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ASSESSMENT OF THE WATER QUALITY OF THE BOUREGREG ESTUARY AFTER THE DEPOLLUTION PROJECT

Asmae EL HARIM*, Essediya CHERKAOUI,
Mohamed KHAMAR, Abderrahman NOUNAH

Civil Engineering and Environment Laboratory (LGCE). Materials, Water and Environment Team, Higher School of Technology, Mohammed V University in Rabat, Morocco

Abstract

On the Atlantic coast of Morocco, the estuary of Bouregreg is the outlet for several solid and liquid discharges favoring the development of a physicochemical and bacteriological contamination throughout its course. What therefore leads to serious pollution problem of its waters, intended for multiple purposes (swimming, fishing). This study highlights the impact of the depollution project (which is part of the Bouregreg Valley development project) on the quality of the waters this estuary. Thus, a follow-up of several physicochemical parameters and indicators of faecal pollution, were carried out along the Bouregreg estuary, in order to be able to follow the spatiotemporal evolution of the water quality of the latter. The results obtained during the present study reveal a significant improvement in the physicochemical quality of the waters of the Bouregreg estuary. However, from a bacteriological point of view, the water of this estuary remains polluted and therefore unsuitable for swimming. According to the report (FC / FS), the source of faecal pollution is strictly of human origin.

Keywords*: Bouregreg estuary; Bacteriological contamination; Depollution project; Physicochemical quality*

Introduction

In Morocco, the Bouregreg estuary is a historical and natural environment steeped in history, having always allowed the implantation of human populations and the development of socioeconomic activities which constantly manages to deteriorate and influence the ecological habitats of this ecosystem. Since 1974, the hydrological regime and the quality of the watercourse of this estuary, has been modified by the construction of the Sidi Mohammed ben Abdellah Dam (SMBA) upstream (23km from the mouth) [1], which aims to supply the region in drinking water.

In the same way, this Atlantic estuary has for a long time faced a great risk of environmental degradation since it was subject to alarming pollution caused by various anthropogenic activities: about twenty domestic and industrial discharges along the left bank and ten discharges on the right bank [2], leachates and various solid wastes from the Akrech and Oulja landfills, pottery discharges de Salé, Salé fish market rejections, the exploitation of eight quarries upstream of the estuary [2], the rejection of agricultural activity in the Bouregreg valley rich in fertilizers and high-dose phytosanitary products, concentrated and uncontrolled road traffic. In 2006 and to face all these constraints, a project of depollution (which enters

* Corresponding author: asmae.elharim@gmail.com

within the framework of the project of development of the valley of Bouregreg) was born in order to protect this ecosystem, to preserve and rehabilitate its patrimony, and finally improve the living environment of local populations by carrying out several environmental actions such as: the elimination of several discharges of wastewater; the rehabilitation and closure of the Oulja and Akreuch dumps [3] and the construction of the inter-municipal waste treatment center at Oum Azza [3].

However, despite these positive actions, this estuary continues to undergo many anthropogenic disturbances, namely the reception of some discharges of sewage of different nature: domestic discharges (rejection of Bettana), mixed or industrial (industrial zones of Takadoum and Oulja), in addition to the discards of some poultry farms [3].

In addition, all the work previously carried out within this estuary revealed a degradation of this site with a very high physico-chemical and microbiological pollution rate often related to the unreasonable number of discharges spread over both banks of the estuary of Bouregreg [4].

It is for this purpose that the present study proposes to make a comparison before and after the execution of the Bouregreg Estuary depollution project, in order to evaluate the physicochemical and bacteriological quality of its water, usually intended for fishing, swimming and various hobbies.

Experimental

Materials and methods

The Bouregreg estuary is located on the Moroccan Atlantic coast at 34°2'9"N and 6°50'7"W, separating two large urban agglomerations Rabat and Salé, limited upstream by the dam of Sidi Mohammed Ben Abdellah and downstream by the two beaches of Rabat and Salé.

It is in the form of an arm emerging from the ocean, extending perpendicular to the sixth meridian and parallel to the level of the 34th parallel, measuring 23km in length and 150m in mean width [5].

Eight sampling stations located from downstream (kilometric point 1) to upstream (kilometric point 20) (Fig. 1), were studied during six study campaigns from February 2014 to February 2015 in order to follow the spatial and temporal evolution of the water quality of the Bouregreg estuary.

