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# Water Quality Modelling of the Sebou River Estuary (Morocco) before and after the Installation of the Kenitra City's Wastewater Treatment Plant

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**ABSTRACT**

Urban wastewaters from Kenitra had been discharged without prior treatment through six collectors into the Sebou estuary (60 km) causing in the process health and environmental problems up until WWTP was installed in 2020. The waste water treatment plant (WWTP) had to gather all urban wastewaters in order to go through treatment. Thus, the WWTP, situated 17 km from the mouth of the estuary, has become the only discharge point for treated domestic wastewater into the Sebou estuary. This study aims to model the Sebou estuary water quality and assessment of the impact of WWTP. Our study started with hydraulic modelling of the river using a 1D model (HECRAS 5.0.6), since water quality is strongly depending on hydraulic regime. HEC RAS has been calibrated and validated using hydraulic and morphological database of the years 2019 and 2021. The spatiotemporal evolution of hydraulic variables (water velocity, water level, etc.) was calculated by the hydraulic model and used in the water quality module to simulate the biochemical oxygen demand ($BOD_5$). Two scenarios were put under examination, one is a simulation of discharges of untreated wastewaters by six collectors (mean $BOD_5$ of 300 mg/L) and the second is a simulation of discharge after treatment at the WWTP (mean BOD5 of 24 mg/L). The simulation showed an impact of the tidal cycle and fresh water flows (coming from the upstream) on the urban wastewater discharges fate. Calculations of the $BOD_5$ provided by the model are in good agreement with field measurements. The first simulation results show that water quality of the Sebou River does not meet WHO standards (average quality about 7 mg/l of $BOD_5$). The second simulation shows that the treatment plant reduces the concentration of $BOD_5$ in the river to about 3 mg/l compared to the case before their installation, the quality of the water in the estuary is changing to become good after having been just average. In addition, the $BOD_5$ concentration downstream of the WWTP changes according to the tidal cycle. Finally, the results show the very positive impact of Kenitra's WWTP on the water quality of the Sebou River estuary.

**Keywords:** Sebou estuary, water quality, modelling, HEC-RAS, $BOD_5$, Kenitra.

## INTRODUCTION

Water is of a paramount importance for the survival and progress of human civilization, it is a vital element in human life and activity. Across the world, water is used in all daily activities either in housing, industry, agriculture, economy, or energy, which makes it a receptor element susceptible to all kinds of pollution. This phenomenon is one of the main causes of water resources limitation. Water shortage is a limiting factor for the development of social and economic sectors of a country. A major goal is to establish policies for sustainable management and governance rules to ensure water resources sustainability (Kettab, 2014).

The traditional water supply in Morocco suffers from scarcity and irregularity. Water-intensive activities and climate change effects are main factors behind this problem (Fennell et al. 2022). As a matter of consequence, we are obliged to find other alternative of water resources which have not yet been put under exploitation e.g. estuary water (Haddout et al., 2016). Hydro-biologically speaking, estuaries or areas of freshwater/saltwater interface are distinguished by specific hydrodynamic features (Haddout et al., 2019). The demographic growth, coupled with the rapid urbanization, has increased the water consumption thereby polluting the rivers basins. Domestic and municipal waste, agricultural activities, run-off, industrial activities and sand mining are all factors causing rivers' pollution and leading to impacts that can be seen clearly in these very fragile ecological balance areas (Wahaba et al., 2019). Also, they are contaminated by point source pollution and non-point source pollution. Besides, it is mandatory to have control over these problems and prevent them through determining the water quality variations (Mergaoui et al. 2003).

The Sebou River is draining in the northwest of Morocco an area estimated by nearly 40,000 km$^2$, amounting to 5.5% of the total area of the country, and running from its source in the central Atlas Mountains to the Atlantic Ocean, a distance of 614 km. Sebou estuary (60 km) is situated between the Lalla Aicha storage dam and the mouth which represents the outlet of Sebou basin (Figure 1). Its flow regime knows seasonal and numerous fluctuations following the tidal regime and the control of numerous dams (Mergaoui et al., 2003; Haddout, et al., 2019). The role of Lalla Aicha dam is to keep enough water for agricultural pumping stations and to avoid upwelling of salty waters toward these stations (El-Blidi & Fekhaoui, 2003; Haddout, et al., 2019).

A significant amount of wastewater heads from Kenitra (about 17 km from the mouth) to Sebou estuary, and this amount is increasing because of the demographic growth, as well as the agricultural and industrial effluent discharges which are loaded with a variety of contaminants susceptible to temporarily damage the quality of Sebou estuary waters at concentration levels exceeding their standards values in an aquatic environment. Before 2020, water was discharged without prior treatment through six collectors into Sebou estuary (Nizar & Igouzal, 2022a). Therefore, the main aim of constructing the wastewater treatment plant (WWTP) in Kenitra was to convey the wastewaters and to put them under treatment, thus making WWTP the only discharge point for Sebou estuary (Nizar et al., 2022b). This study tends to model Sebou estuary water quality and simulate the future of the discharges from the six collectors before installation of the WWTP, and simulate the future of the discharges

