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EFFECTS OF THE POINT SOURCE POLLUTION ON THE CONCENTRATION OF BOD IN THE DANUBE RIVER, ROMANIA

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An attempt has been made to study the effects of the Jidostita tributary as point source pollution on the Biochemical oxygen demand concentration in the Danube River, Romania. A numerical solution was introduced and solved using FlexPDE software. In this paper, three different scenarios of dispersion of BOD along the Danube River were examined by setting different values of river velocity. The temporal variations in simulation of BOD concentration were insignificant in this study and only spatial variations were considered. The results revealed that the BOD concentration at Gura Văii is about 3.4 mg/L in the first case, whereas, the BOD concentration at Gura Văii is about 3 mg/L in the second case and the BOD concentration at Gura Văii is about 2.5 mg/L in the third case. The BOD concentrations were dispersed to less than 0.5 mg/L at Schela Cladovei station in all cases (scenarios). The result of the simulated BOD concentration along the river was in agreement with observed BOD concentration. Therefore, FlexPDE solver can be used as a useful tool for predicting pollution dispersion and provide a good basis for future river water quality policy options for limiting of the pollutant sources.

Keywords: Point Source Pollution, Danube River, FlexPDE, Numerical Simulation, BOD.

1. Introduction

Rivers are considered as essential source for water supply, industrial process and irrigations. On the other hand, the liquid pollutants are usually being discharged to the rivers after proper treatment causing change in the quality of river water. The sources of pollution in rivers are often categorized into point source pollution (such as municipal wastewater and industrial discharge) and non-point source pollution (such as runoffs from urban and discharge from agricultural activities) [1]. This study comprised the effect of Jidostita tributary as point source pollution on the Danube River. For this purpose, mathematical model was used in order to predict the pollutant dispersion which can be an effective tool for the simulation of ordinary discharges in rivers [2].

Danube River is the largest river of Central-Europe and the second largest river in Europe. The river originates from the Black Forest at Germany with a

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total length of 2778 km, and its catchment area covers 817,500 km^2 [3, 4]. The Danube River flows from west to east into the Black Sea with an average annual discharge of 5630 m^3/s [5]. The Danube River flows through many different geological facies and types of land-cover. It is shared by nine riparian countries and five capitals with 0.5 million to 2.5 million inhabitants contributing to extensive water use and pollution [6]. A lot of research has been carried out in order to provide information about the availability of Danube water, its quality, flood control, influence of climate phenomena, modeling techniques, river sediment and the possible ways to improve it by using different tools of river basin management [7-14].

The main aim of this paper is to examine the impact of Jidostita tributary as a waste loads on the receiving Danube River with different set of river velocity by solving a numerical solution. The river has an average discharge of 5600 m^3/sec [15]. The importance of this region is stands out due to the lack of proper sewage collection and treatment facilities in the Drobeta-Turnu Severin [16]. A numerical solution of the dispersion equation was introduced using FlexPDE software [17, 18]. Biochemical oxygen demand (BOD) was selected as a pollutant, for the simulation process. Oxygen is considered as important indicator for water quality control. Its presence is vital to determine the effect of a waste discharge on a river [19].

2. Materials and Methods

Study area

The Danube River is divided into three main parts: the upper Danube course (1060 km), the middle Danube course (725 km) and the lower Danube course (1075 km). The lower Danube course represents Romania's natural border with Serbia, Bulgaria, Ukraine and the Republic of Moldova [20]. The river flows through regions of distinct morphology. In the lower course, the river is flowing through Baziaş and Gura Văii passing the Iron Gate I (144 km) which is located upstream of Drobeta-Turnu Severin. The map of the study area is shown in Fig 1. This study covered almost 12 km length of the Danube River, starting 2 km downstream of the Iron Gate I and extends to Drobeta-Turnu Severin city. The importance of this region is emerged due to the lack of proper sewage collection and treatment facilities in the Drobeta-Turnu Severin [16]. Besides, the effluent discharges from different industries in the region. Two major groups of industries are existing in the region: south-west industrial area (located upstream of Drobeta-Turnu Severin city), and south-east industrial area which located downsterm of Drobeta-Turnu Severin city such as the cellulose and paper industrial plant CELROM [21].

