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THE IMPACT OF THE DEPOLLUTION PROJECT ON THE QUALITY OF THE ESTUARINE ECOSYSTEM OF BOUREGREG (MOROCCO ATLANTIC COAST)

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Abstract

On the Moroccan Atlantic coast, the Bouregreg estuary, known as a site of biological and ecological interest due to its great diversity of flora and fauna, has never ceased to cope with the numerous anthropic disturbances. In the context of environmental protection, a depollution project for the Bouregreg estuary and the coastline was launched in 2006. Present study proposes to evaluate the impact of eight years of depollution project estuary of Bouregreg, on the quality of its three components: water, sediment and benthic macrofauna. For this, six companions of studies of the benthic macrofauna were conducted along the Bouregreg estuary (8 study stations). In parallel, a follow-up of the characteristics of water: physicochemical (dissolved oxygen, electrical conductivity, BOD_5, nitrates, orthophosphates, organic matter, mineral matter), bacteriological (faecal coliforms and fecal streptococci) and edaphic (granulometry and heavy metals) a been carried out during the four seasons of 2014-2015.

Keywords*: Benthic macrofauna; Bacteriological; Bouregreg estuary; Depollution project; edaphic; Physicochemical parameters*

Introduction

Estuarine ecosystems are often subject to significant environmental changes, both natural and anthropogenic (pollution of domestic, industrial and agricultural origin), which greatly disrupt the functioning of these aquatic environments, particularly at the intertidal fringe where ecological parameters are changing rapidly. This is the case of the Bouregreg estuary on the Moroccan Atlantic coast, known for its important ecological diversity, because of its hosting of a large number of fauna species (invertebrates, fish, birds) and diversified flora (phanerogams, algae), which are of great interest for the Moroccan, North African and Atlantic biodiversity. This is how it was ranked among the Sites of Biological and Ecological Interest retained by the Master Plan of Protected Areas in Morocco, to be better preserved and safeguarded [1].

However, before the development project, this Atlantic estuary has long been considered as an outlet for solid waste and discharges of urban and industrial wastewater discharged directly without any monitoring or prior treatment (e.g. rejection of pottery). Thus, due to an increasing production of wastes and their inappropriate management in urban areas, this estuary received multiple anarchic rejections and sheltered the main uncontrolled garbage dumps of the Rabat-Salé-Zemmour-Zaër region, which generated releases of leachates estimated at 36.000

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m^3/year. This was the Oulja landfill located on the right bank of the Bouregreg (Salé) and the Akreuch landfill on the left bank of the Bouregreg (Rabat) (Fig.1A). Similarly, the proximity of these wild landfills and their establishment in the bed of the Bouregreg estuary, generate direct and indirect negative effects on the quality of groundwater and surface water, on the quality of the soil, on the quality of the atmosphere and therefore risks to public health. On the other hand, by its topography, the Bouregreg valley is also the seat of several areas of accumulation of rainwater, which by run-off its waters move all sorts of special and inert waste (rejection of pottery, demolition products) in the Bouregreg Estuary (the final outlet). Finally, these numerous natural and / or anthropogenic factors observed along the two banks of the Bouregreg estuary (pottery, quarries, liquid and solid discharges) certainly affected the ecological balance of this estuarine ecosystem.

To remedy these problems, in 2006 the Estuary of Bouregreg was the subject of a project of depollution, which falls within the framework of the project of development of the valley of Bouregreg, in order to preserve this historical site of the various source's nuisances. And this by carrying out several ecological actions such as: the removal of about twenty wastewater discharges along both banks of the estuary (Fig.1A), the interception of urban discharges from Rabat and Salé to send them to emissaries at sea (projected north of the Salted side and south of the Rabat side), Aïn Aouda wastewater treatment by the realization of a wastewater treatment plant, the rehabilitation and closure of the Oulja and Akreuch landfills, the rehabilitation and reforestation of abandoned quarries upstream of the estuary (Fig.1B), the construction of the inter-municipal waste treatment center of Oum Azza and the construction of the wastewater treatment plant in Rabat. However, despite all these positive actions deployed, the estuary of Bouregreg, following the demographic explosion of two riverside cities Rabat and Salé, continues to undergo some human disturbances, namely the reception of wastewater discharges of different nature (even at low flow): domestic discharge (Bettana discharge), mixed or industrial discharge (industrial zones of Takkadoum) [2].

