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TEMPORAL VARIATION AND RELATIONSHIP BETWEEN HYDROLOGICAL PARAMETERS AND WATER POLLUTANTS ON THE LOWER DANUBE, ROMANIA

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Abstract

The interaction between hydrological parameters and aquatic quality parameters is important nowadays for integrated analysis of the status of an aquatic ecosystem. Discharge, flow speed, current direction, and water level represent some of the most important river parameters that can provide valuable information about the health and integrity of the ecosystem. At the same time, through an interdisciplinary approach that includes water pollution parameters, the status of the ecosystem can be analyzed in an integrated manner. A river's flow can influence how pollutants are transported and dispersed The study carried out on the Lower Danube River part aims for an integrated analysis of these parameters, to establish the behavior of water pollutants according to hydrological parameters. The results show an accumulation of high values of CCO and NH_4^+ *in areas where the hydrological regime of the river is attenuated water flow decreases and where the banks are less steep. By integrating data on hydrological parameters with water quality results we can contribute to the development of effective environmental management strategies to protect and conserve natural resources.*

Key words*: ADCP, pollutants dispersion, river discharge, Sound Velocity Profiler, water quality.*

INTRODUCTION

The application of traditional methods of assessing the quality of water and the correspondence with hydrological parameters, through determining chemical, biological, and physical parameters cannot fully cover all the questions (Albaggar, 2021). From this perspective, different methods are developed based on the interconnection and interdependence of the biotic indicators of the aquatic ecosystem and the characteristics of the habitat of the aquatic biota. The methods of estimating the quality of water and the ecological state of water ecosystems, used in the practice of water management, are based on the determination of chemical, biological, and physical indicators. The joint application of physical, chemical, and biological methods allows for a quantitative analysis of the state of the ecosystem as a whole. However, in many cases, it is impossible, for example, when planning measures for the use and protection of water resources on a large-scale area, where the strategy of using water parameters for a perspective period is considered in the scale of river section, river basin or country region (Salih et al., 2021). Due to its scale and multifactorial nature, this task is quite complex. A large amount of initial data is required, especially those that characterize the quality of water (concentrations of pollutants, hydrobiological indicators, hydrological parameters), while the information is necessary for different models of the water quality in different years (Islam et al., 2021). The situation is exacerbated by the necessity of forecasting the influence of anthropogenic activity on water ecosystems, especially trans-border water systems.

For this study, a proper water body is given by the lower course of the Danube River. This river section allows analysis of the correlation between physicochemical parameters and hydromorphological indicators, in terms of anthropogenic influence on a cross-border area (Iticescu et al., 2019; Radu et al., 2020).

The presented method allows for predicting the quality of water and the environmental condition of rivers using available information about the discharge, water velocity, and some river pollutants.

The study area is situated between 45°15'20" and 45°28'35" North Latitude and 28°00'29" 28°30'2" East Longitude. The total length of the river section is 57 km, with a medium width of 650m. For the water quality and hydromorphological assessment, 10 sampling points were established in the field (Figure 1).

To assess the influence of tributaries, two points were established on the Siret and Prut rivers.