Water quality data

Water quality data were collected in four sampling points (Fig. 1), namely Gura Văii (SS1), Dudașu Schelei (SS2), Schela Cladovei (SS3) and Downstream of Drobeta-Turnu Severin (SS4) for one year (Jan 2008 – Dec 2008). BOD concentrations with the mean values in each station are shown in Figs. 2a-2d. From the Fig.2-a, it can be noticed that the maximum value of BOD in Gura Văii were in the January. In Fig.2-b, it is clear that the maximum value of BOD in Dudașu Schelei station were in May (2.37 mg/L). Whereas, the maximum value of BOD in Schela Cladovei and Drobeta-Turnu Severin stations were noticed in April as shown in Fig. 2-c and Fig. 2-d respectively.

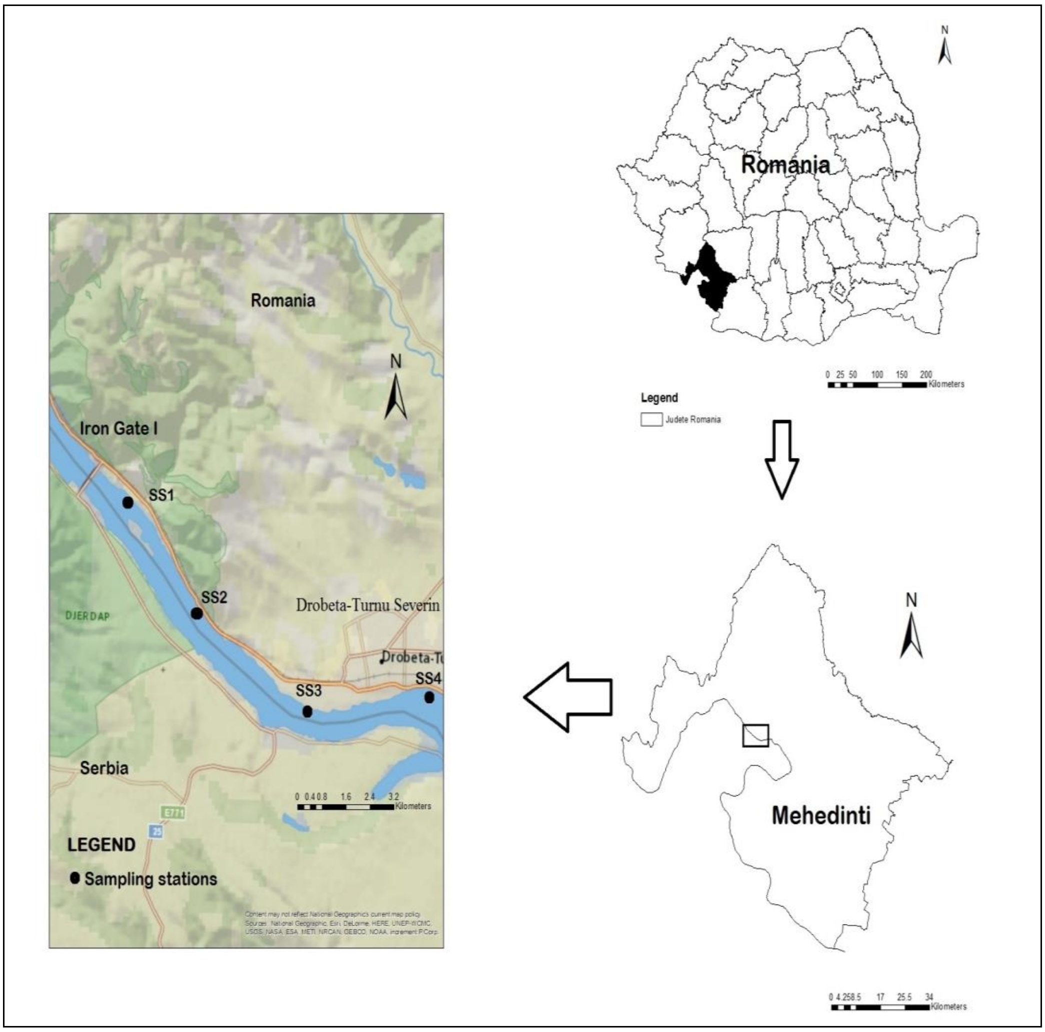

Fig 1 Map of the study area (map created using ArcGIS software)