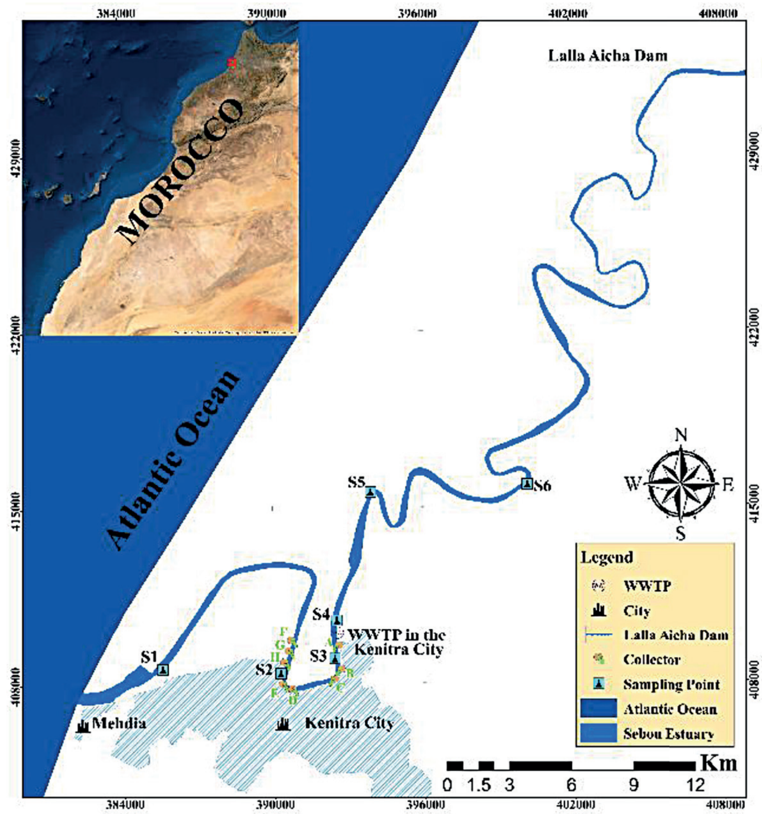


**Figure 1.** Study area

from the WWTP after their installation (Nizar et al., 2022b). The WWTP has a noteworthy importance in minimizing the inlet load of Sebou estuary and it is very significant to observe and assess its impact and efficiency (Nizar et al., 2022b). Water quality is influenced by the tidal hydraulic regime of the estuary, which is being characterised by a filling at high tide through the bottom of the river and by an emptying at low tide (El-Blidi & Fekhaoui, 2003). The semi-diurnal tidal amplitude ranges from 0.97 to 3.11 m and the tides influence extends to 35 km from the mouth (El-Blidi & Fekhaoui, 2003). Furthermore, because the Sebou estuary is narrow, wind has a negligible effect on the flow (Ji, 2008).

A number of scholars quantitatively classified estuaries on stratification by means of dimensionless numbers, such as Estuarine Richardson number NR (Fischer, List, Koh, Imberger, & Brooks, 1979) and estuary number Ne (Thatcher & Harleman, 1981; Haddout, et al., 2019). According to water column stratification, Sebou estuary can be classified as partially mixed (Haddout et al., 2017a) (Haddout et al., 2017b; Haddout, et al., 2019).

Early studies on water quality of Sebou estuary have been carried out since 1966 (S. Haddout, 2016; Mergaoui et al., 2003; Nizar & Igouzal, 2022a; Combe, 1996; Nizar et al.,, 2022b; Nizar et al., 2022c; Haddout, et al., 2019) showed that the physico-chemical quality of Sebou River estuary does not meet the WHO standards for discharges into the natural environment. All of these studies recommended the construction of a WWTP to treat urban wastewaters of Kenitra. However, these studies did not showcase the influence of pollution evolution by hydrodynamic and morphological conditions. Managerially speaking, the managers are seeking rapid estimation of longitudinal pollution distribution in alluvial estuarine. One-dimensional mathematical models can be the appropriate tools for usage because they are easy for application, and more adapted to management contexts. Furthermore, it is methodologically correct to begin with the most basic description of the phenomenon under study and assess the limits of this approximation before investigating on more issues that are complicated.

Since water quality is strongly linked to the hydraulic regime, the HECRAS software was used to model the estuary hydraulic regime. The hydraulic module has been calibrated and validated using a large hydraulic and morphological database. The hydraulic module outputs (water velocity, water level, depth etc.) were used in the water quality module to simulate the biochemical oxygen demand ($BOD_5$). To model water quality and assess the impact of Kenitra's WWTP, two scenarios were put under examination: one is a simulation of release before installation of the WWTP and the second is a simulation of release after their installation. The two simulations showed an impact of the tidal cycle and freshwater flows (coming from the upstream) on the fate of the discharges in the river.

The results demonstrated that the physico-chemical quality of Sebou River estuary does not meet the national standards for discharges into the natural environment, similar results were found by (Nizar & Igouzal, 2022a; Nizar et al., 2022c) which also demonstrated the good impact of the treatment plant on the attenuation of $BOD_5$ in the river, analogous results were obtained by (Nizar et al., 2022b). The simulations provided other answers such as the release dispersion and the residence time in the estuary. This study proves the validity of the recommendations found in previous studies concerning the need for the installation of a WWTP in the city of Kenitra. The WWTP is very effective for the treatment of urban wastewater that now meet national standards.

## MATERIALS AND METHODS

### Processing methods used

The $BOD_5$ was measured at the laboratory of RAK (Kenitra's Autonomous Water and Electricity Distribution Agency). The BOD system was used for $BOD_5$ measurement. This system can measure BOD based on the manometric principle. The Manometric respirometers bind the uptake of oxygen to the change in pressure caused by oxygen consumption while keeping a constant volume. It is important to mention that the BOD level of a sample relies on the amount of the organic matter available, which can mark considerable variation. The BOD measuring system is therefore calibrated according to the volumes of various samples under study. Furthermore, temperature equalisation is necessary before doing biological testing, as temperature has a major impact on biological activity. BOD measurements are performed in a thermostatically controlled cabinet at 20 °C (Rahmati et al., 2021).

## Hydrodynamic model

In this study, we used a one-dimensional approach, which is appropriate in the case of the river reach having long distance. An HEC-RAS mathematical model was employed, which was adopted to simulate the hydrodynamic regime, sediment transport, and water quality for many rivers (Brunner, 2016; Sathya et al., 2021). Water quality is influenced by the Sebou estuary's hydrodynamic regime, which in turn relies highly on the river morphology. The HEC-RAS model is based on the one-dimensional conservation equations of mass and Barré Saint-Venant momentum, which are defined as follows (Brunner, 2016):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_1 \tag{1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (QV)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \tag{2}$$

where: $Q$ – the discharge (m$^3$ s$^{-1}$); $V$ – the velocity (m s$^{-1}$); $A$ – the cross-sectional area (m$^2$); $x$ – the distance along the channel (m); $t$ – the time (s); $q_l$ – the lateral inflow per unit length (m$^2$ s$^{-1}$); $g$ – the acceleration due to gravity (m s$^{-2}$); $Z$ – the flow depth (m); $S_f$ for the frictional slope (Dimensionless).

The frictional slope is expressed as (Brunner, 2016):

$$S_f = \frac{\mathrm{Q}|\mathrm{Q}|\mathrm{n}^2}{2.202\,A^2R^{4/5}} \tag{3}$$

where: $n$ – Manning's roughness coefficient (m$^{-1/3}$s$^{-1}$); $R$ – the hydrodynamic radius (m).

The empirical formula established by Cowan and Chow is used to evaluate initially the Manning coefficient used in the momentum equation:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4).m_5 \tag{4}$$

where: $n_0$ – the basics; n – the value for a straight, uniform, and smooth channel; $n_1$ – the adjustment for the effect of surface irregularity; $n_2$ – the adjustment for the effect of variation in shape and size of the channel cross section, $n_3$ – the adjustment for obstruction, $n_4$ – the adjustment for vegetation; $m_5$ – a correction factor for meandering channels.