MATERIALS AND METHODS

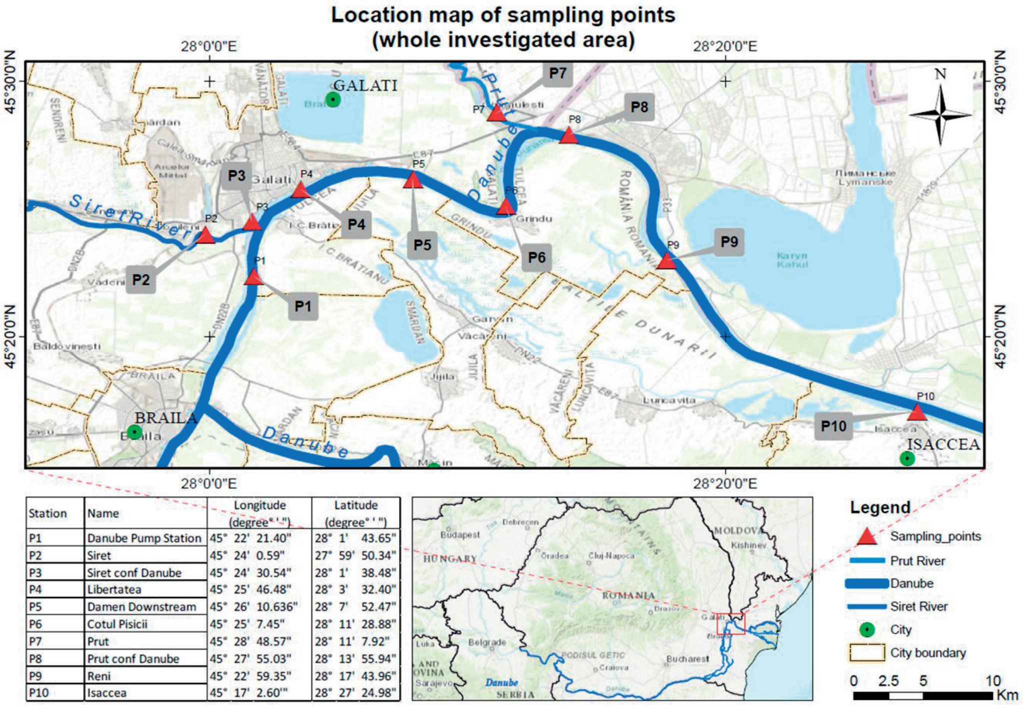
Sampling and survey step

Water was sampled from all 10 points and was made hydrological transects for discharge and flow velocity.

Water sampling was made with a telescopic surface water sampler with a biodegradable bottle (Figure 2). The Swing Sampler enables it to reach out up to 3 m from river banks to take a 1.0 L surface water sample. At the same time, different in-situ parameters were recorded: ph, conductivity, salinity, turbidity, and dissolved oxygen (DO).

Discharge measurement

Bathymetry is a branch of hydrology and is defined as a method that deals with the determination of depths in seas, lakes, rivers, streams, and canals, resulting in the creation of maps and bathymetric sections similar to topographical maps, highlighting the underwater relief (Banescu et al., 2020; Bănescu et al., 2019).



Station	Name	Longitude (degree° ' ")	Latitude (degree° ' ")
P1	Danube Pump Station	45° 22' 21.40"	28° 1' 43.65"
P2	Siret	45° 24' 0.59"	27° 59' 50.34"
P3	Siret conf Danube	45° 24' 30.54"	28° 1' 38.48"
P4	Libertatea	45° 25' 46.48"	28° 3' 32.40"
P5	Damen Downstream	45° 26' 10.636"	28° 7' 52.47"
P6	Cotul Pisicii	45° 25' 7.45"	28° 11' 28.88"
P7	Prut	45° 28' 48.57"	28° 11' 7.92"
P8	Prut conf Danube	45° 27' 55.03"	28° 13' 55.94"
P9	Reni	45° 22' 59.35"	28° 17' 43.96"
P10	Isaccea	45° 17' 2.60'"	28° 27' 24.98"

Figure 1. Location map of sampling and surveyed points

Figure 2. Water sampling and in situ water quality measurements

Currently, single-beam and multibeam sonar systems are used for bathymetric measurements. Sonar sends an acoustic wave from the bottom of a boat to the bottom of the water. One is reflected in the transponder. The time required for the sound wave to be sent and received determines the topography of the water bottom. The longer the time, the deeper water.

ADCP (Acoustic Doppler Current Profile) equipment is used to perform simultaneous measurements of discharge, flow velocities, and depth (Iuliana et al., 2022). This type of equipment is specially intended for measuring the flow rates, currents, depths, and bathymetry of rivers, channels, in various aquatic environments. The equipment can be used both from stationary vessels and from small and medium-sized boats in motion. One such equipment is the RiverSurveyor M9 ADCP system (Moradi et al., 2019), which is used to carry out the bathymetric measurement activity within the project (Figure 3). This equipment offers the possibility of determining the previously specified hydrological parameters. The system combines the acoustic Doppler mode for velocity profiles with a Windows-compatible software package that can be used on a personal computer (PC) or mobile device (smartphone).