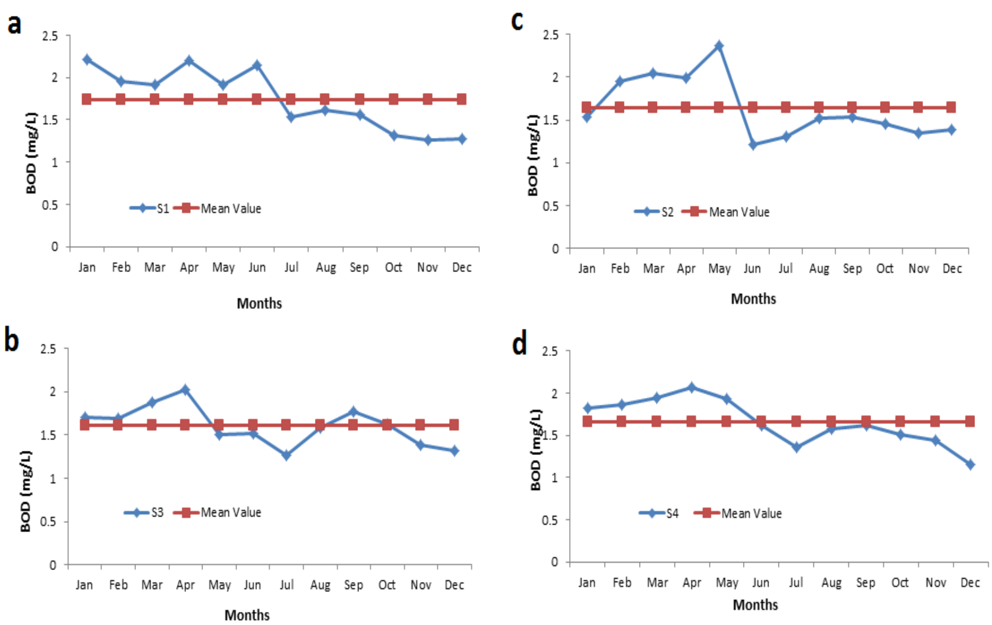

Fig 2 Observed BOD concentrations with the mean values in four stations, a- Gura Văii station, b- Dudașu Schelei station, c- Schela Cladovei station, d- Drobeta-Turnu Severin station

Basic equations

The partial differential equation describing advection-dispersion in rivers can be written in conservation form as

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}(\overline{u}\overline{C})+\frac{\partial}{\partial y}(\overline{v}\overline{C})+\frac{\partial}{\partial z}(\overline{w}\overline{C})=D_m\left[\frac{\partial^2 \overline{C}}{\partial x^2}+\frac{\partial^2 \overline{C}}{\partial y^2}+\frac{\partial^2 \overline{C}}{\partial z^2}\right]+ \\ \frac{\partial}{\partial x}\left[\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right]+\frac{\partial}{\partial y}\left[\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right]+\frac{\partial}{\partial z}\left[\varepsilon_z\frac{\partial \overline{C}}{\partial z}\right]+S(x,y,z,t) \quad (1)$$

where $\overline{C}$ = the substance concentration, $\overline{u}$, $\overline{v}$, $\overline{w}$ = average velocity in the three directions, ε_x = the longitudinal dispersion coefficient, ε_y = the transversal dispersion coefficient, ε_z = the vertical dispersion coefficient, S = the sources and sinks due to settling and resuspension, D_m = the mass diffusion coefficient, t = time.

In rivers, the turbulent mixing is most common and is much more rapid than molecular diffusion [1]. Therefore, the molecular diffusion term can be neglected and thus, the basic equation of advection-dispersion equation (ADE) in rivers and stream (equation 1) can be written as

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{v}\overline{C}\right)+\frac{\partial}{\partial z}\left(\overline{w}\overline{C}\right)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)+\frac{\partial}{\partial z}\left(\varepsilon_z\frac{\partial \overline{C}}{\partial z}\right)+ \\ +S(x,y,z,t) \qquad (2)$$

where $\overline{C}$ = the substance concentration, $\overline{u}$, $\overline{v}$, $\overline{w}$ = velocity in the three directions, ε_x = the longitudinal dispersion coefficient, ε_y = the transversal dispersion coefficient, ε_z = the vertical dispersion coefficient, S = sources and sinks due to settling and resuspension, t = time.