The factor $n_0$ is evaluated using granulometric data taken in the examined reach from upstream to downstream. The other coefficients were evaluated using observations of the river in aerial photos, from the cross-sectional areas and accessible photos, and field visits (Haddout, 2016). The Equations 1 and 2 are solved by the four-point implicit box finite difference scheme. The general forms of derived equations for a function *f* are (Brunner, 2016):

- the time derivative:

$$\frac{\partial f}{\partial t} \approx \frac{\Delta f}{\Delta t} = \frac{0.5\left(\Delta f_{j+1} + \Delta f_j\right)}{\Delta t} \tag{5}$$

- the spatial derivatives:

$$\frac{\partial f}{\partial x} \approx \frac{\Delta f}{\Delta x} = \frac{\left(f_{j+1} - f_j\right) + \theta\left(\Delta f_{j+1} - \Delta f_j\right)}{\Delta \mathrm{x}} \tag{6}$$

- function value:

$$f \approx \bar{f} = 0.5\left(f_{j+1} + f_j\right) + 0.5.\theta.\left(\Delta f_j + \Delta f_{j+1}\right) \tag{7}$$

where: $\theta$ – weighting factor. In HEC-RAS, the default value of $\theta$ is 1 (S. Haddout, 2016).

Finding a solution to the equations system need to spatially discretize the section into characteristic grids and define the river geometry, the conditions of the initial flow and the upstream and downstream boundary. Then, the estuary is discretized into 39 grids with a length between 38 and 157 m, an average value of 97 m. For each grid we have specified the length, the cross section and the Manning friction factor.

## Transport model

The HEC-RAS water temperature model solves the one-dimensional advection-dispersion equation for thermal energy with additional terms to account for lateral inflow, solar radiation, and heat exchange with the atmosphere and the bed of the river. Lateral inflow represents additional water entering the model domain as surface inflow, overland flow, cross flow, and groundwater discharge. The heat transport equation is given as follows (Brunner, 2016):

$$\frac{\partial (VT_w)}{\partial t} = -\frac{\partial (QT_w)}{\partial x} + \frac{\partial}{\partial x}\left(AD_x\frac{\partial T_w}{\partial x}\right) + S_L + S \tag{8}$$

where: $V$ – the volume of the calculation cell (m$^3$); $Tw$ – the water temperature (°C); $t$ – the time (s); $Q$ – the flow (m$^3$ s$^{-1}$); $A$ – the cross-section of the channel (m$^2$); $x$ – the distance along the channel (m); $Dx$ – the dispersion coefficient (m$^2$ s$^{-1}$); $SL$ – the source/sink term representing the inward heat exchange time rate (°C m$^3$ s$^{-1}$); $S$ – the source/sink term representing the rate of change over time of the local external heat exchange (°C m$^3$ s$^{-1}$).

The description of contaminants transport in surface waters is generally made by the advection-dispersion equation which is a derivative of the equation of mass balance (Shehata et al., 2019). The BOD transport equation is given as:

$$\frac{\partial(AC_{BOD})}{\partial t} = -\frac{\partial(QC_{BOD})}{\partial x} + \frac{\partial}{\partial x}\left(AD_x\frac{\partial C_{BOD}}{\partial x}\right) - AK_1C_{BOD} + AR_{BOD} \quad (9)$$

where: $C_{DBO}$ – the concentration of organic matter (kg / m$^3$); $R_{BOD}$ – the release of organic matter (mg / l); $K_1$ – is the oxidation coefficient (days-1); $D_x$ – dispersion coefficient (m$^2$ s$^{-1}$), is key parameter that must be estimated appropriately.

An estimation of this important parameter is elaborated using Fischer equation (1979) (Brunner, 2016). Dispersion coefficient was estimated to 150.27 m$^2$ s$^{-1}$ basing on the Fischer formula.

## RESULTS AND DISCUSSION

### Water quality simulation results before installation of Kenitra's WWTP

Water quality of Sebou estuary was simulated for the period from May to August 2019. In water quality simulations, two scenarios were put under examination; the first being a simulation of release before installation of the WWTP, while the second is a simulation of release after their installation. Concerning the first simulation, raw urban wastewaters have an inflow into the river illustrated in Figure 2 and BOD$_5$ temporal variation shown in Figure 3. Figures 4, 5, 6, 7, 8 and 9 show simulated and measured results, of temporal evolution of BOD$_5$ for six stations along the estuary where we did field measurements (Figure 1).

The results show that the minimum concentration of the simulated BOD$_5$ does not drop below 2 mg/l, but the maximum value always exceeds 6 mg/l up to 8 mg/l, which indicates that the water quality of the Sebou estuary is average according to decree n°1275-01 of October 17, 2002 since it is between 5 mg/l and 10 mg/l. Furthermore, the discharged pollution moves according to the tidal cycles; meaning that it goes down when the tidal cycle is low, and goes up when the tidal cycle is high. Moreover at Point 1, the observed BOD$_5$ fluctuations are attributed to the fact that this point is located near the port of Mehdia which experiences the most significant oscillation, which in turn could be explained by the influence of dilution by the water at low tide. On the other hand, the results of measured BOD$_5$ observed between August 29 and 30 (Figure 4), at the level of the first point suggest a good agreement with the data simulated by HEC-RAS.

Regarding point 3, which is located in the middle of the waste water discharge zone, we note a correlation between the measured results and the simulated one. The BOD$_5$ concentration on August 16 exceeds 8 mg/l and only 4 mg/l on August 11 (Figure 6), and since these concentrations do not exceed 10 mg/l this means that the water quality of the estuary of the Sebou River at this point is average.