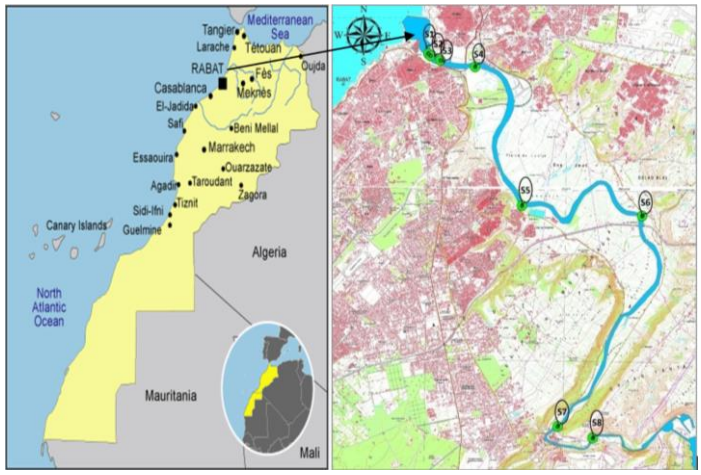

Fig. 1. Location of study stations along the Bouregreg estuary

Moreover, the physicochemical quality of the waters of this estuary was evaluated through a monitoring of thirteen physicochemical parameters: temperature, pH, turbidity,

electrical conductivity, dissolved oxygen, total matter (TM), organic matter (OM), mineral matter (MM), total suspended solids (TSS), biological oxygen demand (BOD_5), chemical oxygen demand (COD), Nitrate and Orthophosphate measured according to the methods approved by Rodier [6-8]. However, the study of the bacteriological quality of water has focused on the determination of the indicators of faecal contamination (faecal coliform (FC) and faecal streptococci (FS)), since they are considered as indicators of recent faecal contamination [6-8] and which also make it possible to determine the origin of the pollution.

Results and discussion

Physico-chemical parameters

The water temperature of the Bouregreg Estuary varies according to the seasons and the nature of the waters that are salted downstream and freshwater upstream. The average water temperature of this estuary oscillates between 19.98°C and 21.80°C (Fig. 2). The temperature rise in the upstream sector can be explained by the direct influence of the air temperature, given the shallow depth of the water layer upstream of the kp 16.

Similarly, the pH values recorded in the eight study stations show that this parameter varies slightly along the Bouregreg estuary: from 7.52 in the intermediate part of the estuary to 8.34 upstream (Fig. 2).

This stability of values can be explained at the mouth of the estuary by the alkalizing effect of marine waters, and upstream by the marly and calcareous nature of the geological formations of the Bouregreg catchment area, thus promoting the release of carbonates and bicarbonates which increase the pH [9]. These results are also in perfect agreement with the latest study carried out in this estuary, after the development project [10].

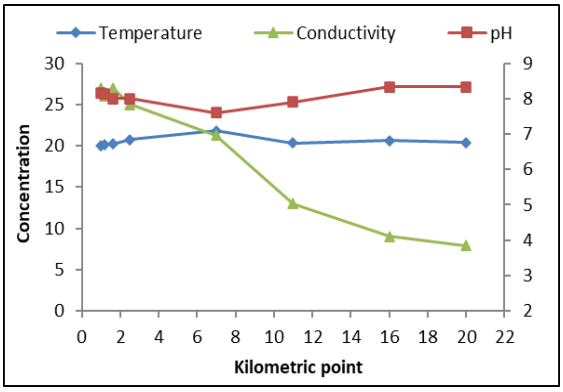

Fig. 2. Spatial evolution of temperature, pH and electrical conductivity along the Bouregreg estuary

Mean values of electrical conductivity recorded along the Bouregreg estuary show a decreasing downstream-upstream gradient (Fig. 2), ranging from 27mS/cm to 1.6kp at 7.90mS/cm at kp 20. These results can be explained by the effect of the descending gradient of marine hydrodynamism in this estuary, where downstream stations are largely rich in dissolved salts by their permanent contact with saline water bodies. By Therefore we conclude that the gradient of electrical conductivity along this estuary, follows perfectly the Downstream-upstream gradient of salinity. These results are comparable to those recorded in the same estuary before the development project of the Bouregreg valley [2, 9].

As for turbidity, the average values recorded hardly exceed 40 NTU, with the exception of the stations at kp 7 and kp 11, which respectively record average values of about 121.90NTU

and 92.63NTU (Fig. 3). This result can be explained at kp 7 by the high load of raw wastewater from the mixed Takadoum discharge and by the direct tributaries in this industrial area, which flow directly and without any prior treatment. However, the high turbidity values recorded at kp 11, are due to the nature of the muddy soils as well as decomposed organic animal and vegetable matter.

