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Predicting the Thermal Regime of the Sebou River Estuary (Morocco) Using a One-Dimensional Model (HEC-RAS 5.0)

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ABSTRACT

Temperature is regarded as one of the most important variables for aquatic life, as well as a key physical criterion of water quality, due to its role in a variety of chemical, physical, and biological processes. We chose the HEC-RAS tool to model the thermal regime of the Sebou-Kenitra river estuary because it is impossible to determine the spatiotemporal evolution of temperature in watercourses using traditional methods such as single measurements or interpolation due to the influence of several factors, including hydraulic, tidal rhythm, upstream contributions, and intrusion. The main goal of this research is to develop and test the "HEC-RAS" model with the aim of better understanding thermal dynamics and predicting the spatiotemporal variation of the Sebou river estuary temperature, using the energy transport equation and a variety of input data such as initial temperature, air temperature, wind speed, and dispersion coefficient. The HEC-RAS model, which takes into account many meteorological and geophysical elements and provides an overview of the thermal situation at our study site "the Sebou river estuary," has also been acknowledged for its deterministic role. We illustrated the impact of meteorological and tidal data on spatiotemporal temperature change at numerous places in the Sebou river estuary by using this model.

INTRODUCTION

The diverse estuarine environment contributes significantly to the life cycle of many species, not only that, but it also serves as a site for human activities (Igouzal et al. 2005). Simply put, estuaries are valuable water bodies where numerous dynamic factors take place and interact (Xu et al. 2015).

Estuaries assemble and gather essential substances of the human-earth system (Savenije 2015), and given that they form part of the relationship between seawater and river, the aforementioned have the properties of both: they simultaneously contain fresh and saltwater and are subjected not only to the tides but also to the floods of the rivers; in addition to naturally support saline and fresh ecosystems (Savenije 2015).

Amongst the most notable advantages to the prediction of water temperature in rivers is; first and foremost dealing with certain environmental problems in addition to carrying out competent management and use of water and aquatic resources (Ouhamdouch et al. 2018, Tavares et al. 2020, Graf et al. 2019).

Accordingly, to visualize the effect of thermal pollution, impact studies are often required to protect the (ichthyoids) fish habitat. Although, before we arrive at the stage of predicting the changes resulting from human activities, it is crucial to first know and be able to envisage the temperature of the water in its natural state according to climatic and hydraulic variations which was the subject of some very fascinating and striking researches conducted by (Haddout et al. 2016, Igouzal & Maslouhi 2010).

Furthermore, knowing the temperature of the watercourses makes it possible to distinguish climate tendencies in the long run. Nevertheless, there is little information on its spatiotemporal variation, due to an obvious lack of habitual and incessant monitoring (Lund et al. 2002, Tao et al.2021).

Our case study is exceptionally innovative on account of being the first one to be carried out to focus solely on examining the temperature of the Sebou Estuary, which is deemed to be the leading watershed in Morocco in terms of water inflows estimated at a whopping 6.6 billion m^3 per year. What's more, this hydrographic basin is ranked second in the surface area: 40,000 km^2 (after the Moulouya basin) and it covers 191,000 ha of agricultural land (Hayzoun et al. 2015). The choice of making this basin the focal point of our study comes from the need to implement for the first time temperature modeling by the HEC-RAS method.

To represent and simulate the thermal regime of the estuary, two types of models are used in general: the first being; the numerical model and the second, it's the analytical model. Presently, digital models are more popular, especially 2D and 3D models (Kärnä et al. 2015; Elias et al. 2012; Zhao et al.2012), due to their ability to provide more spatial and temporal details (Igouzal et al. 2005).

The primary objective of our research is, on one hand, to compose an observation network capable of characterizing the specificity of the study area (Sebou River Estuary) and on the other hand, to design the necessary field campaigns with regard to the hydrological conditions to properly portray the temporal variations of the studied water at distinctive points of our worksite, taking into account that this parameter is of major significance for aquatic life (Morid et al.2020, Qiu et al.2020). The obtained measurements will ergo be used in a temperature model on HEC-RAS and this thermal model will in turn be used to serve as input data for modeling the water quality of the Sebou river estuary on top of assessing the evolution pollution.

The calibration of the thermal model was based on field data collected from six different sampling sites over a time period extending from June 2019 to September of the same year.

In the interest of accomplishing our goal, prior modeling of the hydraulic regime using HEC-RAS was requisite. This hydraulic module calculates the evolution of speed and depth which serve as input parameters to the temperature model.