With regard to the last sampling point 6, the results reveal a good correlation between the simulated BOD5 and that measured, but what is impressive is that this sampling point records the

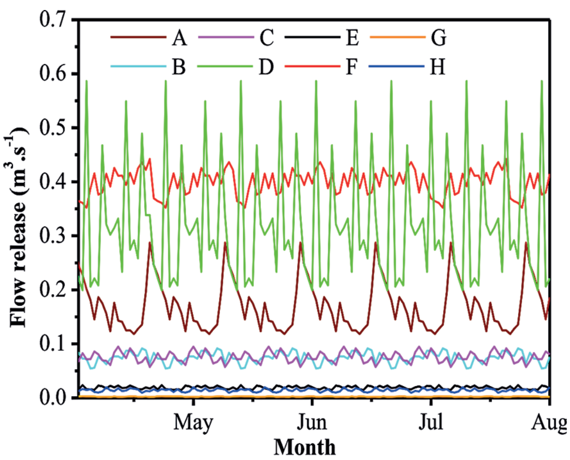


**Figure 2**. Raw water flow released by collectors (May 01, 2019 to August 31, 2019)

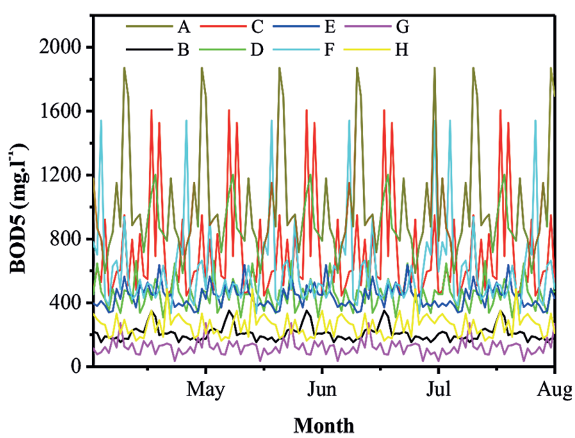


**Figure 3.** BOD$_5$ concentration of raw water, lateral condition (May 01, 2019 to August 31, 2019)

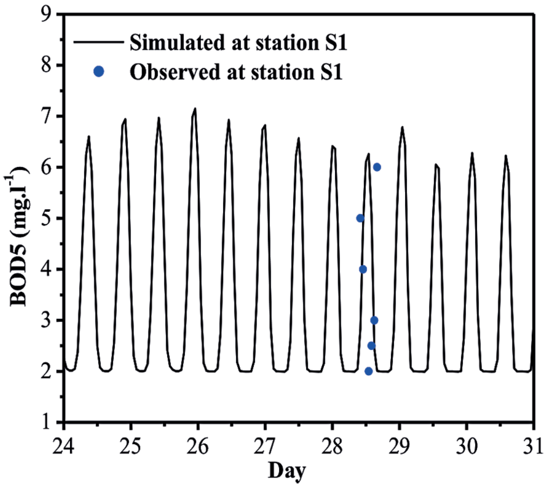


**Figure 4.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 1 in the case before installation of Kenitra WWTP

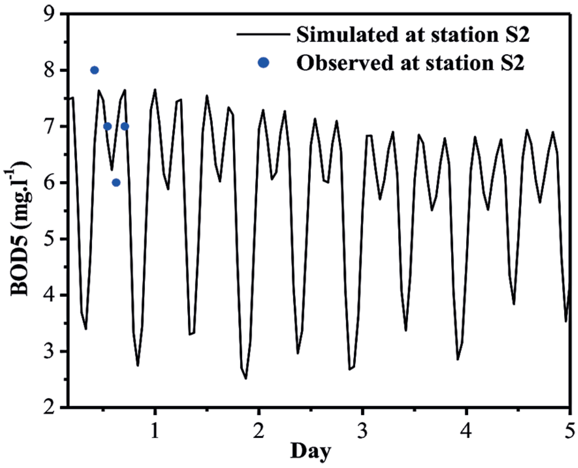


**Figure 5.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 2 in the case before installation of kenitra WWTP

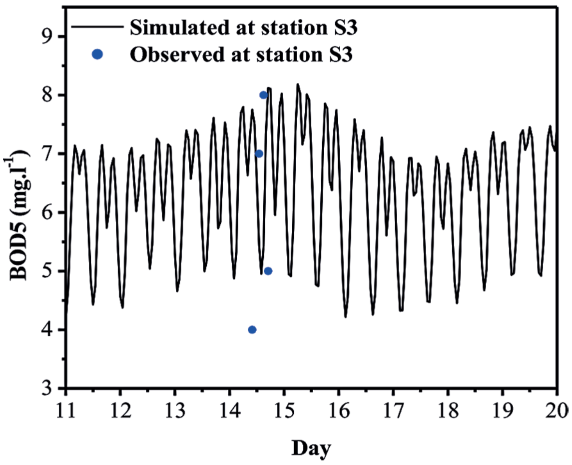


**Figure 6.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 3 in the case before installation of kenitra WWTP

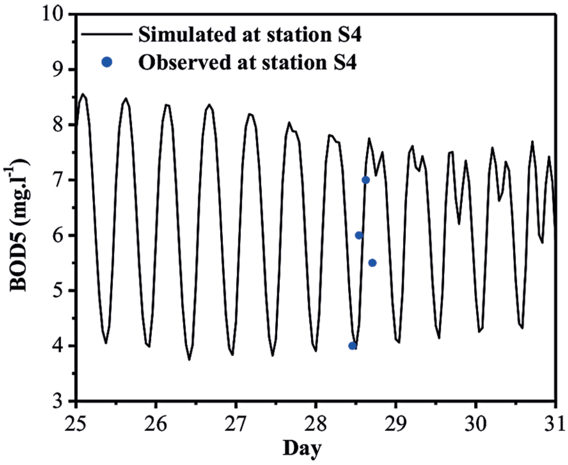


**Figure 7.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 4 in the case before installation of kenitra WWTP

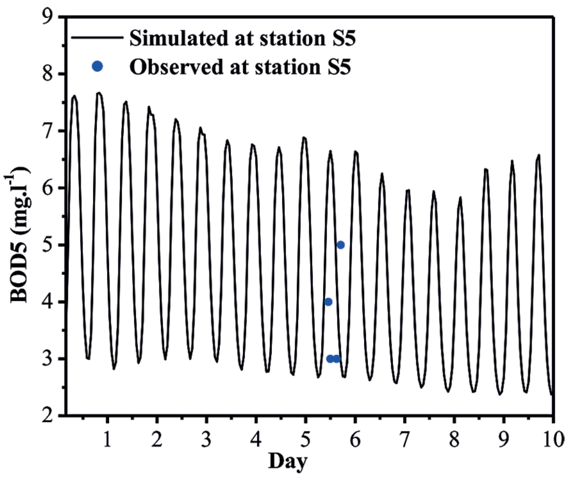


**Figure 8.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 5 in the case before installation of kenitra WWTP

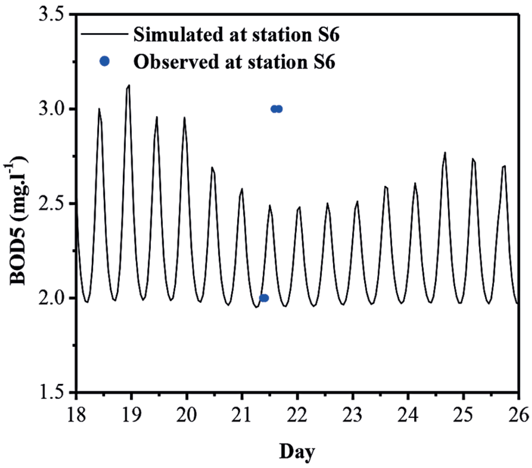


**Figure 9.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 6 in the case before installation of kenitra WWTP

lowest simulated BOD5 concentrations among all studied stations, with values ranging from 2 mg/l to 3 mg/l (Figure 9), which could be due to the fact that this sampling point is located near the Roman ruins of "Thamusida"; an isolated tourist area relatively far from the sources of pollution since it is surrounded by practically no factories as well as green surfaces and few people occupying them, in addition it is less influenced by the tide.