According to the Moroccan standard for surface water classification, the average turbidity values classify the waters of the Bouregreg estuary as excellent (downstream part of kp 2,5 and upstream of kp 16), with poor quality (middle part of the estuary between kp 7 and kp 11).

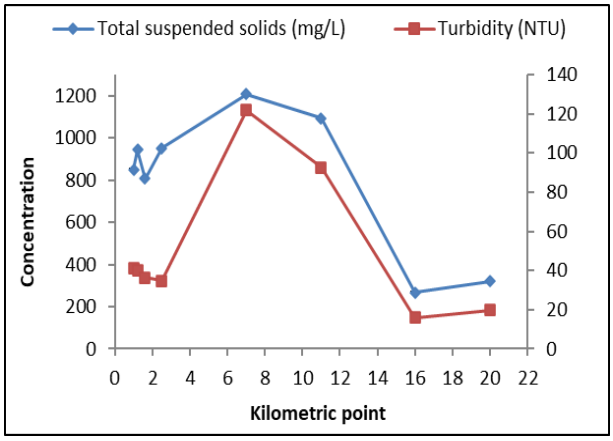

Fig. 3. Spatial evolution of mean turbidity levels and total suspended solids (TSS) along the Bouregreg estuary

The average values of suspended solids vary between a maximum of 1207mg/L recorded at kp 7 (mainly due to mixed releases from the Takadoum industrial area) and a minimum of 267mg/L recorded at kp 16.

The comparison of concentrations of suspended solids along the Bouregreg estuary with the Moroccan standard set at 1000mg/L, places its water in the average quality grid (downstream part of kp 2,5 and upstream of kp 16) to poor quality in the middle part of the estuary (between kp 7 and kp 11).

In addition, the content of the total material that includes both organic and mineral matter, in the waters of the Bouregreg estuary depends on several parameters: the season, the rainfall, the nature of the land crossed. Its spatial evolution along this estuary follows a decreasing downstream-upstream gradient where the average grades pass from 30.02g/L downstream to 9.94g/L upstream (Fig. 4). In addition, the average values of the mineral matter follow the same gradient as the total matter, with maximum values at the mouth of the order of 28.38g/L, and minimum values upstream of the estuary of the order of 6g/L.

The increase in mineral matter values at the mouth of the Bouregreg estuary is in keeping with the high values of suspended solids and those of electrical conductivity, which could be explained on the one hand by the salts seawater minerals and on the other hand the dredging of the estuary bed which allowed a deep agitation of the materials (rocks, sediments) during the whole period of the development works.

However, the organic matter content remains very low compared to the mineral content, where the mean values vary from 2g/L at the mouth to 4.54g/L upstream of the estuary (Fig. 4). However, the highest values are recorded in the stations at kp 11 (5.85g/L) and kp 7 (7.35g/L), which explains in particular the high values of turbidity in these stations. Thus, the origin of this

organic matter in these stations is mainly related to the contributions of raw wastewater rich in organic matter.

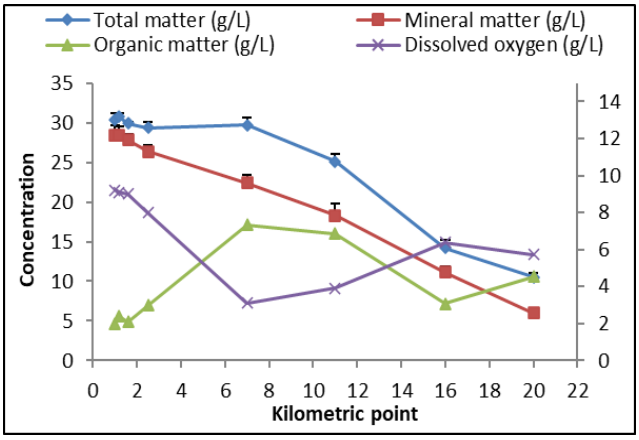

Fig. 4. Spatial evolution of the average dissolved oxygen, total matter, mineral and organic matter contents in the Bouregreg estuary

The seasonal evolution of dissolved oxygen along the Bouregreg Estuary shows higher concentrations during the autumn period (from 3.37mg/L at kp 7 to 9.57mg/L at the mouth) than in summer (from 2.93mg/L at kp 7 to 9mg/L at the mouth). Where in the cold period, heavy rainfall increases the exchange of oxygen with the atmosphere and facilitates the entry of air into the water bodies of this estuary and therefore a dilution of the polluting load.