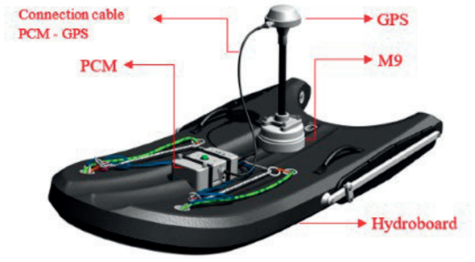


Figure 3. The M9 ADCP principal components

The bathymetric system is composed of the following basic components:

1) The M9 ADP complex system – represents a system with nine fascicles with two sets of four fascicles each for profiling (each set with its frequency) and one vertical fascicle. The M9 has a profiling range for velocities up to 40 m depth and a flow measurement range up to 80 m (when using GPS and vertical beam) (Arseni et al., 2022). Using the acoustic multi-frequency with precise band control, high-precision measurements are obtained and measurements can be made both on rivers and canals, starting from small depths (< 25 cm) to large depths (> 70 m). The M9 ADP module is equipped with a specialized microcontroller that automatically selects the appropriate acoustics and pulse schemes as it is crossed, or the transversal profile of a channel (bad) is created. The 9th beam is the fast-sampling, low-frequency vertical beam that extends the maximum measuring depth of the equipment and provides a superior definition of the channel surface for flow and bathymetry measurements.

2) The PCM module – represents the Power Supply and Communication Module that connects directly to the M9 ADP instrument, through a battery pack. It supplies power to the ADP and allows remote communication with a PC or a mobile device via a radio signal.

3) GNSS receiver - represents the equipment that allows positioning with a precision of less than 50 cm, using SBAS technology, through connection with the DGPS option. It is also connected to the PCM module. The DGPS data is received by the PCM at a frequency of 10 Hz and transferred to the internal memory of the ADP system for integration and processing.

4) Hydroboard II – represents the floating board that was specially created to be used together with the M9 ADP system and components. It is provided with a vertical mounting system for the M9 ADP system and the PCM mode.

A measurement in a transect made by a boat crossing from one bank to the other is divided into two key components: the starting edge, the transect, and the ending edge. So the total flow is calculated by summing the Start Edge, Top Estimate, Measured Area, Bottom Estimate, and

End Edge values (Figure 4) (Rennie & Rainville, 2008; Vermeulen et al., 2014).

Only the Measured Area is measured by the acoustic Doppler system, with the Start Edge and End Edge areas being estimated by automatic calculations (Figure 4).

The measurement limitations of the ADP system are imposed by several factors, such as the existence of a minimum depth at which the profiler can operate (for depths lower than the minimum operating value, the water speed and implicitly the flow must be estimated, based on the speed and the depth from the banks); the mounting depth plus a small distance (called the blind distance) from the instrument to the profile where the velocity measurement starts, leave a section of water from the surface (Figure 5), unmeasured (this surface is called the Top Estimate); possible contamination of the data from the last cell (e.g. the cell partially or completely touches the river bed) or the possible appearance of interference at the end of the profile, leaves a section from the bottom of the water unmeasured (called Bottom Estimate).

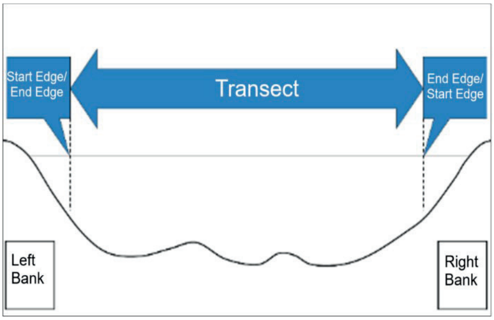


Figure 4. The generally divided sections of an M9 ADCP survey from an entire river cross-section

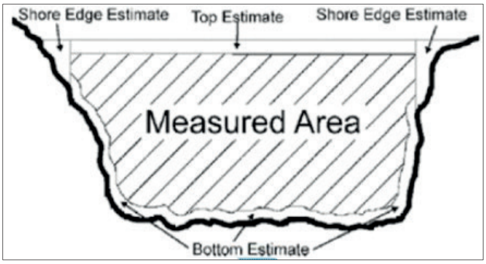


Figure 5. The measured area representation with Top, Bottom, and left/right Edge estimation