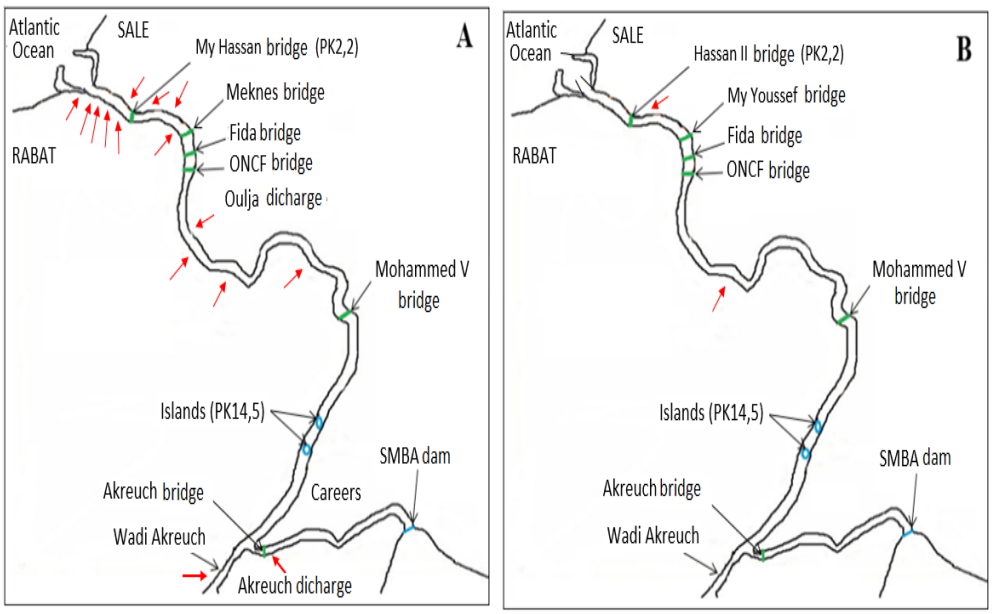

Fig. 1. Location of discharges along the Bouregreg Estuary.
A: before the development project, B: after the development project

Material and Methods

The Bouregreg estuary, which is the subject of this study, is one of the main rivers in the Moroccan river system. Located on the Atlantic coast of Morocco, this stretch of sea separates two large urban agglomerations Rabat and Salé (34° 02′ 09″ North, 06° 50′ 07″ West), limited upstream by the dam of Sidi Mohammed Ben Abdellah (SMBA) and towards the downstream by the two sandy beaches of Rabat and Salé. This stream measures on average 23 km long and 150 m wide.