MATERIALS AND METHODS

The selected methodology for our paper includes:

- Presentation of the study site,
- Timely and punctual measurements over a course of period expanding from the beginning of June to the 1st of September 2019 of different sampling points (six sites to be exact) across the entire basin,
- Modeling by the HEC-RAS 5.0 model, while using outputs (series of calculated temperatures),
- Processing techniques for the collected data (comparison of the average values) obtained for each sample and the variability for each site.

Study Site: The Sebou Estuary

The flow regime in the Sebou estuary is ascertained by notable seasonal and inter-annual changes. Considering the reality that it is contingent on the tidal regime as well as being under the control of several barrages (Igouzal & Maslouhi 2010, Igouzal et al. 2005)

During the "low-flow" period, the hydraulic regime is controlled by the Lalla Aicha barrage which is located 62 km upstream from the river's mouth. This particular barrage was built to contain water from agricultural pumping stations and prevent saltwater from rising to these stations. A volume of 200 $Mm^3$of water is mobilized annually, taking into consideration that before the construction of this reservoir, excessive salinity could extend over an area of 85 km (Combe et al, 1969)

The Sebou estuary is enclosed by the Atlantic Ocean and the Lalla Aicha guard barrage, extending around 69 km long, what's more, it is the only Moroccan estuary equipped with a river port.

Sampling

The 1st step in our action plan tackled the task of collecting daily field data betwixt June and September of the year 2019 in a sampling network of six sites (Fig. 1, Table 1), in fact, temperature values were registered every 15 minutes, culminating thus to recording approximately 96 daily.

Sample Collection

To attain the needed water samples, a 10-meter rope was tied around a water container; the latter was then thrown into the river collecting thus the samples. The water samples were placed later in clean plastic bottles of 1.5 liters each to directly measure the temperature.

Modeling Via the HEC-RAS software

HEC-RAS is an extensively used software application that carries out one-dimensional and two-dimensional hydraulic calculations for a complete nexus of natural and constructed channels, overflow/floodplain areas, protected areas; etc.

Table 1: The six sampling points.

Sampling points	GPS	Location
Point 1	Latitude : 34,272288, Longitude : -6,645024	Located 3.6 km from the mouth of the Sebou.
Point 2	Latitude : 34,269596 Longitude : -6,591051	Located 9.3 km from the mouth of the Sebou.
Point 3	Latitude : 34,275671, Longitude : -6,568179	Located 13 km from the mouth of the Sebou.
Point 4	Latitude : 34,292163, Longitude : -6,567193	Located 15 km from the mouth of the Sebou.
Point 5	Latitude : 34,292163, Longitude : -6,567193	Located 17 km from the mouth of the Sebou.
Point 6	Latitude : 34,338430, Longitude : -6,488273	Located 24 km from the mouth of the Sebou.

