,GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

8. Calcium (Ca^{2+}) and magnesium (Mg^{2+})

The monthly values of calcium and magnesium content are presented in Figs. (9, 10), respectively. The highest average of Ca^{2+} was estimated at 390mg/ l at Hadj-Tahar swamp in August while the lowest was observed in March with 22mg/ l at Messaouassa swamp. However Ca^{2+} levels did not exceed 142mg/ l throughout all months of the study at Messaouassa and Ben M'Hamed swamps (Fig. 9). The same results were obtained for Mg^{2+}, where higher mean concentrations were recorded at Hadj-Tahar swamp, whereas maximum seasonal average was observed during summer with 230mg/ l and minimum seasonal average during winter with 15mg/ l, respectively. In general, the Mg^{2+} levels are mostly below the maximum acceptable concentrations (125mg/ l) for drinking water with the exception of July, August, and September (Fig. 10). Ca^{2+} and Mg^{2+} rich water at Hadj-Tahar swamp is probably due to the predominance of lime rich rocks in wetlands' bed **(Khan *et al*., 2004)**.

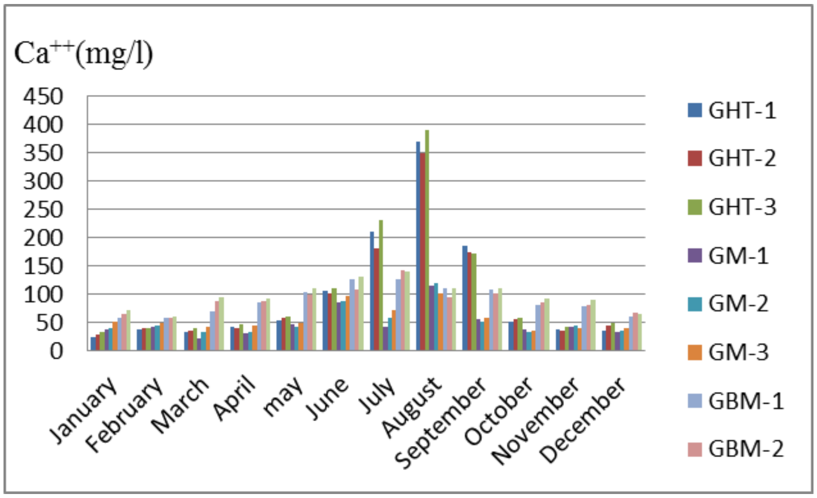

Fig. 9. Spatiotemporal variation of Calcium ions in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher, GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

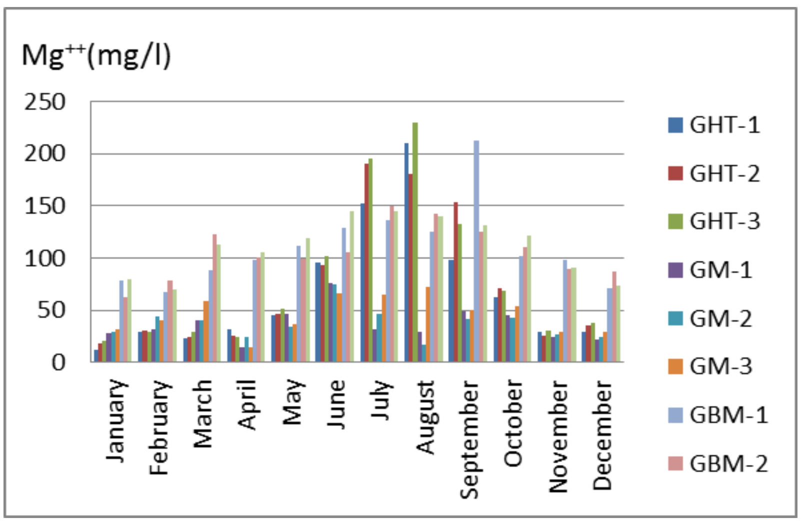

Fig. 10. Spatiotemporal variation of Magnesium ions in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher, GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

9. Chlorides

The values of Cl^- ranged from 28.8mg/ l in February at Messaouassa swamp to 444.6mg/ l in September at Ben M'Hamed swamp. Throughout the study period, Hadj-Tahar and Ben M'Hamed recorded the highest concentrations of Cl-, which is probably related to the nature of the soils of these two water bodies (saliferous soils) **(Hedjal*et al.*, 2018)**. In addition, higher concentrations of Cl^- could also be due to anthropogenic activities, or wastewater contamination. Our results suggest that, with the exception of September's values, the waters of the three wetlands have a good quality compared to the standard water quality ($Cl^- \leq$ 250mg/ l) **(WHO, 2004)** (Fig. 11).