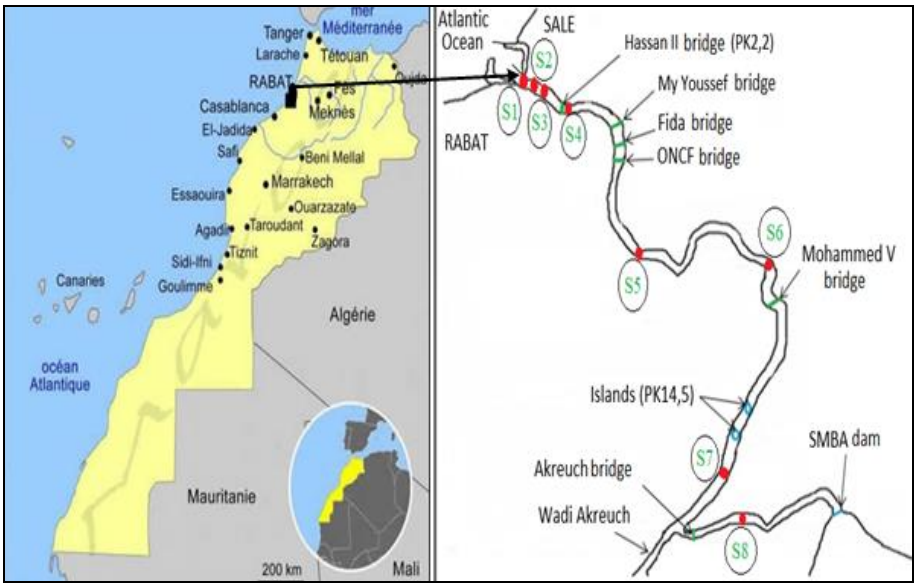

Fig. 2. Location of study stations along the Bouregreg estuary

In order to evaluate the impact of the depollution project on the quality of the estuarine Bouregreg ecosystem (water, sediment and benthic macrofauna), eight study stations have been chosen, from downstream (the mouth) towards upstream of the estuary (20 km) (Fig. 2). The choice of sampling sites considered the ease of access to samples, the choice of previous work, the lithological heterogeneity, and especially the distribution of anthropogenic activities along the Bouregreg estuary.

Our various samples of water, sediment and benthic macrofauna were collected during six campaigns of studies throughout the year 2014 - 2015.

The objective of this study is to establish the current state of the Bouregreg estuary after the realization of the depollution project, based on the spatio-temporal comparison of several indicators of evolution in the quality of aquatic ecosystems.

Water

In order to evaluate the physicochemical quality of the waters of the Bouregreg estuary, seven physicochemical parameters were measured (electrical conductivity, dissolved oxygen, organic matter, mineral matter, biochemical oxygen demand - BOD_5, nitrates and orthophosphates) according to the methods approved by RODIER 2009 [3]. However, the enumeration of bacteriological parameters (faecal coliforms and fecal streptococci) was performed using the indirect method of multiple tube fermentation in selective media [3].

Sediment

At the level of each study station (Fig.1), a sediment sample is taken using a corer. In the laboratory, the sediment was dried at 60°C until complete dehydration. A quantity of 200g of

dried sediment was washed on a 63 µm sieve. The difference between the initial weight and the dry weight of this refusal allows obtaining the percentage of mud. This same refusalis was dried and then sieved on a column of 15 AFNOR-type sieves (from 63µm to 2000µm). Considering the classification of Chasse and Glémarec (1976) [4], we have identified tree fractions: mud (< 63µm), fine sands (between 63 - 500 µm) and coarse sands and gravels (between 500 – 2000 µm). Each station is represented by the average values of the three fractions.

Thus, a sediment sample from each study station is also used for the determination of metal trace elements (Cd, Cr, Cu, Pb and Zn). For this, our samples were acidified during digestion by the addition of 1 mL of nitric acid and 3 mL of chloridric acid. These samples were analyzed by ICP-AES (Induced Plasma Coupled Atomic Emission Spectrometry) in the laboratory of the National Center for Scientific and Technical Research of Rabat (Morocco).

Benthic Macrofauna

Sampling of benthic macrofauna is carried out at low tide in the intertidal zone of the Bouregreg estuary, using a flat spade [5, 6], in an area of 0.25 m² and a depth of 30 cm [6, 7].

After sampling, sieving was carried out on site using a 1 mm² sieve. In the laboratory, the residues are carefully sorted and the benthic macrofauna was isolated and preserved in 70% ethanol before identification and counting operations using a dissecting microscope.

Results and Discussion

Water

The bacteriological quality of the waters of the Bouregreg estuary shows an improvement after the realization of the depollution works, where the concentration of fecal coliforms (FC) increased from 2.4×10^7 FC/100 mL before the development project [8], to 4×10^6 FC/100 mL after the development project, and that of faecal streptococci (FS) increased from 2.4×10^6 FS/100 mL [8] to 6×10^4 FS/100 mL after the development project. However, despite the decrease in bacterial load after the development project, the high concentrations show the impact of the activities frequently carried out along the Bouregreg estuary (fishing, jet skiing, swimming and some discards) by the population riverside areas of Rabat and Salé.

However, from a physico-chemical point of view, the electrical conductivity increased from 45 mS/cm before the development project [9] to 50.52 mS/cm after the development project and the dissolved oxygen level increased from 5.50 mg/L before the development project [9] to 6.75 mg/L after the development project. The increase of the electrical conductivity in the waters of this estuary reflects a high mineralization mainly due to the construction of the SMBA dam (in 1974) upstream, which stopped all freshwater supply and consequently the Bouregreg estuary has since been transformed into arm of the sea, powered by marine waters at the mouth. However, the increase in the dissolved oxygen level clearly shows the improvement of the water quality of this estuary after the many positive actions provided by the depollution project, especially after the construction of the new dike and the role of pressure it exerts to penetrate a large quantity of marine water, in order to constantly renovate and dilute the waters of the Bouregreg estuary.