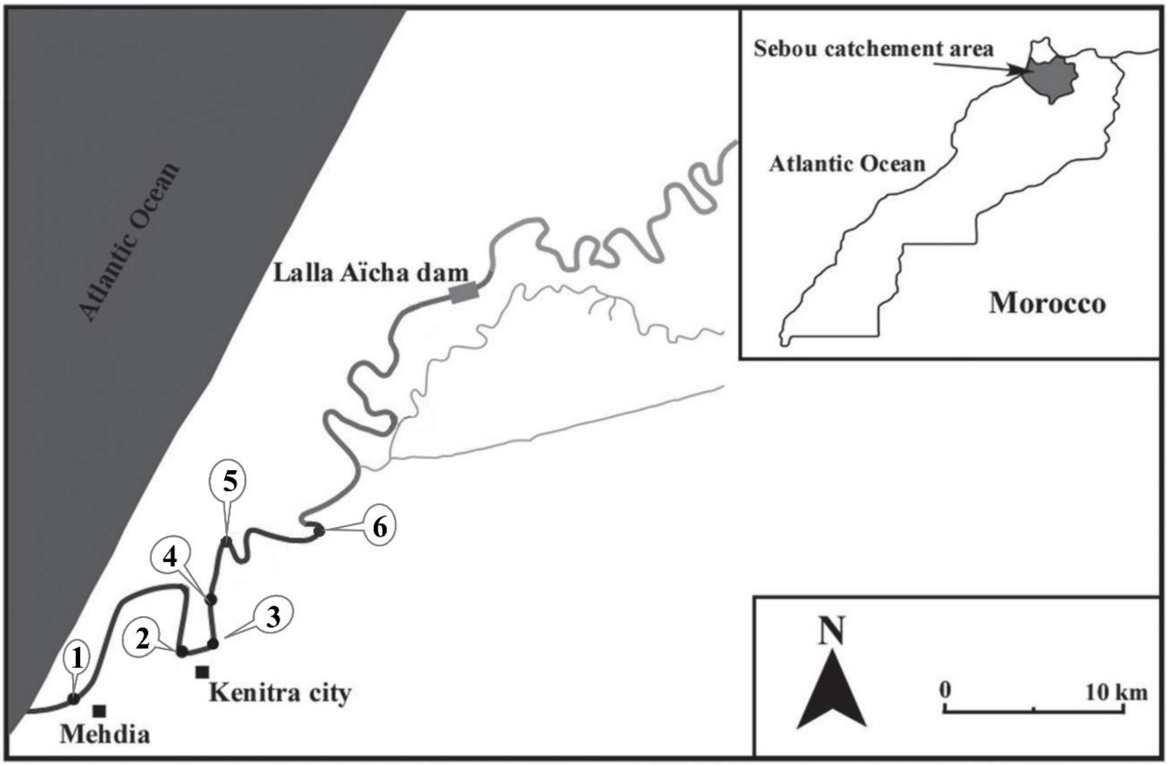

Fig.1: Map of the geological surface of the Sebou Estuary and the distribution of the sampling points.

The second step of our work involved the modeling of the hydraulic regime using HEC-RAS which is based on the energy transport equation.

To reach the objective of modeling by HEC-RAS, several data are demanded, in particular: the initial temperature state, the dispersion coefficient, the flow speed, the atmospheric pressure, the air temperature, the relative humidity, the cloudiness, the speed of the wind and solar radiation. The result of the transport module is the spatio-temporal evolution of the temperature in the river.

Hydraulic Modeling of the Sebou Estuary

This regime has been gauged and corroborated by employing a large hydraulic and morphological database. To initiate the process, entering several data is vital, principally: initial temperature condition, dispersion coefficient, flow velocity, atmospheric pressure, air temperature, relative humidity, cloudiness, wind speed, and solar radiation (Fig. 2).

Hence, to be capable of modeling the Sebou Estuary temperature on HEC-RAS 5.0, it is necessary to establish the hydraulic model of the said estuary.

HEC-RAS is based on the Saint-coming equations (Brunner 2016, Haddout et al. 2015, 2016, Igouzal & Maslouhi, 2005) which are written as follows:

$$\frac{\partial Q}{\partial x} + B\frac{\partial Y}{\partial t} = q$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = gA\left(\frac{\partial Y}{\partial x} - S_f\right) \qquad \ldots(1)$$

Where Y = the depth of water; Q = the flow; x = the distance along the river; t = the time; B = the river with; q = lateral influx; A = the cross section; g = the acceleration due to gravity; Sf = the friction slope.

The friction slope is expressed as:

$$S_f = \frac{n^2}{R^{4/3}}U^2 \qquad \ldots(2)$$

Where n is the Manning coefficient of friction.

Thermal Modeling of the Sebou Estuary

The studied T parameter of the estuary water is calculated from the thermal energy transport equation.

When T is applied to an open channel with a constant cross-section, we find the following equation:

$$\frac{\partial T}{\partial t} = -U\frac{\partial T}{\partial x} + D_L\frac{\partial^2 T}{\partial x^2} + \frac{S}{\rho c_\rho} \quad \ldots(3)$$

Where T = water temperature; x = distance downstream; t = time; DL = a longitudinal dispersion coefficient in the direction of flow (x direction); S = a source or sink term that includes heat transfer with the environment; U = average speed of the channel; h = average depth of the channel; *P* = density of water; and Cp = calorific capacity of water.

A more general form of the equation is:

$$A\frac{\partial T}{\partial t} + \frac{\partial(QT)}{\partial x} = \frac{\partial}{\partial x}\left(AD_L\frac{\partial T}{\partial x}\right) + \frac{BS}{\rho c_\rho} \quad \ldots(4)$$

RESULTS AND DISCUSSION

Once the model was provided with the meteorological data and boundary conditions (Drake et al.2010), the HEC-RAS water temperature model was then launched and operated using a one-hour time step, from the 1^{st} of June to the 1^{st} of September 2019 depending assuredly on available data. The water temperature model for the Sebou river estuary was calibrated with the available observed data that was previously mentioned in the material and methods section.