To simplify the equation the orthogonal Cartesian system Oxy is considered for the Eq. 2 and the dispersion equation can be written as

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{v}\overline{C}\right)+=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)+S(x,y,z,t) \qquad (3)$$

The models rely on the fundamental advection–dispersion equation and the parameter considered for dispersion modeling is the Biochemical Oxygen Demand (BOD). Furthermore, Neumann type condition were considered in which $\frac{\partial C}{\partial n}$ = 0 [22]. It is considered the first-order decay term for the BOD consumption. The dispersion equation in these conditions becomes:

$$\frac{\partial \overline{C}}{\partial t}+\frac{\partial}{\partial x}\left(\overline{u}\overline{C}\right)+\frac{\partial}{\partial y}\left(\overline{v}\overline{C}\right)+=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial \overline{C}}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial \overline{C}}{\partial y}\right)-k\cdot C \qquad (4)$$

A numerical solution for the equation 4 was achieved using FlexPDE program. FlexPDE is a finite element solution environment for numerically solving partial differential equations.

Boundary conditions

The constants in the equation (4) were obtained based on the relevant literature [23, 24] and certain characteristics were estimated using ArcGIS software. The mesh and geometry of the study is shown in Fig. 3. The characteristics were chosen for the simulation of the pollutant dispersion in the Danube River are: length of the river = 12 km, average width = 1.3 km, initial condition value for BOD concentration = 0.2 mg/L, longitudinal dispersion coefficient ε_x = 2 m^2/sec, Transverse dispersion coefficient ε_y = 5 m^2/sec, k= 0.1 day^{-1}, BOD concentration in the main river was considered as a mean value in the four stations as shown in Fig. 2. The concentration of BOD in the Jidostita tributary was assumed to be 10 mg/L. Since, there is no water quality data available for Jidostita tributary. We assumed this value due to the fact that Jidostita tributary does not receive domestic or industrial effluent in the surrounding area and it is flowing through agricultural areas [25]. This may reduce the likelihood of the high organic contamination for the river. Numerous scenarios were examined by set different values of velocities (*u* and *v*) in the main river. The adopted cases are: Case 1: u = 3 and v = 0.3 (m/sec), Case 2: u = 2 and v = 0.2 (m/sec), and Case 3: u = 1 and v = 0.1 (m/sec).

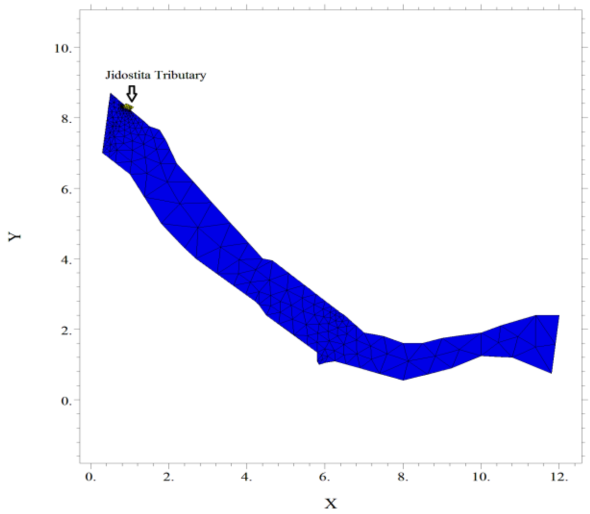

Fig. 3 Meshing and the geometry of the study domain (X and Y = distance in km)

3. Results and discussion

The study examines three different scenarios of dispersion of BOD along the Danube River by setting different values of river velocity. The temporal variations in simulation of BOD concentration were insignificant in this study and thus, only spatial variations were considered in which the results regarding the time were not shown.

In case 1, longitudinal velocity (*u*) and lateral velocity (*v*) were set as 3 m/sec and 0.3 m/sec respectively and the results are shown in Fig. 4 and Fig. 5. In this case, it can be observed that the BOD concentration at Gura Văii (2 km downstream of the Iron Gate 1) in the mid river is about 3.4 mg/L and this value decreased to 0.5 mg/L at Schela Cladovei station. Moreover, the predicted results show good agreement with observed values of BOD in the river with some exceptions as shown in Fig. 5. The results were calibrated with minimum, maximum and mean values of observed BOD concentration for 12 months. Only first three locations were considered for calibration process in order to examine the errors in the simulation. As shown in Fig.5, the highest errors between the predicted and observed values of BOD was noticed downstream of Schela Cladovei station and extend to Drobeta-Turnu Severin station and however, the results were acceptable.