However, we note that the nitrates decreased from 31 mg/L [10] before the development project to 23.56 mg/L after the execution of this project, the orthophosphates went from 1.75 mg/L [9] at 0.22 mg/L, mineral matter decreased from 103.6 g/L [10] to 34.02 g/L, organic matter increased from 11.6 g/L [10] to 4.39 g/L and BOD_5 increased from 150 mg O_2/L [9] to 28 mg O_2/L. The fall of concentration of these water pollution indicator parameters after the development project, clearly shows the improvement of the physicochemical quality of water in the Bouregreg estuary follows the elimination of several sewage discharges of various kinds (urban and industrial), as well as the elimination of leachates through the closure and rehabilitation of the two landfills in the region (Oulja and Akreuch dumps) (Fig.1B).

Table 1. Comparison of the maximum values of the main parameters measured before and after the development project

Main measured parameters	Before the development project	After the development project (present study)
Conductivity (mS/cm)	45	50.52
Nitrate (mg/L)	31	23.56
Orthophosphate	1.75	0.22
Dissolved Oxygen (mg/L)	5.50	6.75
Mineral matter (g/L)	103.60	34.02
Organic matter (g/L)	11.60	4.39
BOD_5 (mg O_2/L)	150	28
Faecal coliform (FC/100mL)	2.4×10^7	4×10^6
Faecal streptococci (FS/100mL)	2.4×10^6	6×10^4

Sediment

Granulometry

In order to evaluate the place of the granulometry in the variability of the benthic macrofauna along the intertidal zone of the Bouregreg estuary, we determined the sedimentary texture and we followed its evolution over time.

Dimensional analyzes (granulometry) made it possible to characterize the sediment of the estuary based on three main granulometric fractions of which the fine fraction or rate of pelites (<63 µm), the sandy fraction or fine sand (63÷500 µm) and the coarse fraction or coarse sands and gravel (between 500 – 2000 µm) (Fig.3).

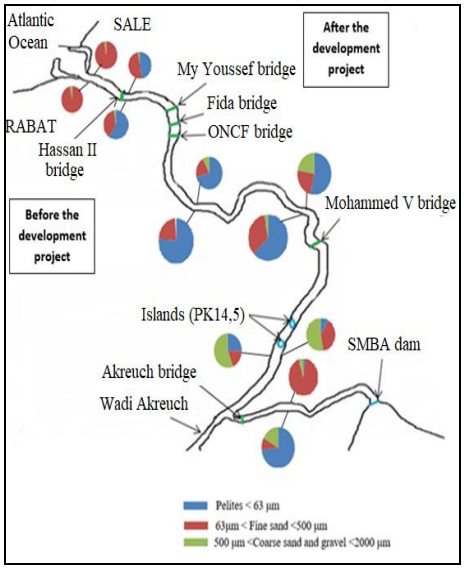

Fig. 3. Spatio-temporal evolution of the granulometric fractions that characterize the sediment of the Bouregreg estuary

In comparison with the work carried out previously, before the depollution project [9, 10], we note that the granulometry of the Bouregreg estuary has not changed too much over time. Near the mouth, it is always the fine sand that dominated under the effect of hydrodynamics after the construction of the SMBA dam upstream. In the middle part of the estuary, still dominates the very fine sands and the pelites. On the other hand, near the two islands, we notice that the rate of fine sands has increased compared to the rates of the pelites, this can be explained by the impact of the strong hydrodynamism to transport fine sands during

high tides upstream of this estuary (at 18 km). Where before the development project, the pelitic fraction predominated the sediment of this area of the estuary [10]. However, after the development project, this zone is currently rich in fine to very fine fraction, where coarse sands are not widespread [11].