The chronological series of the water temperatures predicted and observed by HEC-RAS in the six sampling points along the Sebou estuary from the Lalla Aicha barrage to the outlet in Mehdia before (A) and after (B) adjusting are illustrated in Figs. 3 to 8:

Based on the results observed in the figures, it is abundantly clear that there is a significant difference between the two graphs, before (A) and after (B) calibration. The figures display a scatter plot of instantaneous temperature predictions versus temperature observations presented in a discontinued line. Upon inspecting the figures we can distinguish that by comparing the model predictions and the observed data, the two seem to be very close, especially when moving away from upstream to downstream, where the impact of boundary conditions is reduced, moreover, the same can be said for the time factor.

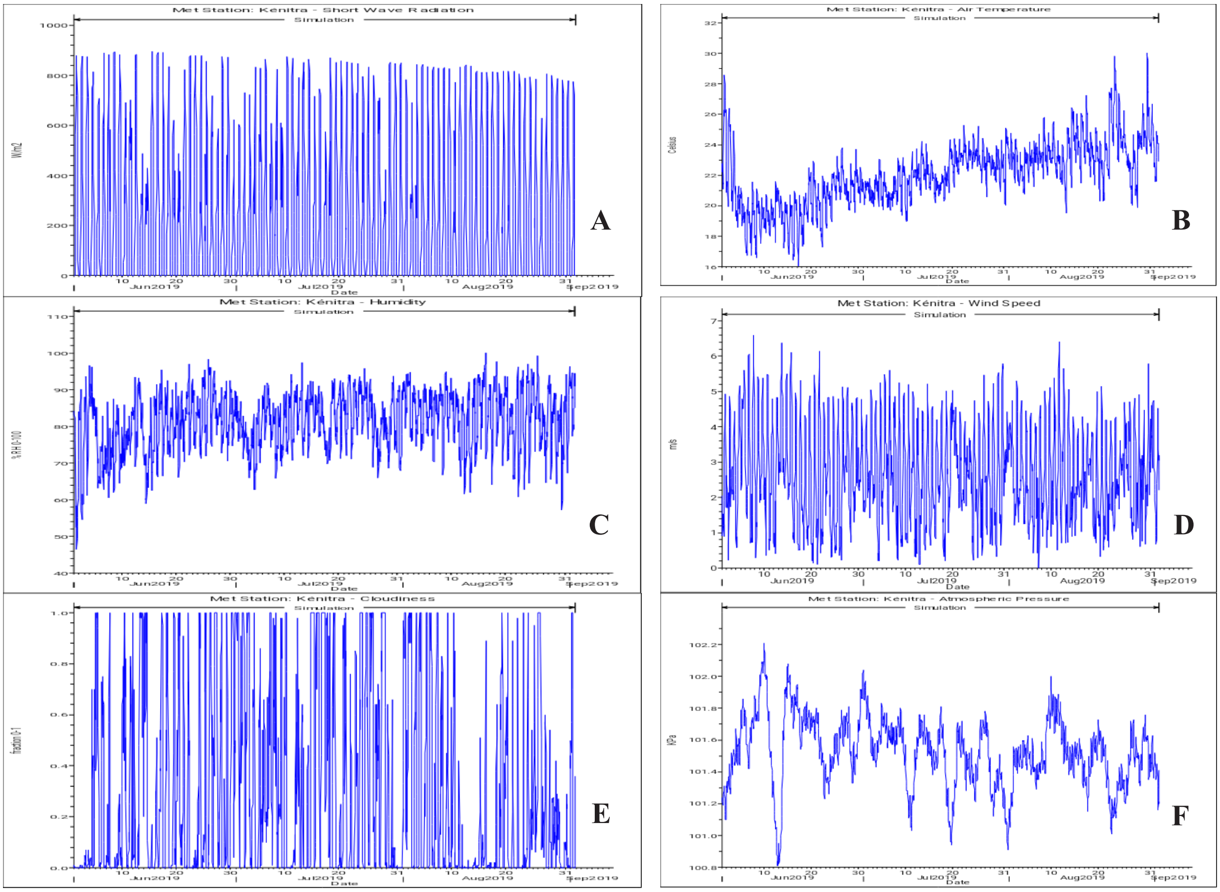

Fig.2: Input data timetable for (A) solar radiation, (B) air temperature, (C) humidity, (D) wind speed, (E) cloudiness and (F) atmospheric pressure.