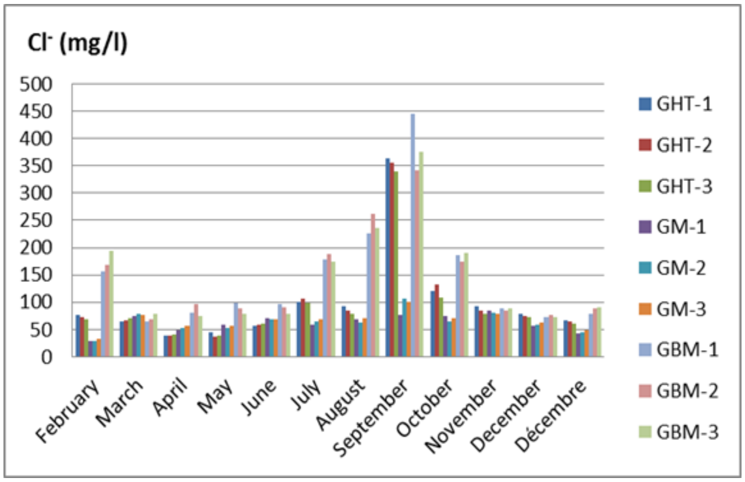

Fig. 11. Spatiotemporal variation of chloride ions in water at three swamps of Guerbes-Sanhadja complex (2021). GHT: Garaet Hadj-Taher GM: Garaet Messaoussa and GBM: Garaet Beni M'Hamed

10. Principal component analysis (PCA)

Based on 9 physico-chemical parameters (variables shown in Table 2), a PCA was carried out to categorize the spatial similarity groups of all the sampling sites depending on their water quality. The PCA based on the correlation matrix was able to distinguish between the water quality of the three sampling sites based on the studied parameters (Figs. 12, 13, 14 & Table 3). The first two components of the PCA analysis (PC1 and PC2) explained more than 56% of the total variance. The first component (PC1) which explained 40.66% of the variance was negatively correlated with conductivity, dissolved oxygen, pH, TDS, rate of nitrates, nitrites and the mineral variables (calcium, magnesium and chloride). The second component (PC2) explained 15.92% of the variance (Fig. 12). PC1 characterizes the mineralization of the water and nitrogen pollution. These variables are mostly dependent on anthropogenic activities and the effect of domestic wastewater and agricultural activities on the quality of surface water **(Liu *et al*., 2003; Elhatip *et al*., 2008; Omo-Irabor*et al*., 2008)**. Finally, PC3 which explains 11.45% of the total variance (Fig. 13) was correlated to dissolved oxygen, and it defines an axis of pollution by organic particles brought by runoffs during the flood period.

Table 3. Descriptive statistics of variables

	Valid N	Mean	Minimum	Maximum	Std. Dev.
pH	108	7.380	6.00	9.40	0.82
CE	108	1043.87	310.00	2330.00	453.49
TDS	108	726.61	202.24	1491.20	288.58
O_2	108	6.91	5.20	8.70	0.80
NO_3^-	108	24.34	8.00	37.00	6.43
NO_2^-	108	0.08	0.01	0.34	0.07
Ca^{++}	108	81.39	22.00	390.00	64.29
Mg^{++}	108	74.33	12.00	230.00	50.25
Cl^-	108	102.05	28.30	444.60	79.06

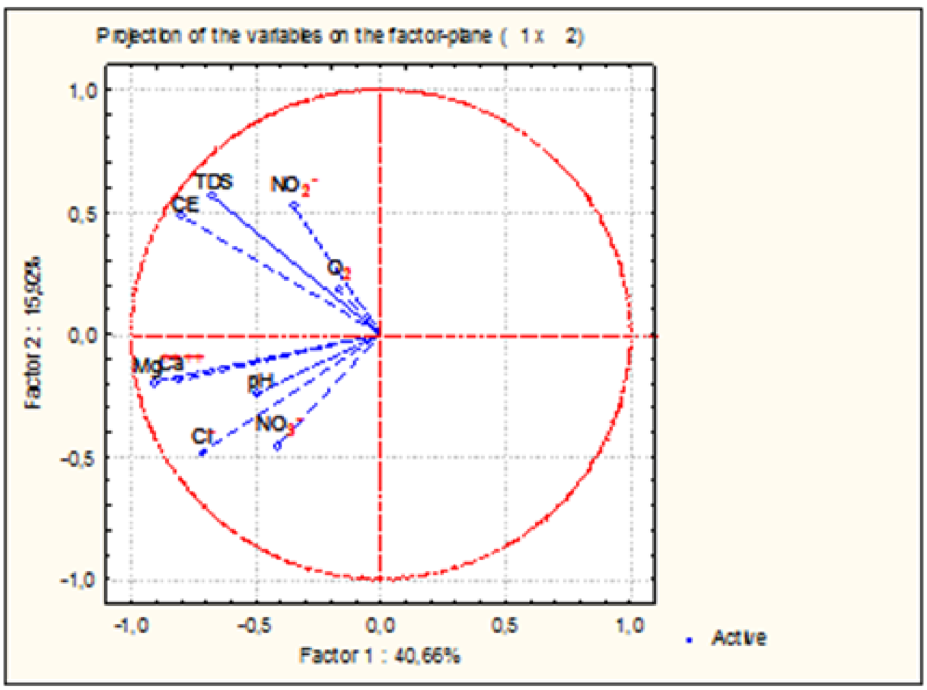

Fig. 12. Biplot of PCA (PC1- PC2) based on all samples in the three wetlands and nine physico-chemical parameters of the water