Heavy Metals

The Bouregreg estuary has always been the seat of intense human activity following the rapid development of the two riverside towns of Rabat and Salé, leading to spills of various types of pollutants that certainly disturb the natural functioning of this estuarine ecosystem. The numerous organic pollutants and the various metallic trace elements introduced into this arm of the sea are distributed among the three compartments of the aquatic system: dissolved, particulate and organic phases. It is considered, however, that 99% of pollutants are stored in sediments [12], but once resuspended they cause serious (at high concentration) environmental problems with ecological, health and certainly economic consequences [13].

The present work aims to evaluate the degree of contamination of sediments of the Bouregreg estuarine after realization of the development project, and this through a spatio-temporal study of five metallic trace elements (Cd, Cr, Cu, Pb and Zn). We present in this part of the study, the results of two sampling campaigns, the first conducted in December 2014 (winter period) and the second in July 2015 (summer period) in order to see the behavior of these heavy metals according to the seasons.

The spatial evolution of the five metallic elements (Cd, Cr, Cu, Pb and Zn) shows that their distribution remains regular along the entire Bouregreg estuary. However, the temporal analysis of the metallic elements studied shows that they behave according to a seasonal rhythm, where the summer period corresponds to the maximum of the concentrations, and the low metallic concentrations coincide with the winter period.

During the summer period, the highest concentrations of the metal trace elements studied, are recorded in the downstream part of the Bouregreg estuary: Cu (7.45 mg/Kg), Cr (8.06 mg/Kg) and Cd (2.94 mg/Kg). This can be linked to the concentration of anthropogenic activities at the mouth of this estuary especially during the summer: fishing, swimming, restaurants. However, low levels of zinc (0.18 mg/Kg) and lead (1.05 mg/g) were recorded during this study period (summer period).

During the winter period, the low metal concentrations: Cu (1.53 mg/Kg), Cd (1.87 mg/Kg, Cr (3.54 mg/Kg), recorded in the superficial sediment of the stations located at the mouth of the Bouregreg estuary, is explained by the fact that this area is subject to a very agitated marine environment, which seems to disturb the trapping of metals by its sediment. However, the high levels of lead (17.92 mg/Kg) and zinc (13.62 mg/Kg) recorded at the mouth during this study period (winter period) could only be explained by contamination accidentally through the runoff of rainwater, that flow all the impurities in the estuary of Bouregreg. In the case of lead, the contamination is direct by the atmospheric deposition released by the exhaust pipes of the engines of the vehicles [14], but in the case of zinc the contamination seems to be indirect and this after the leaching of the uncontrolled garbage deposited frequently along the mouth of the estuary of Bouregreg.

The comparison of our results with a study carried out in the first years of the development project [15], shows a significant decrease in heavy metal concentrations, where average values of chromium (27 to 82.14 mg/Kg) and of the lead (8 to 18.17 mg/Kg) were significantly elevated compared to the concentrations recorded in this study (after realization of the development project). This may be related mainly to the role played by the new dike (Fig.1B) in the propulsion of a large amount of marine water felt even at the foot of the dam SMBA (upstream), which certainly allows to suspend the surface layers of the sediment in the Bouregreg estuary, and therefore prevent the trapping of the metal trace elements on their surface.

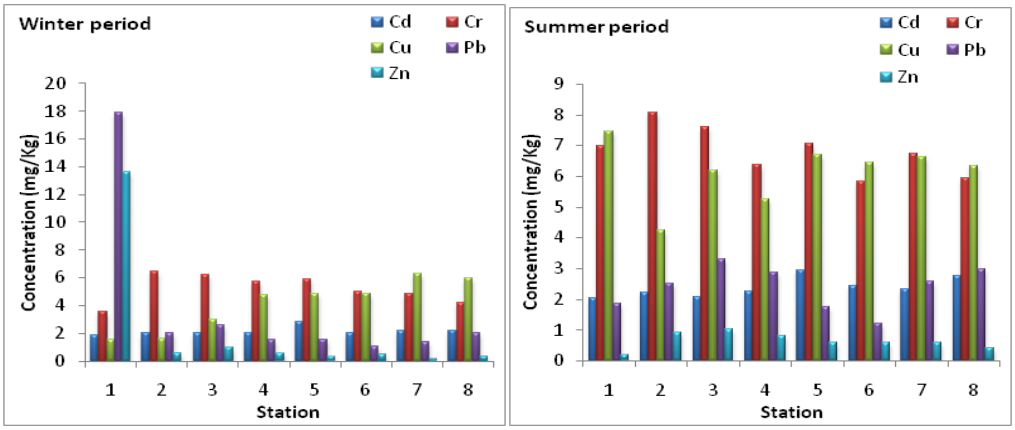

Fig. 4. Spatio-temporal evolution of metallic trace elements in sediment of the Bouregreg estuary