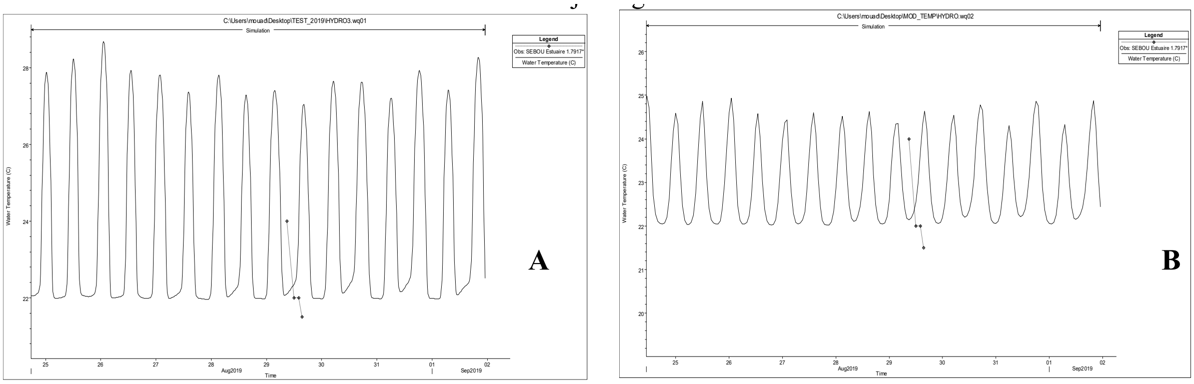

Fig.3: HEC-RAS results vs observed temperature from point 1 at the Sebou Estuary before (A) and after (B) adjusting.

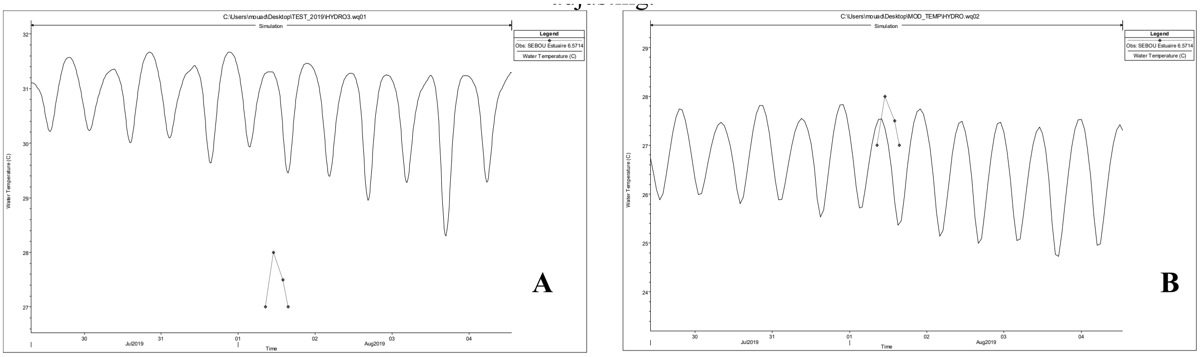

Fig.4: HEC-RAS results vs observed temperature from point 2 at the Sebou Estuary before (A) and after (B) adjusting.

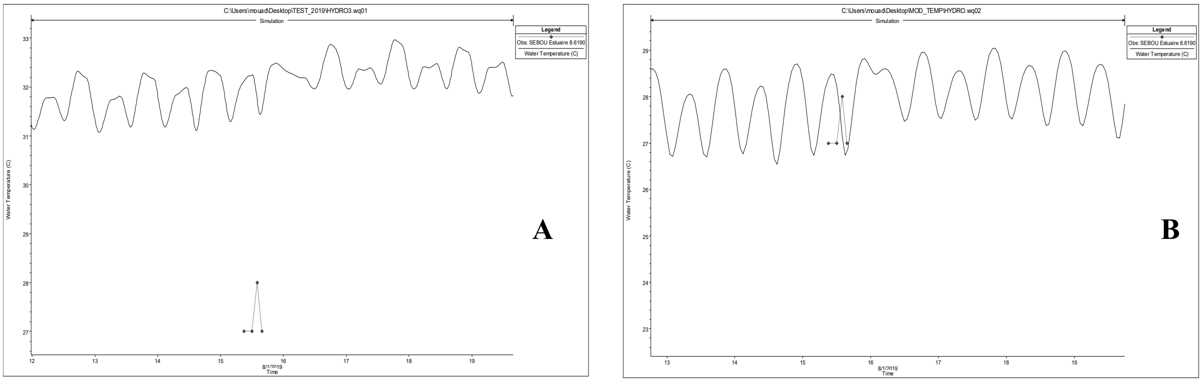

Fig.5: HEC-RAS results vs observed temperature from point 3 at the Sebou Estuary before (A) and after (B) adjusting.