Figure 10 and 11, show longitudinal evolution of $BOD_5$ from downstream (river mouth, 0 km) to upstream (Lalla Aicha dam, 69 km) for high tide and low tide respectively. $BOD_5$ concentration increases either during upstream or downstream, but it is higher in downstream parts of the river. At high tide, the downstream concentration of the waste water discharge zone is greater than that at low tide; this is due to the effect of dilution by unpolluted continental waters. The pollution displaces on the basis of the tide cycles; that is, it moves downwards when the tide cycle is low, and moves upstream when the tide cycle is high and it's associated with an accumulation of the pollution in the downstream and the decrease in its amplitude by the dispersion and biochemical reactions. The increase in $BOD_5$ does not reach the areas located more than 30 km upstream of the mouth, similar results were observed by (Nizar et al., 2022b).

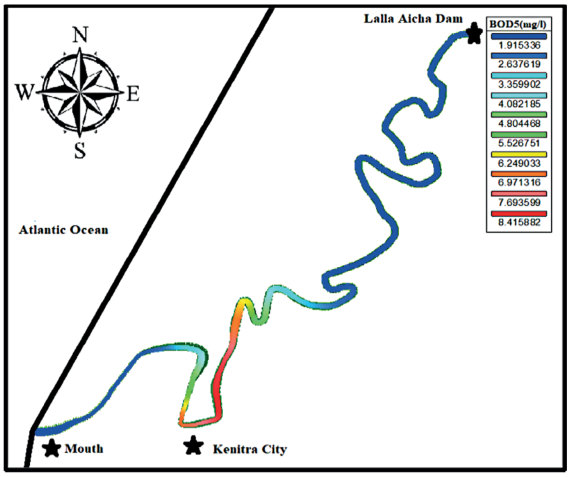


**Figure 10.** Longitudinal evolution of the $BOD_5$ in the case before installation of Kenitra's WWTP at high tide (August 23, 2019)

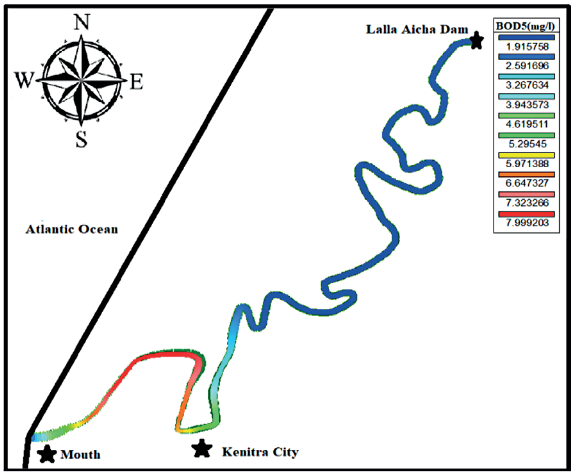


**Figure 11.** Longitudinal evolution of the $BOD_5$ in the case before installation of Kenitra's WWTP at low tide (August 20, 2019)

## Water quality simulation results after installation of Kenitra's WWTP

The second simulation of water quality concerns urban wastewaters after being put under treatment by the WWTP. Figure 12 represents the urban waters flow released into the river after treatment during period May 01, 2021 to August 31, 2021 and $BOD_5$ temporal variation shown in Figure 13. Figure 4, 5, 6, 7, 8 and 9, exhibit that the discharge of wastewater into the receiving environment of the Sebou River estuary without any type of treatment in 2019 had very negative effects which resulted in high levels of $BOD_5$. Figure 14, 15, 16, 17, 18 and 19, show an obvious drop in $BOD_5$ levels in sampling points in the simulated HEC-RAS results after installation of the WWTP, reaching a maximum value of only 3 mg/l compared to a value of 7 mg/l recorded before the installation of the WWTP, this means that according to decree n°1275-01 of October 17, 2002, the quality of the water in the estuary is changing to become good after having been just average, which subsequently demonstrates the undeniable positive impact of the sewage treatment plant in the city of Kenitra. On the other hand, the measured BOD results show that it also varies between 2 mg/l and 3 mg/l, especially when inspecting the period between July 25 and 28, 2021, thus demonstrating that the results are consistent between them, which prove the proper functioning of our HEC-RAS model in the validation phase.

When describing the evolution of BOD5 along the estuary during low and high tides before the implementation of WWTP (Figure 10 and Figure 11), we noticed that the concentration of $BOD_5$ sometimes resulted in 7.99 mg/l, while it weakened as we moved away from the discharge points. Figure 20 and 21 showed the results that