The measurement of flows, speed, and depth with RiverSurveyor M9 ADCP equipment consists of the following work steps:

a) mounting/attaching the RiverSurveyor equipment to a boat - the equipment can be mounted directly on the boat or attached to its side, to take measurements (Figure 6).

b) configuring the main settings of the equipment - this stage consists of checking all the basic settings and functional parameters of the equipment (checking the power supply, DGPS connection, and radio transmission, calibrating the compass, making a recording in test mode, checking the water temperature measurement, checking the records given by each cell, the introduction after pre-measurement tests of the initial data of the project.

The Velocity Profile Extrapolation technique is used to estimate the unmeasured values and is used to estimate the unmeasured areas from the base and surface. Velocity Profile Extrapolation uses an accredited velocity profile, proposed by Chen (1991), for the calculation of velocities above and below the Measured Area. The extrapolation is calculated using the next equation:

$$\frac{u}{u_*} = 9.5 * \left(\frac{z}{z_0}\right)^b \tag{1}$$

where:

- u represents the velocity at height z, measured from the base of the channel;
- u^* is the bottom shear velocity; z_0 is the height of the base roughness;
- b is a constant (equal to 1/6, according to Chen, 1991).

Figure 6. Basic configuration for data collecting of M9 ADCP system

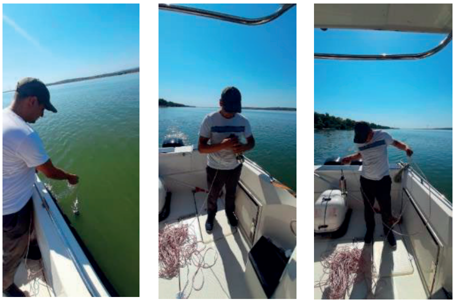


Figure 7. The survey with Swift SVP equipment

Sound velocity in water measurements

The ADCP survey was calibrated and adjusted with an in-situ survey of the following parameters: Sound velocity in water, Pressure, Temperature, Salinity, Conductivity, and Density. All these parameters were measured in situ with a Sound Velocity Profiler, produced by Valeport, model SVP Swift Profiler (Figure 7).

The SWiFT profiler is available for survey in two main forms – SVP and CTD. The SVP is fitted with sound velocity, temperature, and pressure sensors, the CTD is fitted with conductivity, temperature, and pressure sensors. Configuration and data download is via dedicated Valeport Ocean software to a PC or mobile device. The downcast mode of survey was used, by 1m trigger interval (Figure 8).

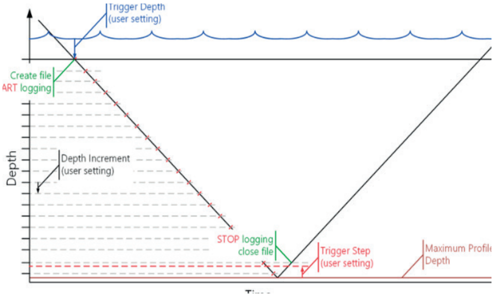


Figure 8. The downcast method of the SVP survey

RESULTS AND DISCUSSIONS

For the validation of the discharge measurements and the final flow rate, a series of at least 4 measurements were made in the same transect profile. Thus, those measurements were chosen that are very close, eliminating determinations with high deviation from the compared profiles.

For the determination of discharges and flow velocities, measurements were made with the ADCP equipment at each sampling point P1-P10, during 2 periods: July 2022 and October 2022. Next, the main results expressed graphically, for both bathymetric measurement campaigns, of flow velocities and flow rates for each sampling point are presented (Figure 9).

Table 1 presents the values data of discharge (Q), water level at Galati and Isaccea hydrometric station (WL_{GL}, WL_{IS}), maximum water velocity (V_{max}), mean water velocity (V_{avg}), maximum measured depth (D_{max}) and measured cross-section width (W).