Thus, the curve of the spatial variation of the dissolved oxygen along the Bouregreg estuary is in the shape of a bag, this pace is complementary to the curve of the organic matter, where it is noted that the more the organic matter increases in a station, the lower the dissolved oxygen content in this station (Fig. 4).

The lowest concentrations of dissolved oxygen are recorded in the stations located at kp 7 and kp 11 which undergo strong anthropogenic pressure by solid waste, air pollution, the action of microorganisms (depleting the oxygen medium by degrading the abundant organic matter in these stations), but especially by the warming of the water of these stations by discharges of raw sewage rich in fermentable organic matter, which are liable to be oxidized causing a decrease in the dissolution of oxygen [11].

Our dissolved oxygen results are still higher than those recorded in this estuary before the development works of the Bouregreg valley (from 1.5mg/L to 5.5mg/L) [2], and at the level of Wadi Khoumane (3.29mg/L to 5.92mg/L) [12] but lower than those recorded in Oued Laou (from 3mg/L to 13mg/L) [13]. According to the Moroccan classification of surface waters, the waters of this estuary are classified from average to good quality.

In addition, mean BOD_5 values vary from 8.5 mg O_2/L at the mouth of the estuary to 28 mg O_2/L at kp 7, while those at COD increased from 38 mg O_2/L at the mouth to 239 mg O_2/L at kp 7.

The spatial evolution of these two parameters shows bell-shaped curves (Fig. 5), and this same shape of curve is also confirmed by a very high correlation coefficient of 95 % linking these two parameters.

The maximum values are recorded at the middle part of the estuary, while the low values are recorded in both the downstream and upstream parts, this can be explained by the existence of several discharges in the middle part and the absence of these in the other two parts. Similarly, the high penetration of marine waters at the mouth of the Bouregreg estuary certainly dilutes its waters and consequently a decrease in BOD_5 and COD.

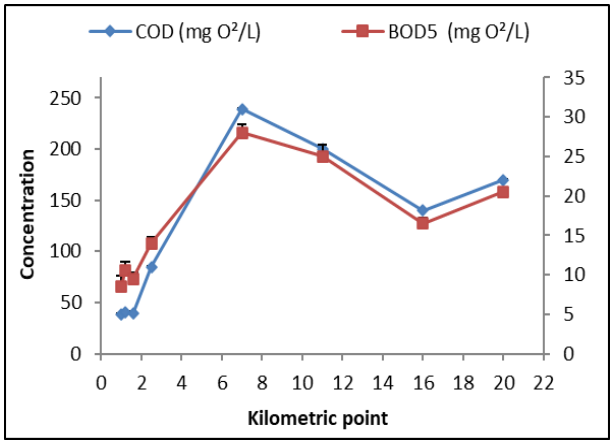

Fig. 5. Spatial evolution of average values of BOD_5 and COD along the Bouregreg estuary

To complete the analysis of physicochemical parameters, two major nutrients, pollution indicators (nitrate and orthophosphate) were studied along the Bouregreg estuary. The spatial evolution of nitrate shows an increasing downstream-upstream gradient, with average grades ranging from 12.61mg/L recorded in the downstream sector to 23.56mg/L reported upstream (Fig. 6). This increase in nitrate in the upstream sector can be explained by the leaching of organic amendments at kp 16 and by the natural decomposition of dead organic matter at kp 20, but, their concentration in the intermediate zone is linked to the different releases of chemicals of industrial and domestic origin. By cons, their presence at the mouth of the estuary, may be strictly marine.

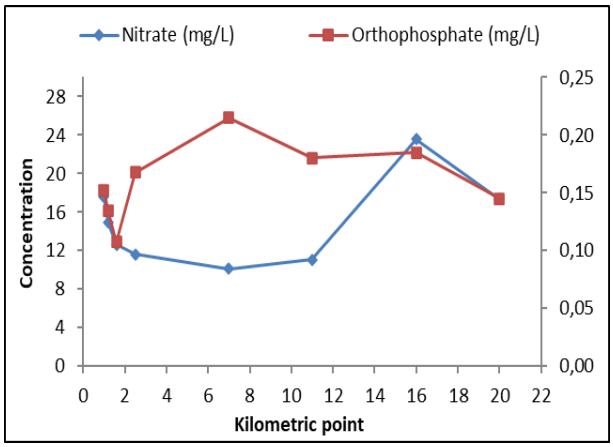

Fig. 6. Spatial evolution of mean nitrate and orthophosphate concentrations along the Bouregreg estuary