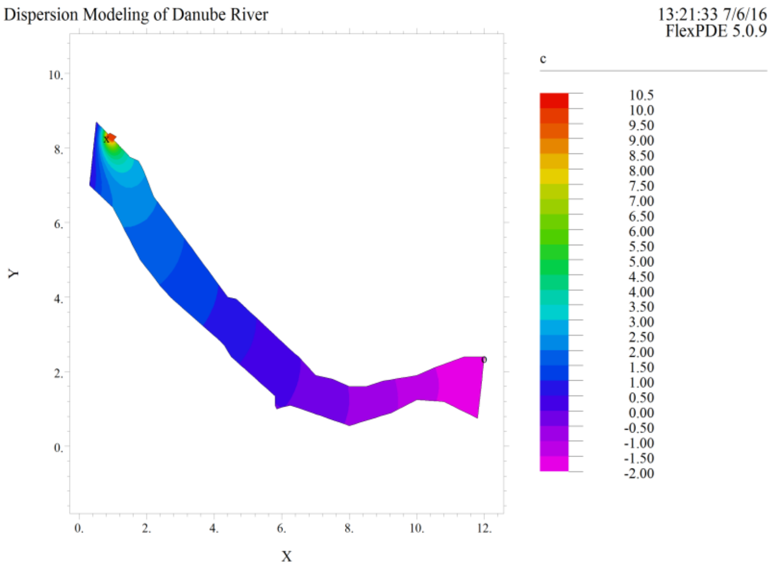

Fig 4 Dispersion of BOD from Jidostita tributary along Danube River, *u*= 3 and *v*= 0.3 (m/s)

Moreover, the variations in simulation for BOD concentration along the downstream distance were insignificant due to the fact that the pollution load connected to the river from Jidostita tributary has low discharge compared to the flow of the river. Danube River has an average discharge of 5600 m^3/sec [15] and thus this value is extremely higher than the flow rate of Jidostita tributary which make the dilution process is larger.

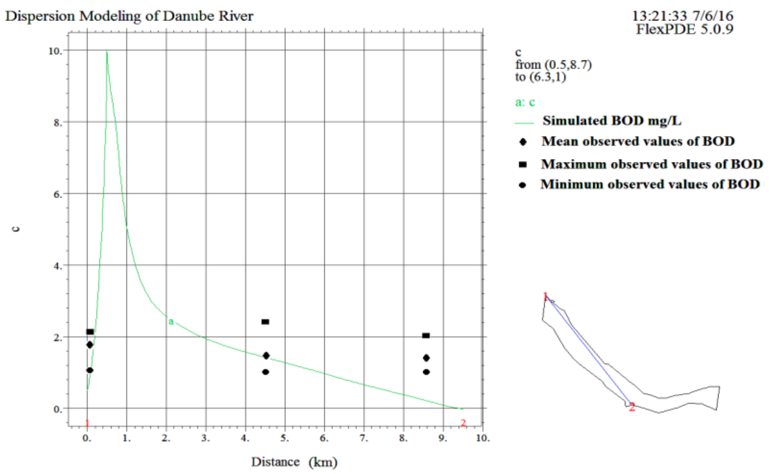

Fig 5 Graphical representation of predicted and observed BOD concentration along Danube River, *u*= 3 and *v*= 0.3 (m/s)

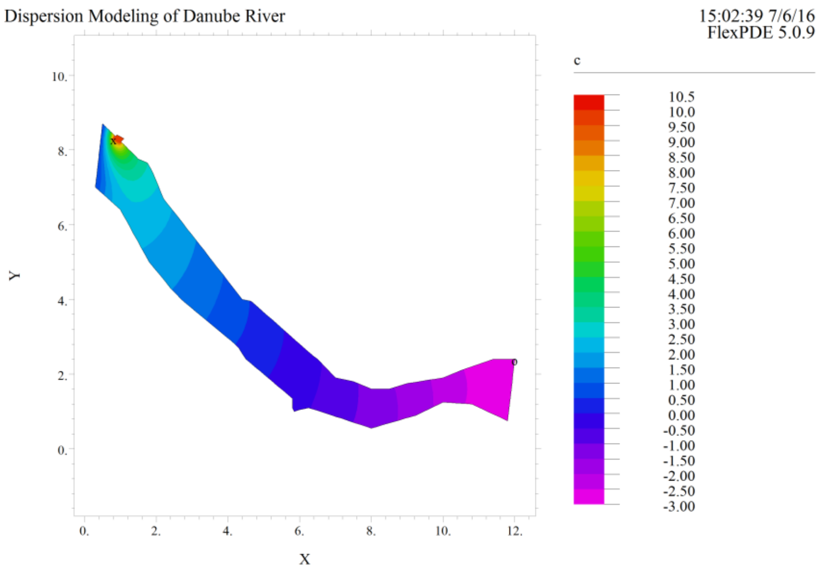

Fig 6 Dispersion of BOD from Jidostita tributary along Danube River, *u*= 2 and *v*= 0.2 (m/s)