Benthic Macrofauna

Benthos and macrofauna, are considered as good indicators of environmental changes [16]. In fact, the macrofauna populations integrate the variations of the environment, and their appearance at the moment of observation (composition, biomasses, abundances, diversity) is the result of these conditions [17].

The assessment of the state of health of aquatic ecosystems disturbed or not, requires a good prior knowledge of its benthic populations, the provision of a reference state that must be both qualitative and quantitative. This is the case of the Moroccan Atlantic estuary of Bouregreg, which has been well studied from the point of view of water quality, but which remains little known and little studied from the point of view of macrozoobenthic stands, insofar as only one study was conducted before the construction of the Sidi Mohammed Ben Abdellah dam (SMBA) in 1974 [18] and two others after its construction [9, 10].

These last diagnoses revealed a disturbed state of this estuarine ecosystem with a level of pollution, generally related to numerous human activities practiced along both shores of this estuary (pottery, quarries, liquid and solid discharges) (Fig.1A), and whose consequences certainly influenced the ecological balance of this ecosystem. In this sense, and in order to improve its overall quality (ecological, sedimentological, bacteriological), the Bouregreg estuary depollution project was launched in 2006.

After the execution of the depollution project, it was necessary to carry out the present study, with the aim of supplying a last diagnosis on the health of this aquatic ecosystem and to reveal the impact of the last environmental modifications on the spatio-temporal evolution of macrozoobenthic settlements in this arm of the sea.

The comparison between the studies carried out before the development project [9, 10] and the present study shows the conservation of the three dominant zoological groups of estuaries and Moroccan lagoons: molluscs, polychaetes and crustaceans. However, the relative importance of these three zoological groups changes spatially but also temporally (Fig.5). Their spatial variation depends on the type of sediment, the impact of hydrodynamics, but also the water quality of each part of the estuary.

Prior to the development project, the predominant taxa prior to the construction of the SMBA dam were crustaceans (28 species), polychaetes (24 species) and molluscs (12 species) [18]. After the construction of the dam, polychaetes predominated qualitatively with 17 species, followed by crustaceans (11 species) and molluscs (9 species) (Fig.5). However, after the depollution project, the qualitative succession became as follows: molluscs (47 species), crustaceans (13 species) and polychaetes (22 species). Thus, species richness has undergone a significant change, from 74 species (before dam construction) to 52 species in 1986 [10], then

to 41 species in 1998 [9] (after construction of the dam), and currently 90 species (after the development project) [11]. This significant increase in the number of species after the Bouregreg estuary depollution project, testifies to an improvement of the conditions of the environment, following to the improvement of the water quality and the decrease of the metallic load which have certainly favored the repopulation of the species.

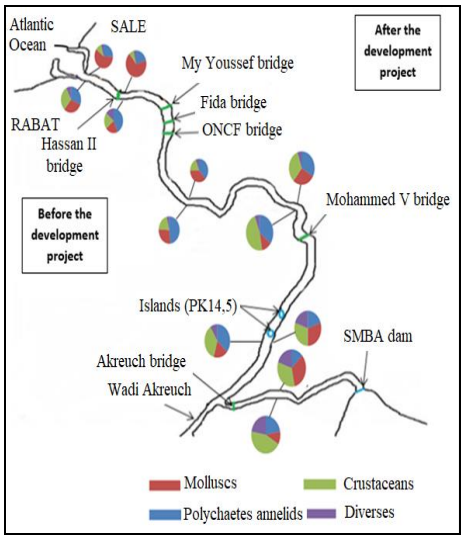

Fig. 5. Spatio-temporal distribution of the number of species by taxonomic groups