The chronological series' graphs indicate a good concurrence between the HEC-RAS prognostication and the observations for the six calibration locations along the Sebou River estuary, which complies with the analogous results found in other studies (Drake et al.2010; Abdi et al.2020, Ren et al.2020; Qiu et al.2020), excluding the sixth point, which perhaps may be attributed to the fact that the measurements were executed at the start of the simulation.

Appertaining to the Figs. 9 and 10, it is easily visible that the water temperature is incessantly increasing upstream from the mouth of the river in the Sebou estuary. Indeed, during high tide, the temperature rise seems to take place after 5 km from the mouth of the river, nevertheless, the temperature rise occurs quite instantaneously during low tide.

As far as we know, the uncertainty of the water temperature model also emanates from the shortage of monitoring

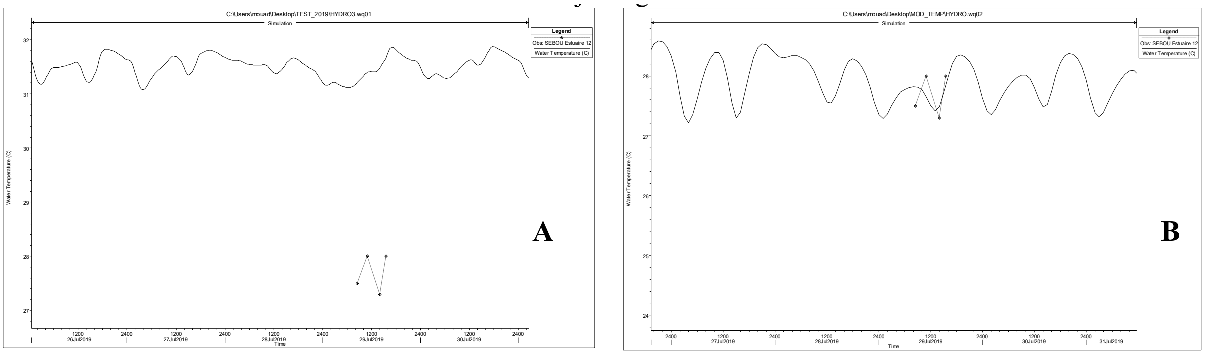

Fig.6: HEC-RAS results vs observed temperature from point 4 at the Sebou Estuary before (A) and after (B) adjusting.

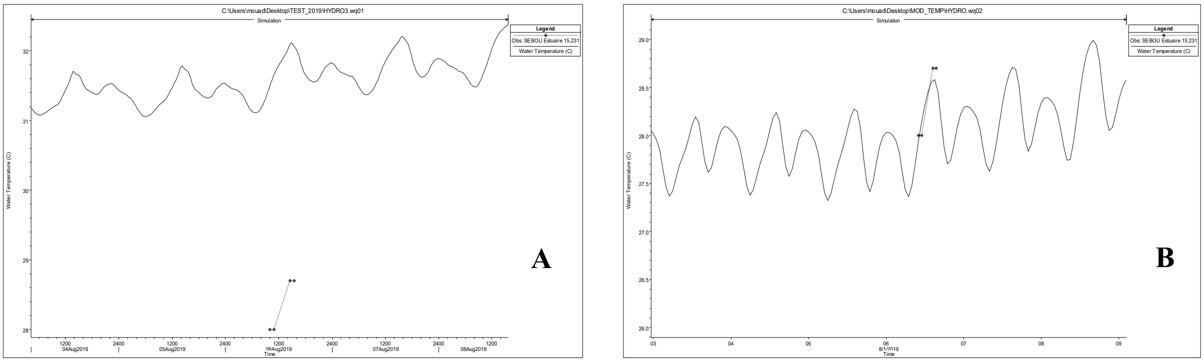

Fig.7: HEC-RAS results vs observed temperature from point 5 at the Sebou Estuary before (A) and after (B) adjusting.