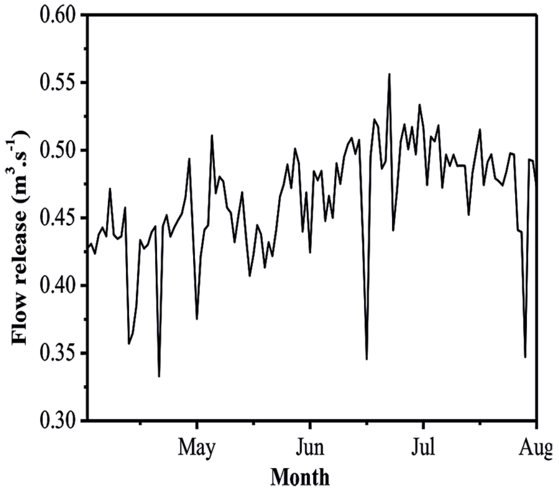


**Figure 12**.Treated water flow released by Kenitra's WWTP (May 01, 2020 to August 31, 2020)

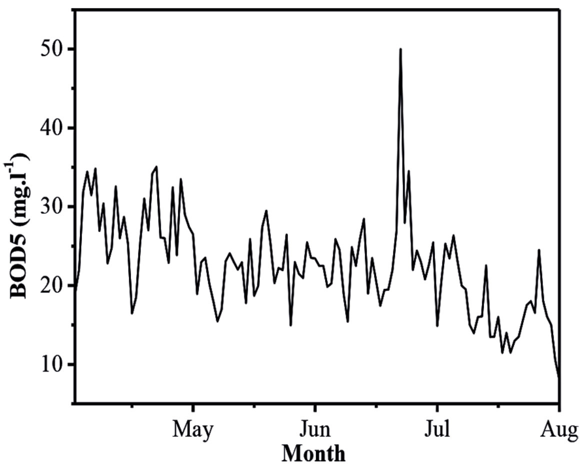


**Figure 13**. BOD5 concentration of water treated, lateral condition (May 01, 2020 to August 31, 2020)

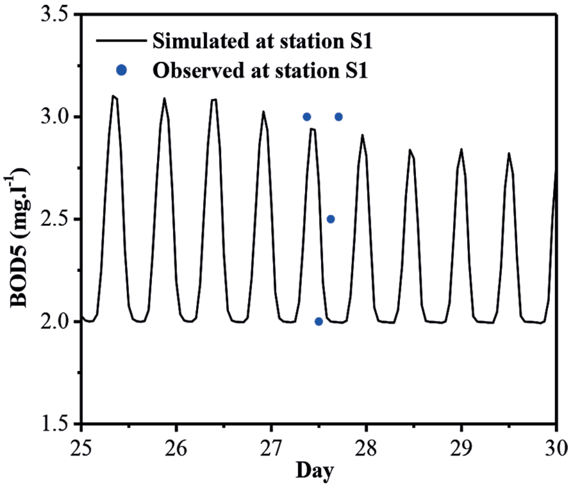


**Figure 14.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 1 in the case after installation of Kenitra WWTP

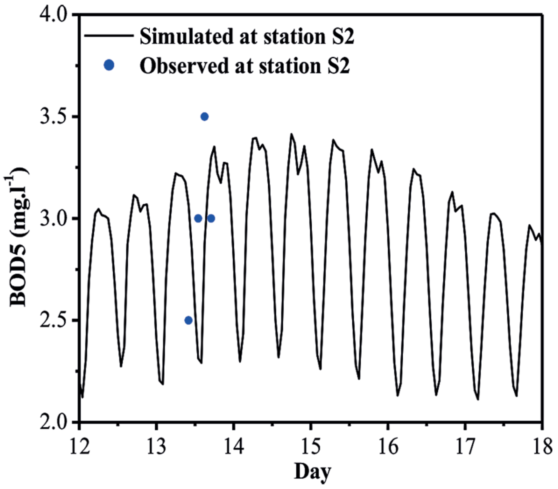


**Figure 15.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 2 in the case after installation of Kenitra WWTP

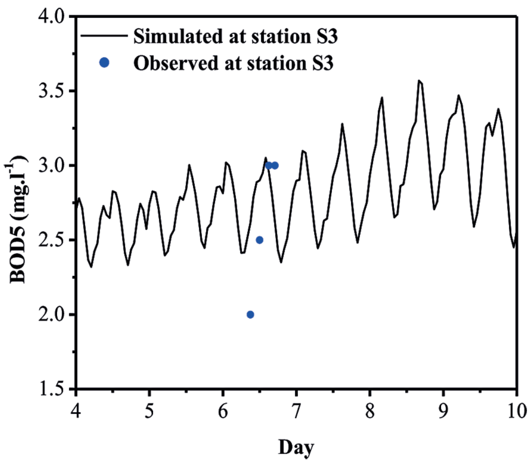


**Figure 16.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 3 in the case after installation of Kenitra WWTP

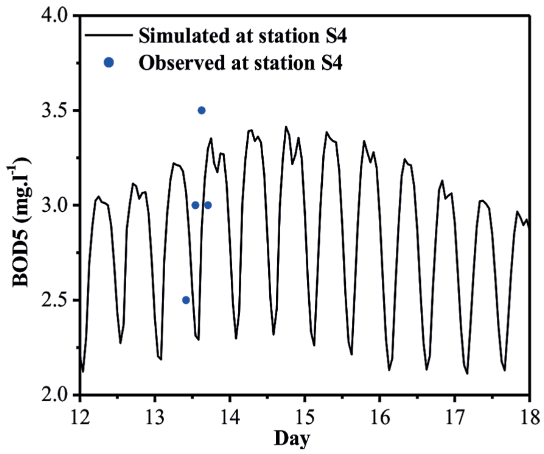


**Figure 17.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 4 in the case after installation of Kenitra WWTP

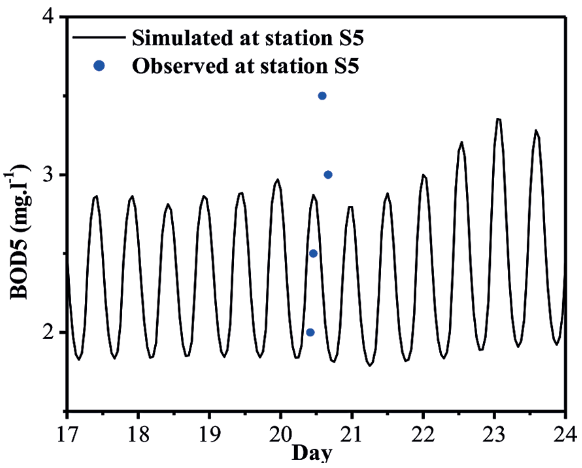


**Figure 18.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 5 in the case after installation of Kenitra WWTP

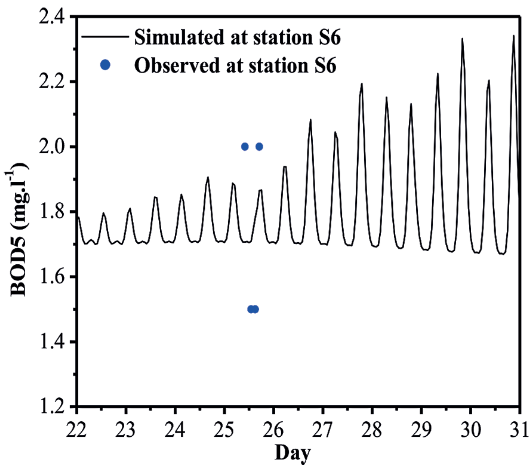


**Figure 19.** Temporal evolution of the simulated and measured of the $BOD_5$ at point 6 in the case after installation of Kenitra WWTP