The normalization of distance from the streambed, by separating each segment of the cross-section into 5 percent, ranging from 0.05 to 1, shows the deviation of discharge and depth data (Figures 10 and 11). The median value was used to represent each discharge section. Only medians with sufficient points were utilized to compute extrapolation for non-measured depth cells, using the 20% thresholds (Roșu et al., 2022). By breaking the cross-section into smaller parts and normalizing the distance, we effectively create a consistent framework for comparing data regardless of the section's exact size. The result of normalization show a deviation from median between 0.1 to 0.8.

The results of the 10 physico-chemical parameters of water quality (BOD_5, CCO, Cl^-, Fe^{2+}, N-total, NH_4^+, $N\text{-}NO_2$, $N\text{-}NO_3$, $P\text{-}PO_4^-$, SO_4^{2-}) analyzed ex situ using electrochemical and spectrophotometric methods following the standards in force and combined with the results of in-situ parameters (pH, conductivity, turbidity, dissolved oxygen,) were introduced in a mathematical model and computed for dispersion in the entire river section. By applying the ADCP survey results the dispersion model was calibrated.

The hydrological dispersion of water quality parameters shows how these move across a river channel. It takes into consideration both advection (moving with the flow of the river) and dispersion (spreading caused by turbulence or mixing) (Ciucure et al., 2023; Simionov et al., 2023).

The equation can be expressed as:

$$\frac{\partial P}{\partial t} + v_{avg}\frac{\partial P}{\partial d} = D\frac{\partial^2 P}{\partial d^2} \qquad (2)$$

where:

- P is the physico-chemical parameter concentration being transported;
- t is time; d is the distance along the river channel;
- v_{avg} is the mean velocity of the flow;
- D is the dispersion coefficient.

The maps from Figures 12 to 22 represent the geospatial dispersion of water quality parameters for the July and October survey campaigns (left respectively right image).

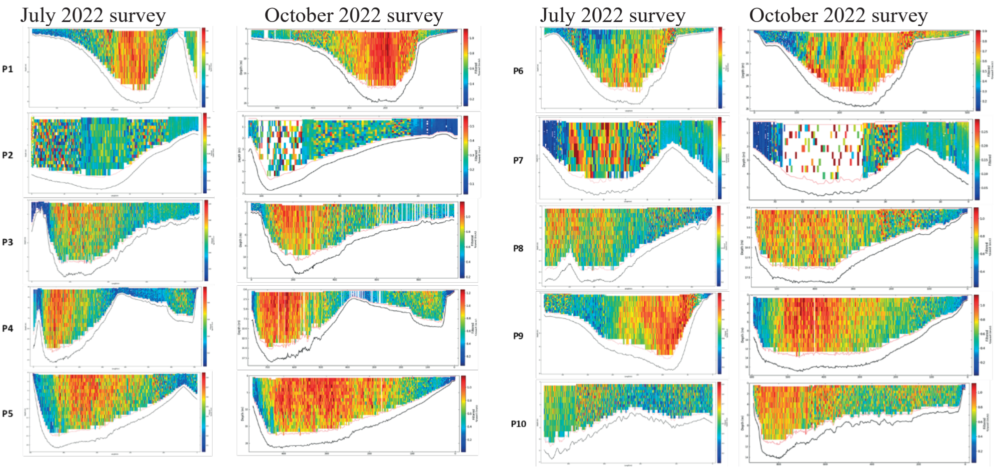
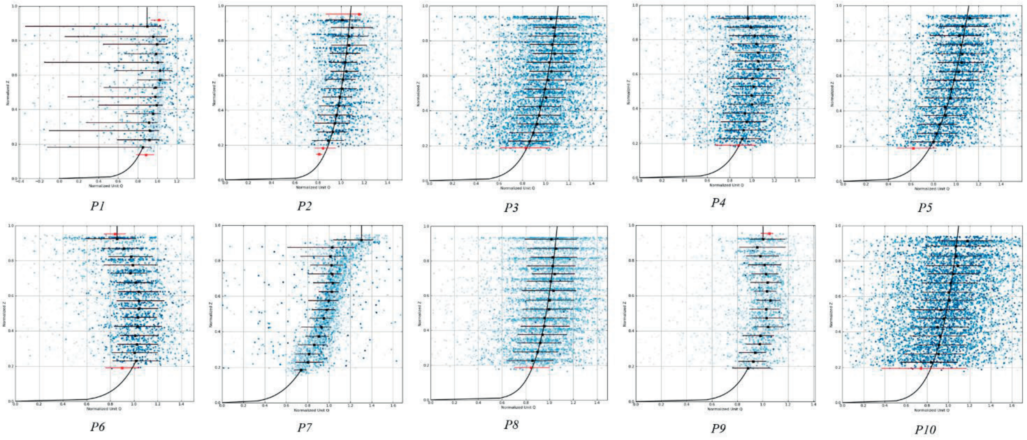