Generally, our average nitrate values remain well below 30mg/L, set by the Moroccan standards of surface water, which allows us to conclude that the waters studied along the Bouregreg estuary do not present any risk of pollution by nitrate. On the contrary, the nitrate at low doses in the water is transformed into a depolluting agent, because by absorbing the light at 302 nm, they generate hydroxyl radicals which degrade pollution [14]:

$$NO_3^- + H_2O + h\nu \rightarrow NO_2^{\bullet} + {}^{\bullet}OH^- + {}^-OH$$

In natural water, the generation of $OH^{\bullet}$ radicals from organic matter allows the rapid degradation of certain micropollutants [15].

Thus, our nitrate results are still much lower than those recorded before the development project (39.02mg/L) [9], which clearly shows the positive impact of the depollution work that the Bouregreg estuary has undergone, on the quality of its waters.

In addition, orthophosphate levels along the Bouregreg Estuary vary very slightly from one station to another, where the highest mean value was recorded at kp 7 (0.22mg/L) and the lowest at 1.6 kp (0.11mg/L) (Fig. 6).

The comparison of these results with those carried out previously within the same estuary, clearly shows the positive impact of the Bouregreg estuary depollution project, where the quality of the water has gone from bad (1.75mg/L) [2] to excellent (<0.2mg/L). As a result, the waters of the Bouregreg estuary no longer pose any danger of pollution by orthophosphate ions.

Finally, and contrary to the results recorded previously before the development project in the Bouregreg estuary [2], most hydrological factors, pollutant indicators (turbidity, organic matter, BOD_5, COD, TSS) no longer show a gradient increasing or decreasing. But a bell-shaped shape, which clearly reveals the positive impact of the Bouregreg Estuary depollution project at its mouth and upstream sector. On the other hand, the maximum of the hydrological factors studied, are concentrated in the intermediate zone, between the Hassan II bridge and the Mohamed V bridge, where the anthropogenic impact is concentrated [16].

According to the spatio-temporal evolution of physicochemical parameters, the Bouregreg estuary can be subdivided into three parts:

- A first upstream: where water quality is excellent since it is protected from human activity, especially after quarry closure, the elimination of the Akrech spill and the rehabilitation of the Akrech landfill.

- A second intermediate: located from the Hassan II bridge to the Mohamed V bridge, where the water quality in this zone has only slightly improved, since it receives, even at low doses, wastewater discharges raw without any prior treatment, which still classifies the waters of this zone in the grid of poor water quality. Therefore, the protection of waters in this area against various anthropogenic pollution is imperative, so that they can be used for fishing and swimming without any risk of contamination.

- And a third downstream (at the mouth): unlike the intermediate zone, this area has experienced a remarkable improvement in terms of water quality. Insofar as, by comparing our results with the previous works (before the development project), we can clearly see the positive impact of the depollution project, which the Bouregreg Estuary has experienced, following the radical elimination several sewage outlets, as well as liquid discharges from the port of Salé which were transferred far from the estuary. Nevertheless, the risks currently threatening this downstream area boil down to the irresponsible activities of local residents and local fishermen.

Bacteriological parameters

The average concentrations of the bacteriological parameters obtained reveal that the waters of the Bouregreg Estuary have a very high load of bacteria indicating fecal contamination. In fact, the lowest bacterial load concentrations are recorded at the mouth of the Bouregreg estuary, where they vary from $6 \cdot 10^4$ FC/100 mL to $4 \cdot 10^5$ FC/100 mL and from $6 \cdot 10^4$ FS/100 mL to $7 \cdot 10^4$ FS/100 mL. However, the highest concentrations of fecal contamination

indicator germs are noted at the kp 7 station which continuously receive wastewater, where their concentrations vary from $2.1 \cdot 10^5$ FC/100 mL to $11 \cdot 10^6$ FC/100 mL and $7 \cdot 10^4$ FS/100 mL at $4 \cdot 10^5$ FS/100 mL (Fig. 7).

Throughout the study period, this station (kp 7) proved to be the most degraded because of its location near the open sewer networks: discharge from the industrial district of Takadoum, where the flow of raw wastewater discharged into the estuary without any prior treatment is worrying, especially since they are added to the liquid discharges from the marble factories which are located at the edge of the estuary (a few meters from the Takadoum discharge).