Correlation Matrix

Numerous toxicological studies have analyzed the effects of the pollution indicator parameters on the Bouregreg aquatic system ecosystem by taking them separately. However, the action of each of the parameters studied depends in many cases on other elements that coexist with it (in the same time and environment), without neglecting the role of environmental factors. In this sense, and to systematically explore the relationship between the different quality parameters of this sea-arm, a correlation matrix has been calculated. Table 2 shows the correlation coefficients between all the parameters studied in this study. Variations in organic matter content largely depend on the type of sediment. A positive correlation of 0.88 value between organic matter and the rate of pelites shows the ability of the pelites to adsorb and trap the organic load on their surface [19]. In addition, we note significant correlations between the kilometric point on the one hand with the conductivity (-0.925) and on the other hand with the mineral matter (-0.989) (Table 2). These negative correlations show that these two parameters decrease with distance from the sea. It is therefore concluded that their spatial evolution follows a decreasing gradient from downstream to upstream. On the other hand, from the metallic point of view, we notice a strong significant correlation of around 0.879 value between lead and zinc, which makes it possible to envisage, in their actions, the possibility of a synergy.

Conclusion

The comparison of the different parameters indicating the quality of the Bouregreg estuary, before and after the execution of the development project, shows that the many positive actions provided by the depollution project have certainly contributed to the evolution of this arm of the sea, from a polluted environment to a healthy ecosystem by the improvement of the quality of water, the decrease of the metallic load as well as the dominance of the zoological group of molluscs (healthy ecosystem indicator) instead of annelids (pollution indicator).

Table 2. Correlation matrix between the different parameters studied (Kp: Kilometric point; CS: Coarse Sand; OM: Organic Matter; MM: Mineral Matter; FC: Faecal Coliform; FS: Faecal Streptococci)

	Kp	Pelites	FineSand	CS	Gravels	Cd	Cr	Cu	Pb	Zn	OM	MM	BOD_5	Conductivity	Nitrate	Orthophosphate	Dissolved oxygen	FC	FS
Kp	1.000																		
Pelites	0.656	1.000																	
FS	-0.704	-0.861	1.000																
CS	0.567	-0.087	-0.391	1.000															
Gravels	0.749	-0.028	-0.474	0.821	1.000														
Cd	0.652	-0.225	0.080	0.203	0.240	1.000													
Cr	-0.548	-0.306	0.331	0.015	-0.179	-0.218	1.000												
Cu	0.713	0.315	-0.527	0.208	0.601	0.379	-0.678	1.000											
Pb	-0.445	-0.554	0.647	-0.384	-0.250	-0.397	-0.061	-0.283	1.000										
Zn	-0.400	-0.310	0.428	-0.370	-0.242	-0.341	-0.207	-0.295	0.879	1.000									
OM	-0.507	0.880	-0.526	-0.466	-0.484	-0.313	-0.110	-0.003	-0.410	-0.228	1.000								
MM	-0.989	0.080	0.214	-0.464	-0.574	-0.736	0.516	-0.723	0.433	0.434	0.331	1.000							
BOD_5	-0.418	0.704	-0.472	-0.065	-0.401	-0.475	0.116	-0.374	-0.390	-0.221	0.787	0.474	1.000						
Conductivity	-0.925	-0.307	0.539	-0.469	-0.522	-0.409	0.603	-0.700	0.570	0.467	-0.028	0.868	0.072	1.000					
Nitrate	0.553	-0.659	0.269	0.472	0.661	0.449	-0.039	0.250	0.233	0.209	-0.884	-0.505	-0.851	-0.195	1.000				
Orthophosphate	0.322	0.779	-0.865	0.186	0.406	-0.056	-0.375	0.487	-0.479	-0.135	0.488	-0.205	0.290	-0.523	-0.080	1.000			
Dissolved oxygen	0.691	-0.701	0.335	0.443	0.591	0.648	-0.124	0.369	0.127	-0.005	-0.884	-0.683	-0.894	-0.296	0.918	-0.267	1.000		
FC	-0.337	0.796	-0.394	-0.551	-0.604	-0.262	-0.081	-0.153	-0.306	-0.068	0.966	0.429	0.777	0.117	-0.860	0.410	-0.885	1.000	
FS	-0.372	0.899	-0.614	-0.354	-0.340	-0.446	-0.220	0.030	-0.223	-0.011	0.916	0.446	0.786	0.077	-0.821	0.535	-0.884	0.901	1.000

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