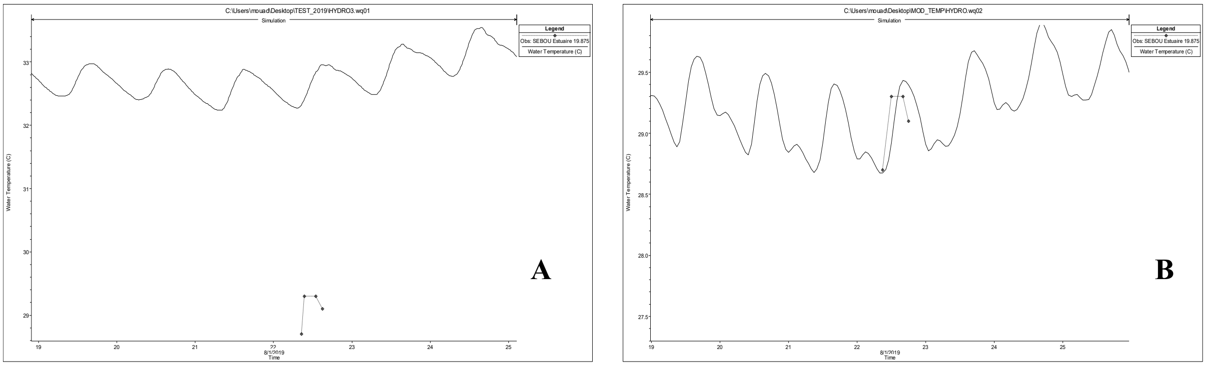

Fig.8: HEC-RAS results vs observed temperature from point 6 at the Sebou Estuary before (A) and after (B) adjusting.

gauges for the water quality of rivers in the basin and the restricted amount of data available at these gauges. All water quality sample readings for this study were obtained during the summer. Additional observed water temperature data is needed to improve and refine the HEC-RAS water temperature model of the Sebou River Estuary.

It's interesting to point out that the calibration could be improved if the measurements were available over a longer period spanning several tidal cycles.

CONCLUSION

Owing to the fact that the rivers' water temperatures are highly affected by countless factors, the prime objective of this study was to model the water temperature of the estuary of the Sebou river using the hydraulic model in conjunction with the meteorological data and boundary conditions.

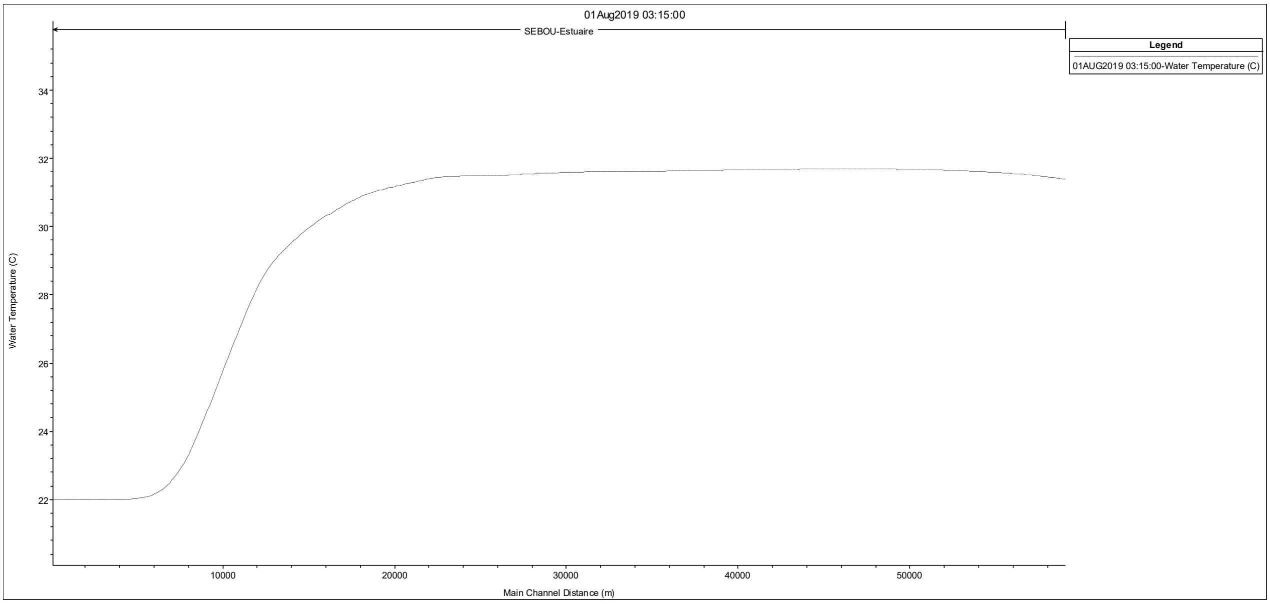

Fig.9: Longitudinal profile of the High tide temperature.