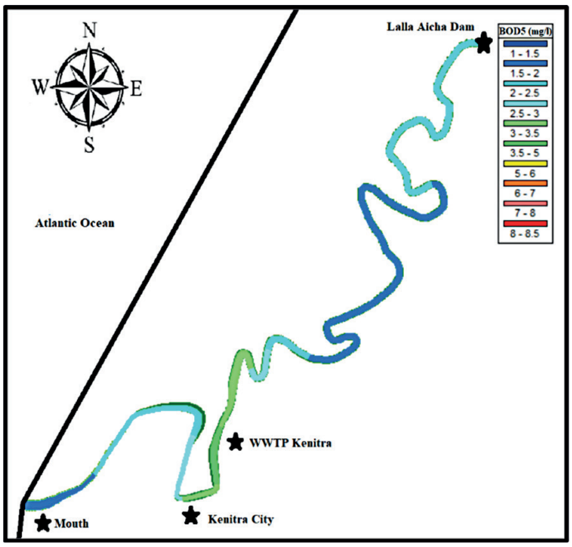


**Figure 20.** Longitudinal evolution of the $BOD_5$ in the case after installation of kenitra's WWTP at high tide (August 18, 2021)

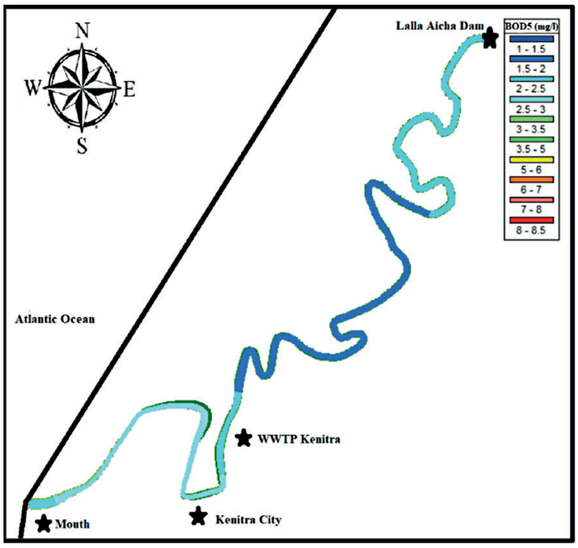


**Figure 21**. Longitudinal evolution of the $BOD_5$ in the case after installation of kenitra's WWTP at low tide (August 20, 2021)

we achieved after the start of the WWTP, it's evident from the figures that there is a significant change in the quality of the wastewater from the estuary, which shows that the concentration of $BOD_5$ of the treated wastewater during the 18 August of the year 2021 varies between only 1.72 mg/l and 2 mg/l, during high tide. However, the $BOD_5$ concentration was slightly more noticeable at low tide ranging from 2.41 mg/l to 2.82 mg/l. But in general, the huge drop in $BOD_5$ in the estuary testifies to the extremely positive impact that the treatment plant has on the environment.

The quality of estuary waters has been positively impacted by discharges from the sewage treatment plant, which eliminate all pollution that can influence the quality of the waters of the Sebou estuary. This confirms the good performance of the Kenitra wastewater treatment plant.

According to Figures 22 and 23 illustrating the longitudinal profile of the $BOD_5$ of the Sebou estuary at high tide and at low tide on August 22, 2021 after the implementation of the WWTP, a remarkable evolution was observed compared to the results of the longitudinal profile before the installation of the WWTP. The results indicate that the discharged pollution moves downstream during low tide cycles by strongly weakening its amplitude up to 1 km, then it rises upstream

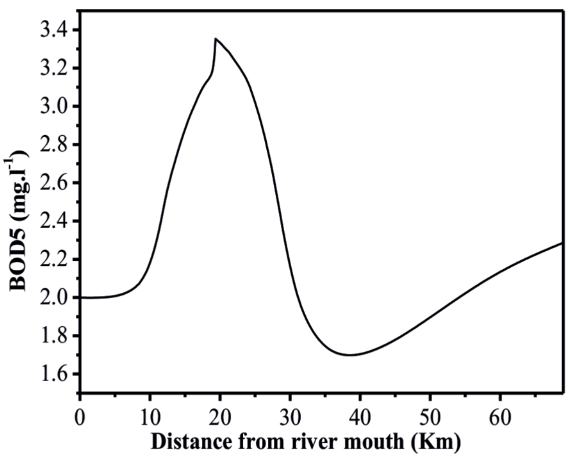


**Figure 22**. Longitudinal evolution of the $BOD_5$ in the case after installation of Kenitra's WWTP at high tide (August 22, 2021)

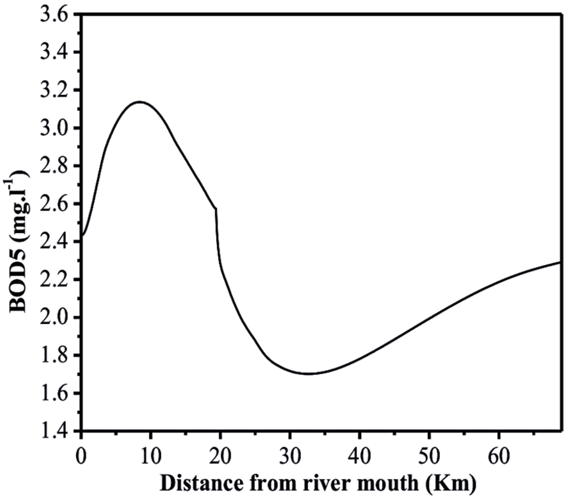


**Figure 23**.Longitudinal evolution of the $BOD_5$ in the case after installation of Kenitra's WWTP at low tide (August 22, 2021)

during high tide cycles to reach 3.75 mg/l and also decreases in amplitude downstream, the discontinuity of the curves (Figures 22 and 23) 22 km from the mouth is due to the impact of industrial discharges on water quality. This shows that the pollution decreased exponentially after the implementation of the WWTP, which subsequently corroborates our previous conclusions concerning the very positive impact of the WWTP in the city of Kenitra on the receiving environment which, in our case, is the Sebou River estuary.

Finally, it should be noted that the water quality simulations can be considered credible because the transport model is based on a calibrated hydrodynamic model and series of large and precise measurements of the water quality at the outlet la treatment plant and at the level of raw wastewater outfalls, as well as measurements. In addition to field measurements at six stations along the estuary, these were used as calibration and validation data for the model, which gave good agreement between the simulated data and those measured for the different modelling periods.