In fact, these sewages discharged into this station, along with those of runoff, carry large quantities of debris, suspended solids and metallic elements [17]. The same observations were reported in 2015 [10] where the high concentrations of metallic elements in the waters of the intermediate sector of this estuary were explained by the impact of anthropic activities that generate permanent pollution in form of domestic wastewater from industrial city of Takaddoum and Maadid, which flow directly into the Bouregreg estuary without prior treatment [10], which consequently explains the high values of fecal pollution indicator germs at this station.

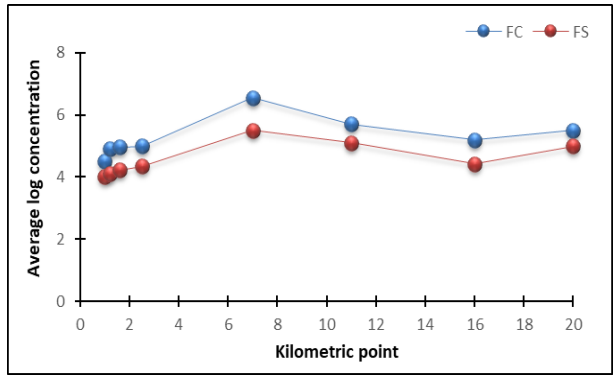

Fig. 7. Spatial evolution of fecal pollution indicators (FC and FS) along the Bouregreg estuary

However, it was found that throughout the study period, bacterial load in FC far exceeds that in FS, which is consistent with the results of previous work within the same study site [2], as well as in other wadis [18-19]. This has been explained by a difference in the rate of decline, which is faster in FS [20] and is certainly influenced by abiotic factors in the natural environment [18].

The spatio-temporal evolution of FC varie in the same way as that of FS (Fig.7), which has also been confirmed by a high correlation coefficient of about 90%, linking these two bacteriological parameters.

In addition, in order to determine the origin of faecal pollution along the estuary, the ratio R = FC/FS (faecal coliform on faecal streptococci) is used as a first-rate element [21]. Indeed, the calculation of the FC / FS ratio of all the stations during the study period, reveals values higher than 4, which confirms that the fecal pollution is strictly of human origin, something which can be linked to the intense activities and permanent fishers and local residents along the Bouregreg estuary.

These results are in perfect agreement with those recorded on the same site before the depollution project of the Bouregreg valley [2], which allowed us to observe that the origin of fecal pollution did not change during in recent years since it has kept its exclusively human origin (FC/FS > 4) since 1998 [2], despite the depollution efforts deployed along this estuary as the removal of several discharges of wastewater (discharges of clubs (left bank), rejections of the Salé sports association, leachate from the household waste treatment unit, leachates from Salé and Rabat landfills...) which should have brought positive actions on the bacteriological quality of waters of this estuary.

However, water contamination is not exclusively of human or animal origin, but also the influence of physicochemical parameters such as temperature and pH which can contribute to bacterial activity [21-22].

According to the Moroccan surface water classification, the values of the concentrations of faecal pollution indicators identified in the present study are well above the standards (> 50000 FC/100 mL and greater than 10000 FS/100 mL), which classifies the waters of the Bouregreg estuary of poor bacteriological quality.

Thus, in accordance with the Moroccan Bathing Water Standard (FC > $2 \cdot 10^4$ UFC/100 mL), the waters of this estuary are declared polluted, of poor quality and unsuitable for bathing in the large part of their path. The same findings were revealed in 1991 ($40 \cdot 10^3$ FC/100 mL) [23], in 1996 ($2.4 \cdot 10^7$ FC/100 mL) [24], in 1998 (from 10^4 FC/100 mL to $4 \cdot 10^6$ FC/100 mL) [2], and finally in 2010 where the waters of this estuary were considered highly polluted and unsuitable for swimming [3].

The results of this study are in perfect agreement with the observations of bacteriological analyzes of various surface waters in large urban and rural agglomerations made by other authors: where the quality of the waters of the wadi Fez and Sebou has degraded in poor quality in 2008 [25] to very poor quality in 2014 [7], the bacteriological quality of Wadi Boufekrane has deteriorated over the years, polluted in 1996 [19] and in 2007 [18] to very polluted in 2010 [21].