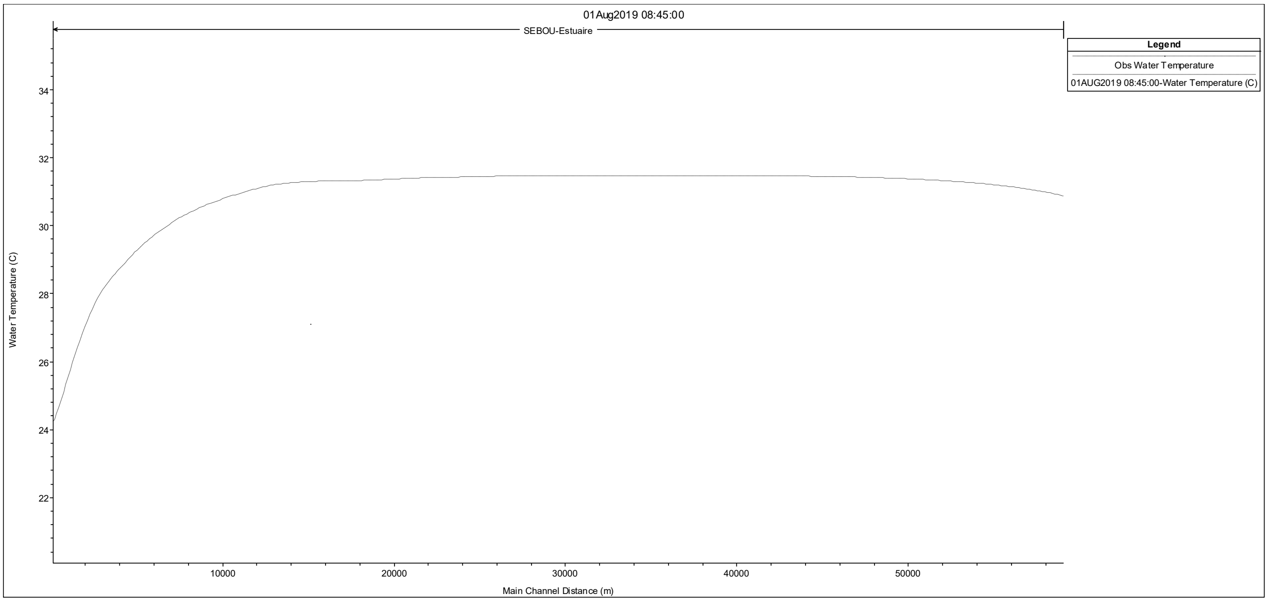

Fig.10: Longitudinal profile of the Low tide temperature.

Subsequently, the HEC-RAS model allotted us to reach the temperature according to the spatio-temporal variation within the estuary. The said model is an initial endeavor at attaining a one-dimensional representation before we can move forward into performing thermal modeling using 2D and 3D models.

Following the calibration of the model by tangible measurements at six different sampling points of the Sebou River, we acquired an assortment of results which in turn will be extracted in the form of a database. The latter will be considered as a representation of the advantages of the HEC-RAS model in terms of modeling the water temperature of rivers; nonetheless, the calibration could be redrafted if the measurements were spread over a longer period of time with various tidal cycles.

The formulated model mandated a colossal amount of input data, namely: solar radiation, air temperature, humidity, wind speed, cloudiness, atmospheric pressure, and water temperature of sea. The procured results constituted a large database and were classified as measurements with a primary aim of developing other models of temperature prediction of the estuary of the Sebou River for future work, bearing in mind that they are going to be coupled with artificial intelligence models such as neural network models and linear regression models to achieve efficient prediction of water temperature with minimal input data, area temperature as an example. The hydraulic model of the Sebou river estuary, as well as the thermal model object of this work, will be practical for modeling pollution at the same site.

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