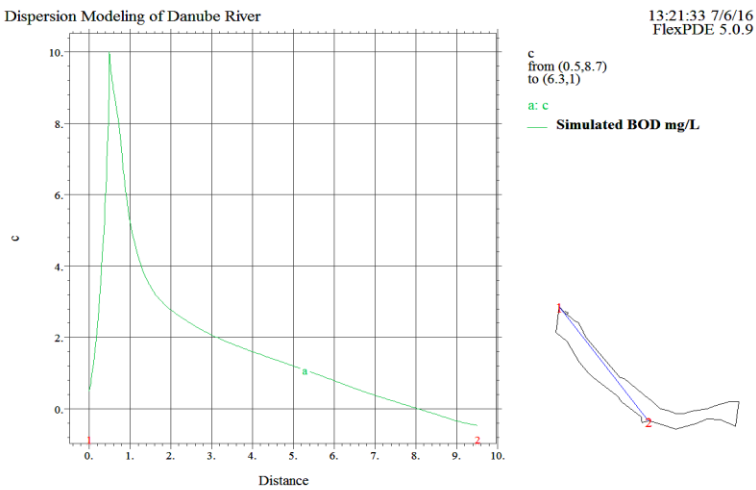

Fig 7 Graphical representation of predicted BOD concentration along Danube River, *u*= 2 and *v*= 0.2 (m/s)

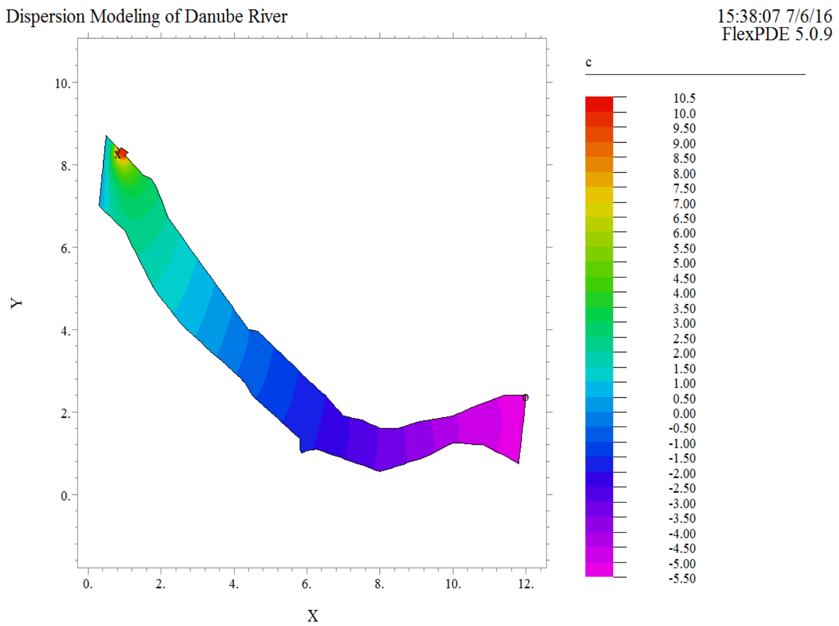

Fig 8 Dispersion of BOD from Jidostita tributary along Danube River, *u*= 1 and *v*= 0.1 (m/s)