Principal Component Analysis (PCA)

In order to establish a relationship between the different physicochemical and bacteriological parameters studied and to better assess the impact of the depollution project on the water quality of the Bouregreg estuary, a statistical analysis of principal component analysis was carried out on 8 stations and 15 variables: Temperature, pH, Turbidity, Electrical Conductivity, Dissolved Oxygen, Total Matter, Organic Matter, Mineral Matter, total suspended solids, BOD_5, COD, Nitrate, Orthophosphate, Fecal coliform and Fecal streptococci. This method is widely used to interpret hydrochemical data [26]. Figure 8 and Table 1 respectively give the correlations between variables and factors according to their affinities and groupings, as well as their projection in the space of the factorial axes F1 and F2.

The analysis of factorial design F1 and F2 shows that more than 87.59 % of the total information is expressed. The F1 axis has a variance of 60.17 % and is expressed by TSS, COD, BOD_5, organic matter, turbidity, temperature, orthophosphate, nitrate, dissolved oxygen, fecal coliform and faecal streptococci. The F2 axis has a variance of 27.41 % and consists of the variables: electrical conductivity, total material, mineral matter and pH (Fig. 8).

The elements: TSS, COD, BOD_5, organic matter, faecal coliform, electrical conductivity, total matter and mineral matter, occupy the upper right quarter of the factorial plane, these elements therefore have "positive" connections with Components 1 and 2.

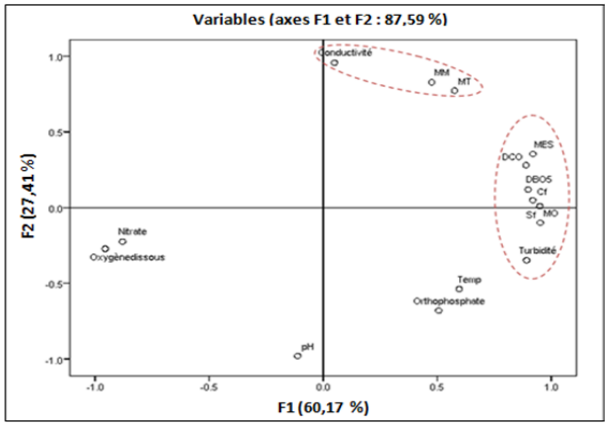

Fig. 8. Distribution of physico-chemical and bacteriological parameters according to the F1xF2 plan

Table 1. Correlation between variables and factors

Variables	Factors	
	F1	F2
Dissolved Oxygen	-0.956	-0.272
Organic matter (OM)	0.951	-0.100
Faecal streptococci (FC)	0.949	0.009
Total suspended solids (TSS)	0.919	0.354
Faecal coliform (FC)	0.919	0.048
Biological oxygen demand (BOD_5)	0.898	0.119
Turbidity	0.892	-0.347
Chemical oxygen demand (COD)	0.889	0.280
Nitrate	-0.880	-0.225
Temperature	0.596	-0.538
pH	-0.112	-0.979
Conductivity	0.049	0.956
Mineral matter (MM)	0.476	0.827
Total matter (TM)	0.576	0.772
Orthophosphate	0.506	-0.680

Temperature, turbidity, orthophosphate and fecal streptococci occupy the lower right quarter of the factorial plane, these elements therefore have "positive" links with the CP 1 and "negative" with the CP 2. Thus, the two variables representing Fecal streptococci and turbidity show stronger associations with CP 1 than CP 2.

The elements: nitrate, dissolved oxygen and pH, occupy the lower left quarter of the factorial plane, these elements thus have "negative" connections with CP 1 and 2.

The positioning of the 15 variables studied at the extremity of the factorial planes, show that they are very well explained by the two main components 1 and 2.

Similarly, the strong correlation that exists between these different variables and their proximity to the two factors F1 and F2, shows that their existence is governed by the same phenomenon. In the first F1 axis, the parameters are closely related to the impact of anthropogenic pollution (TSS, COD, BOD_5, organic matter, turbidity). However, the second axis F2 is mainly reflected by the mineralization parameters of the waters of this sea arm (electrical conductivity and mineral matter).

The grouping of pollution indicator parameters around the first F1 axis reveals the importance they play in assessing the water quality of the Bouregreg estuary. Similarly, the difference in the directions of the vectors of the parameters of the component F1, informs that any increase in concentration of chemical pollution indicators (TSS, COD, organic matter…) and faecal pollution indicators (faecal coliform and faecal streptococci) is accompanied by a decreased level of dissolved oxygen and nitrate (Fig. 8).