Figure 9. The flow velocity graphs obtained after the ADCP M9 transects was adjusted with SVP info

Table 1. The main surveyed hydromorphological parameters for the July and October 2022 campaign

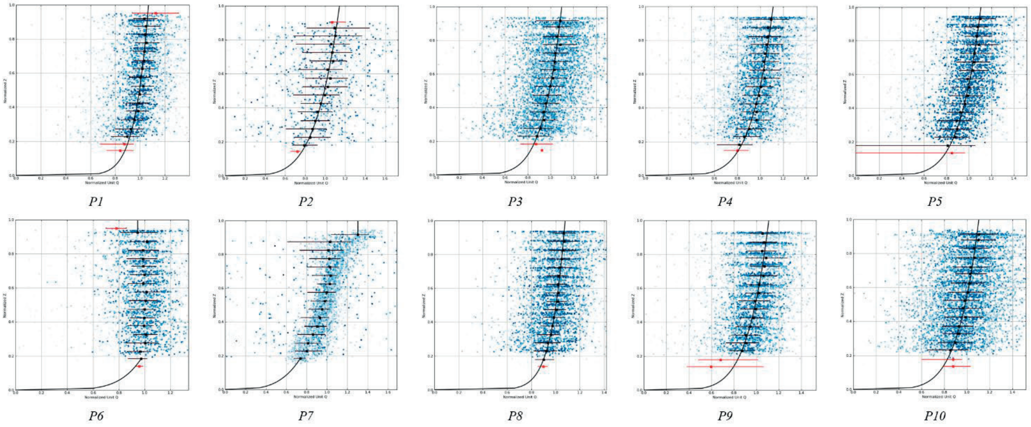
Station	July 2022 campaign							October 2022 campaign						
	Q [mc/s]	WL_{GL} [m]	WL_{IS} [m]	V_{max} [m/s]	V_{avg} [m/s]	D_{max} [m]	W [m]	Q [mc/s]	WL_{GL} [m]	WL_{IS} [m]	V_{max} [m/s]	V_{avg} [m/s]	D_{max} [m]	W [m]
P1 (Danube)	2916	0.79	0.80	1.080	0.518	25.827	569	4839	2.28	1.76	1.291	0.766	24.628	590
P2 (Siret)	53			0.607	0.242	4.814	98	91			0.750	0.234	6.869	109
P3 (Danube)	2854			1.460	0.520	24.011	952	4851			1.547	0.703	13.071	1041
P4 (Danube)	2943			1.302	0.485	18.428	715	4968			1.556	0.719	18.649	775
P5 (Danube)	2944			1.132	0.495	20.917	424	5138			1.326	0.745	21.377	491
P6 (Danube)	2851			1.002	0.386	32.380	525	4640			1.127	0.536	33.838	559
P7 (Prut)	30			0.645	0.115	5.701	74	33			0.648	0.119	5.786	77
P8 (Danube)	2949			1.048	0.481	17.509	617	4926			1.318	0.729	18.850	581
P9 (Danube)	3002			1.078	0.511	29.498	344	4908			1.366	0.718	16.941	545
P10(Danube)	2976			1.310	0.530	13.867	773	4941			1.357	0.662	14.255	895



P1 *P2* *P3* *P4* *P5*

P6 *P7* *P8* *P9* *P10*

Figure 10. The extrapolation statistical analysis depends on medians for depth data of each beam cell, for transects measured in the July 2022 survey campaign for P1 to P10 sampling station



P1 *P2* *P3* *P4* *P5*

P6 *P7* *P8* *P9* *P10*

Figure 11. The extrapolation statistical analysis depends on medians for depth data of each beam cell, for transects measured in the October 2022 survey campaign for P1 to P10 sampling station