## CONCLUSION

Urban wastewaters from Kenitra had been discharged for a long time without prior treatment into Sebou River estuary until WWTP was installed in 2020. This study aims to simulate the fate of the urban wastewaters discharged into the river before and after the installation of the WWTP and to assess the impact of the latter on the water quality of the river, using HEC-RAS 5.0.6 model. Since water quality is strongly depending on the hydraulic regime HEC-RAS has been calibrated and validated using hydraulic and morphological database. Two scenarios were put under examination, one is a simulation of discharge by six collectors of untreated discharge (mean $BOD_5$ of 300 mg/L) and the second is a simulation of discharge after treatment at the WWTP (mean $BOD_5$ of 24 mg/L). The first simulation results carried out for the period before the commissioning of the WWTP from May to August 2019 show that the water quality of the Sebou River is average according to national standards (average quality around 7 mg/l of $BOD_5$). Regarding the second simulation carried out for the period after the commissioning of the WWTP between May and August 2021, it shows that the treatment plant reduces the concentration of $BOD_5$ in the river to around 3mg/l compared to the case before their installation, the water quality of the estuary evolves to become good after being just average. The simulations also showed the influence of the tidal cycle on the water quality of the estuary. Indeed, the $BOD_5$ concentration downstream of the treatment plant changes according to the tidal cycle. It is higher at high tide than at low tide, with a difference of around 0.3 mg/l on average. It should be noted that the water quality simulations can be considered credible because the transport model is based on a calibrated hydrodynamic model and series of large and precise water quality measurements at the outlet of the treatment plant and at the raw sewage outfalls, in addition to field measurements at six stations along the estuary, these were used as calibration and validation data for the model, which gave good agreement between the simulated and measured data for the different modelling periods, these field measurements deserve to be carried out with a higher density to further improve the quality of the model. Finally, the results show the very positive impact of the Kenitra wastewater treatment plant on the water quality of the Sebou River estuary.


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## REFERENCES


1. Brunner, G. 2016. River Analysis System Hydraulic Reference Manual (HEC-RAS 5.0 Reference Manual). Davis California, USA: U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC).
2. Combe, M. 1996. Etude des marées dans l'oued Sebou et des pollutions qu'elles provoquent à l'étiage (Study of Tidal Cycle in the Sebou Estuary During Low Water). Rapport inédit, Rabat, MTPC/DH DRE, 108.
3. El-Blidi, S., Fekhaoui, M. 2003. Hydrology and tidal dynamic in the Sebou estuary (Gharb, Morocco). Bull. Inst. Sci. Rabat, Sect. Life Sci, 25, 57–65.
4. Fennell, J., Soulsby, C., Wilkinson, M., Daalmans, R., Geris, J. 2022. Assessing the role of location and scale of Nature Based Solutions for the enhancement of low flows. International Journal of River Basin Management, 1–16.
5. Fischer, H., List, E., Koh, R., Imberger, J., Brooks, N. 1979. Mixing in Inland and Coastal Waters. New York: Academic Press, 483.
6. Haddout, S., Baimik, I., Maslouhi, A., Igouzal, M., Bouchaib Magrane, B., Marah, H. 2019. The influence of spring and neap tide on salt intrusion and stratification in Sebou estuary (Morocco). International Journal of River Basin Management, 17(1), 131–142. https://doi.org/10.1080/15715124.2018.1476365
7. Haddout, S., Igouzal, M., Maslouhi, A. 2017b. Seawater intrusion in semi-closed convergent estuaries (case study of Moroccan Atlantic Estuaries): Application of salinity analytical models. Journal of Marine Geodesy, 40, 275–296.
8. Haddout, S., Maslouhi, A., Igouzal, M. 2017a. Predicting of salt water intrusion in the Sebou river estuary (Morocco). Journal of Applied Water Engineering and Research, 5, 40–50.
9. Haddout, S., Maslouhi, A., Magrane, B., Igouzal, M. 2016. Study of salinity variation in the Sebou River Estuary (Morocco). Desal. Water Treat, 57, 17075–17086.
10. Ji, Z.G. 2008. Hydrodynamics and Water Quality: Modeling Rivers, Lakes, and Estuaries. John Wiley & Sons Inc., Hoboken, New Jersey.
11. Kettab, A. 2014. Water for all with quality and quantity: it is the concern of all!. Desal. Water Treat, 52, 1965–1966.
12. Mergaoui, L., Fekhaoui, M., Bouya, D., Gheı¨t, A., Stambouli, A. 2003. Water quality and benthic macrofauna the estuarine environment of Morocco: The case of the Sebou estuary. Bull. Sci. Inst. Sect. Life Sci, 25, 67–75.
13. Nizar, Y., Igouzal, M. 2022a. Assessment of urban wastewater pollution discharged by the Moroccan city of Kenitra at the Sebou river estuary. Poll Res,, 41 (2), 153–162.
14. Nizar, Y., Touazit, A., Igouzal, M. 2022c. Predicting the thermal regime of the Sebou river estuary (morocco) using a one-dimensional model (HEC-RAS 5.0). Nature Environment and Pollution Technology, 21(2), 883–890.
15. Nizar, Y., Touazit, A., Igouzal, M. 2022b. Water quality modelling of Sebou River estuary (Morocco) after the installation of the Kenitra town's WWTP. Desal. Water Treat, 1–8.
16. Rahmati, M., Tishehzan, P., Moazed, H. 2021. Determining the best and simple intelligent models for evaluating BOD5 of Ahvaz wastewater treatment plant. Desal. Water Treat, 209, 242–253.
17. Haddout, S.A.M. 2016. Study of salinity variation in the Sebou River Estuary (Morocco). Desal. Water Treat, 57, 17075–17086.
18. Sathya, A., Thampi, S., Chithra, N. 2021. Development of a framework for sand auditing of the Chaliyar River basin, Kerala, India using HEC-HMS and HEC-RAS model coupling. International Journal of River Basin Management, 1–14. https://doi.org/10.1080/15715124.2021.1909604
19. Shehata, D., Abdelmonem, Y., Soussa, H., Abdel-fattah, S., Moussa, A. 2019. Assessment of Longitudinal Dispersion Coefficient Using One-dimensional Numerical Modeling Equation. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 16(4), 57–66.
20. Thatcher, M., Harleman, D. 1981. Long-term salinity calculation in Delaware estuary, 107(11–27).
21. Wahaba, N., Kamarudina, M., Torimanb, M., Juahira, H., Saada, M., Ataa, F., Harithe, H. 2019. Sedimentation and water quality deterioration problems at Terengganu River Basin, Terengganu, Malaysia. Desal. Water Treat, 149, 228–241.