Referring to the matrix of correlations between the 15 variables studied, we find that the majority of hydrological factors have significant correlations between them and stronger since they are positioned at the ends of the first F1 axis: BOD_5 & TSS (0.92), Turbidity & OM (0.82), BOD_5 & OM (0.79), BOD_5 & COD (0.95), Turbidity & COD (0.73), COD & TSS (0.96), Dissolved O_2 & TSS (-0.98), FC & OM (0.97) and FS & TSS (0.85) (Table 2). In addition, we can conclude that the mineral matter is the major hydrological factor influencing the mineralization of the waters of this estuary. Its strong affinity with electrical conductivity (r = 0.87) reflects its influence on the total mineralization of surface water in the Bouregreg estuary.

Table 2. Matrix of correlation between the studied variables

Variables	Kp	Temp	TSS	TM	OM	MM	BOD_5	pH	Turbidity	Conductivity	COD	Nitrate	Orthophosphate	Dissolved Oxygen	FC	FS
Kp	1.000															
Temp	0.163	1.000														
TSS	-0.674	0.310	1.000													
TM	-0.961	0.041	0.809	1.000												
OM	-0.231	0.658	0.793	0.445	1.000											
MM	-0.989	-0.047	0.743	0.992	0.331	1.000										
BOD_5	-0.418	0.306	0.916	0.553	0.787	0.474	1.000									
pH	0.937	0.422	-0.430	-0.824	-0.028	-0.865	-0.168	1.000								
Turbidity	-0.046	0.699	0.736	0.272	0.821	0.175	0.793	0.274	1.000							
Conductivity	-0.925	-0.340	0.358	0.820	-0.028	0.868	0.072	-0.972	-0.323	1.000						
COD	-0.564	0.207	0.960	0.678	0.749	0.612	0.953	-0.352	0.729	0.232	1.000					
Nitrate	0.453	-0.342	-0.860	-0.594	-0.884	-0.505	-0.851	0.308	-0.682	-0.195	-0.852	1.000				
Orthophosphate	0.322	0.774	0.239	-0.131	0.488	-0.205	0.290	0.569	0.682	-0.523	0.230	-0.080	1.000			
Dissolved Oxygen	0.591	-0.427	-0.978	-0.764	-0.884	-0.683	-0.894	0.360	-0.778	-0.296	-0.916	0.918	-0.267	1.000		
FC	-0.337	0.504	0.814	0.532	0.966	0.429	0.777	-0.175	0.713	0.117	0.764	-0.860	0.410	-0.885	1.000	
FS	-0.372	0.555	0.854	0.542	0.916	0.446	0.786	-0.163	0.799	0.077	0.849	-0.821	0.535	-0.884	0.901	1.000

For this study of the assessment of the surface water quality of the Bouregreg estuary, the PCA is a tool that has offered the possibility to simplify the study of our aquatic ecosystem and to reduce the costs by the reduction of the number of variables to be taken into account. We have shown in this study that it is possible, in the perspective of creating a management tool, to simplify the model initially built from 15 variables, to reduce it to the measure of 7 parameters only, which are: TSS, COD, BOD_5, organic matter, faecal coliform, electrical conductivity and mineral matter.

Conclusion

At the end of this study, the results obtained by the physicochemical parameters studied seem to highlight the positive impact of the Bouregreg estuary depollution project, since the

quality of its water has changed from poor to average in the upstream sector, and from bad to excellent in the downstream sector. On the other hand, there is still a deterioration in the physicochemical quality of the waters of the intermediate zone (between the Hassan II bridge and the Mohamed V bridge) particularly the stations subject to random spillage and without prior treatment wastewater, as well as the almost permanent presence of solid waste thrown on both banks of the Bouregreg estuary and which undoubtedly constitute a threat to the health of the riverside and user populations of this estuary: swimming, fishing, irrigation. However, on the bacteriological basis and throughout the study period, the concentrations of fecal pollution indicators remain very high along this estuary.

Indeed, according to the Moroccan classification of surface waters and the Moroccan standard of bathing water, the waters of the Bouregreg estuary are now classified as of poor bacteriological quality and not in conformity with bathing. Therefore, this classification asserts that the bacteriological quality of the waters of the Bouregreg estuary, did not show a great improvement after eight years of depollution and decontamination of the wadi and the coastline, thus highlighting the impact of the hydrodynamism accentuated on this arm of sea, the final outlet of all the rejections of the anthropic activities of the two riparian towns (RABAT & SALE).

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