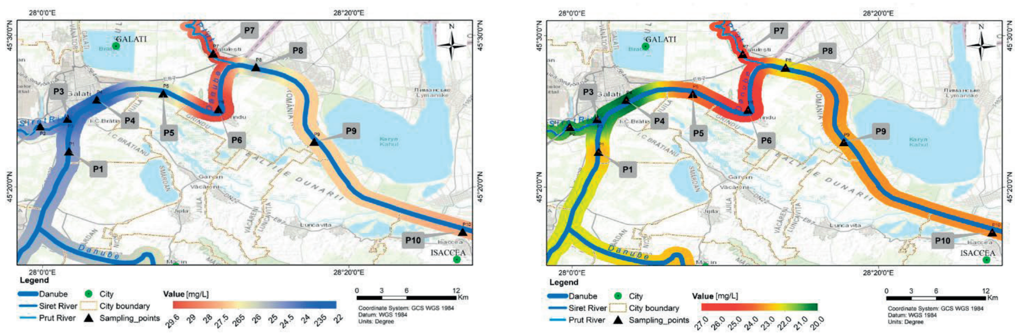


Figure 12. The dispersion map of BOD_5

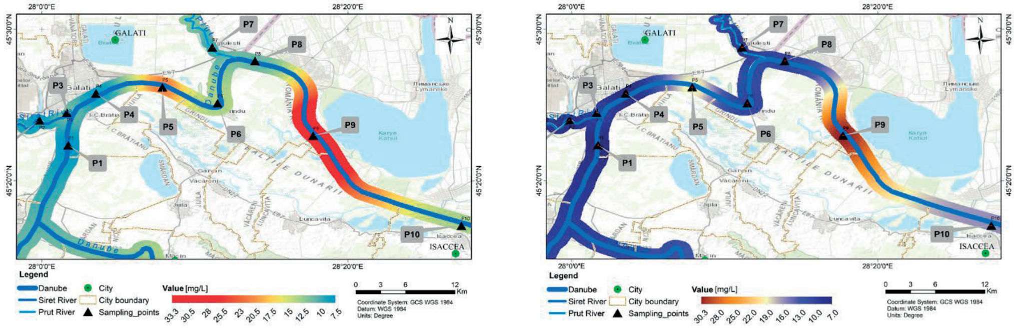


Figure 13. The dispersion map of CCO

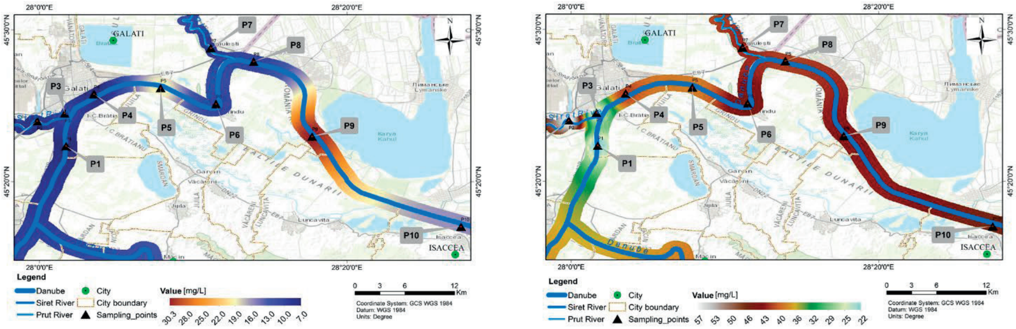


Figure 14. The dispersion map of Cl^-

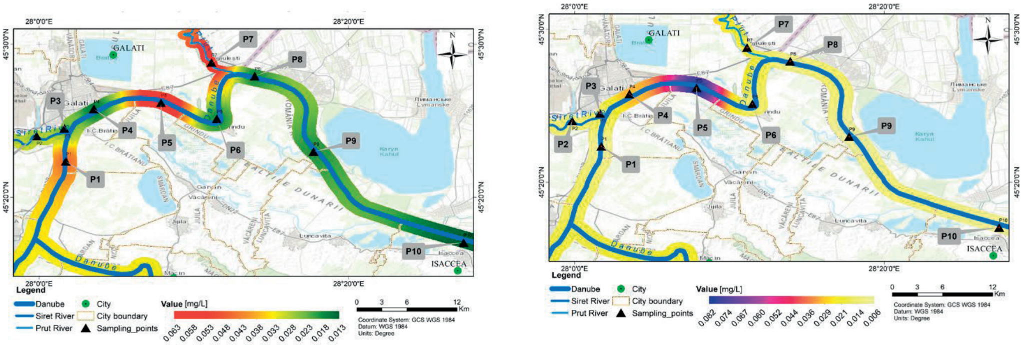