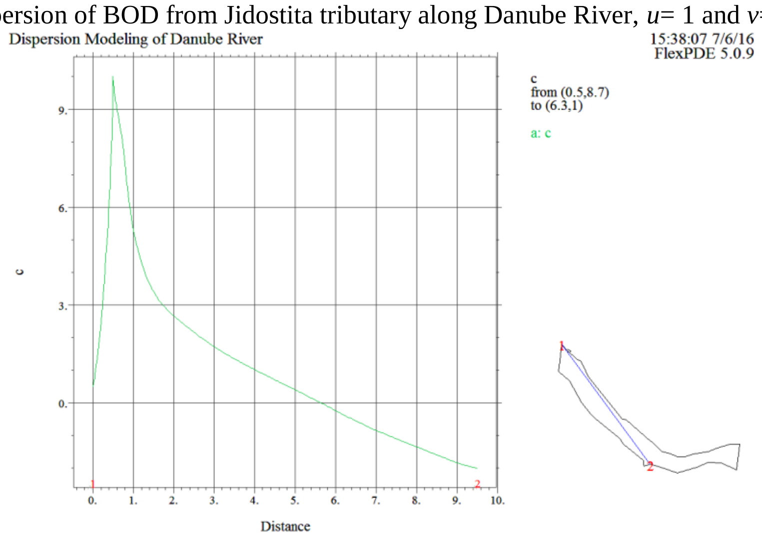

Fig 9 Graphical representation of predicted BOD concentration along Danube River, *u*= 1 and *v*= 0.1 (m/s)

In case 2, longitudinal velocity (*u*) and lateral velocity (*v*) were set as 2 m/sec and 0.2 m/sec respectively and the results are shown in Fig. 6 and Fig. 7. In this case, it can be observed that the BOD concentration at Gura Văii (2 km downstream of the Iron Gate 1) in the mid river is about 3 mg/L and this value decreased to less than 0.5 mg/L at Schela Cladovei station. No significant difference was noticed in comparison with previous case (case 1).

In case 3, longitudinal velocity (*u*) and lateral velocity (*v*) were set as 1 m/sec and 0.1 m/sec respectively and the results are shown in Fig. 8 and Fig. 9. In this case, it can be observed that the BOD concentration at Gura Văii (2 km downstream of the Iron Gate 1) in the mid river is about 2.5 mg/L and this value decreased to less than 0.5 mg/L at Schela Cladovei station.

Therefore, the variation in river velocity can affect the dispersion of BOD along the river, in spite of the simple variation between the three examined cases as shown in Fig. 10. It can be concluded that the higher the velocity in the river, the time required for self-purification increased for the river. Moreover, the self-purification process is highly affecting the BOD concentration in all cases in which, it is one of the most important indicators for the river health [26]. According to the results, it was noticed that in higher velocities, the river need long downstream distance to return to its original state by self-purification process.

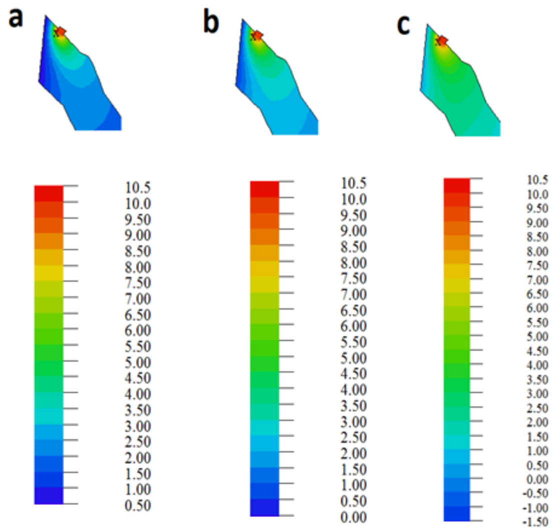

Fig 10 BOD dispersion from Jidostita tributary along the study region of Danube River for the three examined cases, a = case 1, b = case 2, c = case 3

4. Conclusions

Three different scenarios were presented to explore the effect of velocity variation on the dispersion behavior and to examine the effect of the pollution load from Jidostita tributary on the Danube River. The results demonstrated that the relationship between simulated results by FlexPDE was in agreement with the observed data. In cases 1, 2 and 3, the BOD concentration at Gura Văii in the mid river was about 3.5, 3, 2.5 mg/L respectively, and these values decreased to equal or less than 0.5 mg/L at Schela Cladovei station. In conclusion, the variation in river velocity can affect the dispersion of BOD along the river, in spite of the simple variation between the three examined cases.

Furthermore, the results revealed that, the higher the velocity in the river, the time required for self-purification increased. Moreover, the variations in simulation for BOD concentration along the downstream distance were insignificant due to the fact that the pollution load connected to the river from Jidostita tributary has low discharge compared to the flow of the river.

Further studies may be required to predict and simulate other parameters responsible for deterioration of the river water quality considering the other sources of pollution in the region.

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