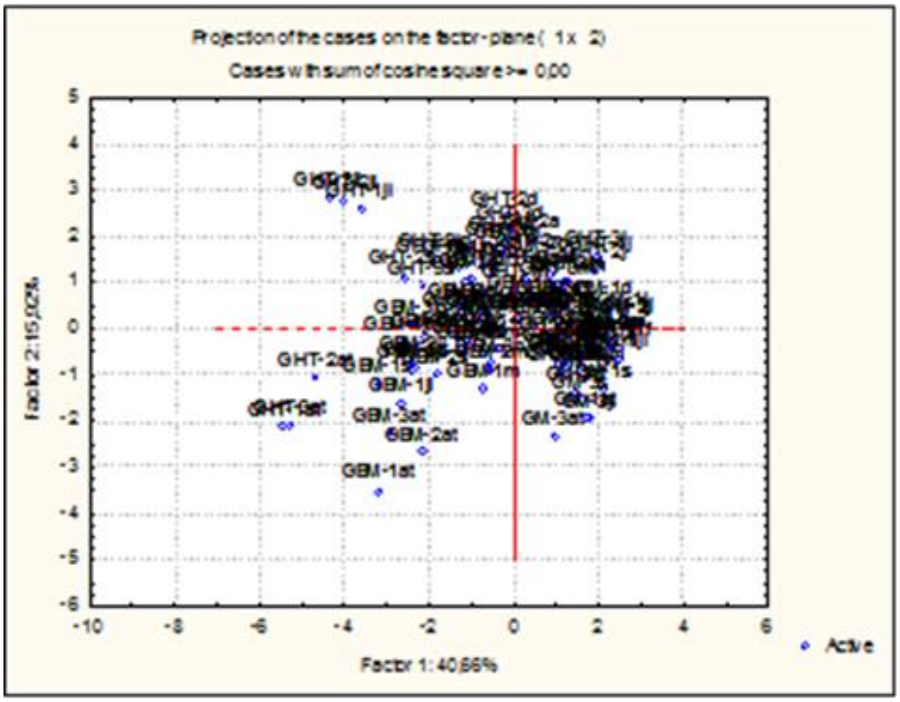

Fig. 13. Biplot of PCA (PC1- PC3) based on all samples in the three wetlands and nine physico-chemical parameters of the water

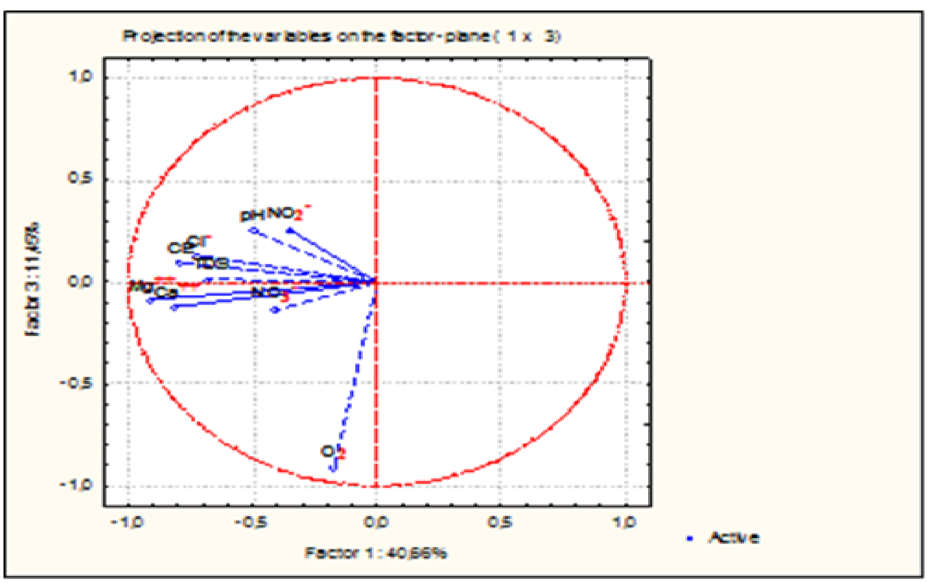

Fig. 14. Discriminant plot showing spatial variation of water parameters

CONCLUSION

In this study, statistical analyses were used to evaluate variations in surface water quality of three swamps at Guerbes-Sanhadja complex. According to physico-chemical results obtained during our study Hadj-Tahar, Messaouassa and Ben M'Hamed swamps have an acceptable water quality. All physico-chemical parameters measured do not exceed the standards required, except for Ca^{++}, Mg^{++} and Cl^{-} ions. The high values of these parameters are highly likely the result of leaching of geological formations. We suggest that regular monitoring of quality of these wetlands is necessary to protect the integrity of these ecosystems and conserve their biodiversity.

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