Figure 15. The dispersion map of Fe_2^+

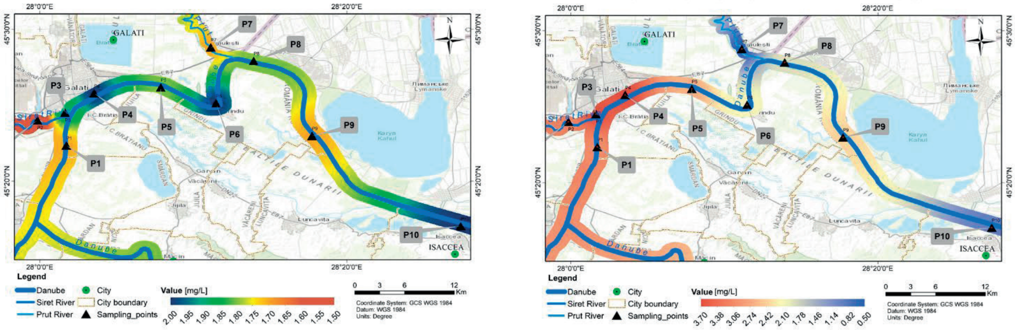


Figure 16. The dispersion map of N-total

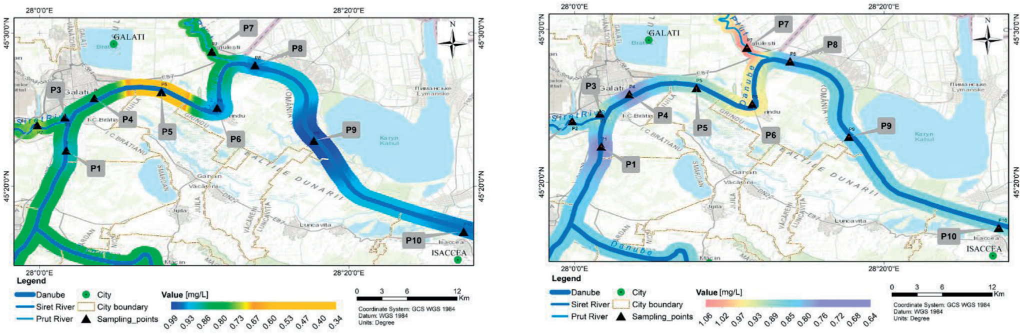


Figure 17. The dispersion map of NH_4^+

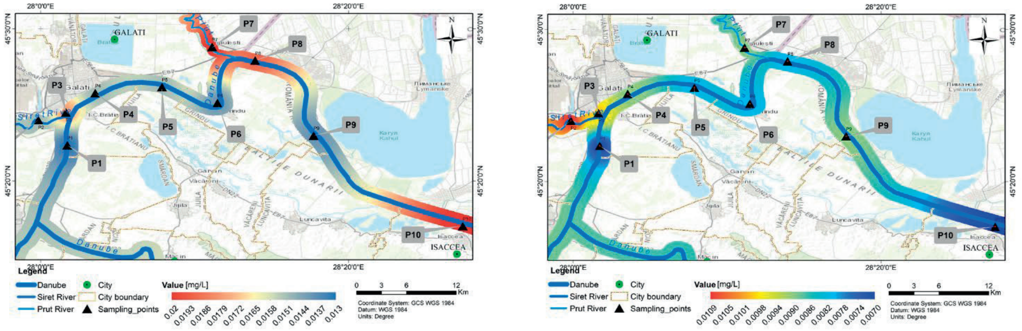


Figure 18. The dispersion map of N-NO_2

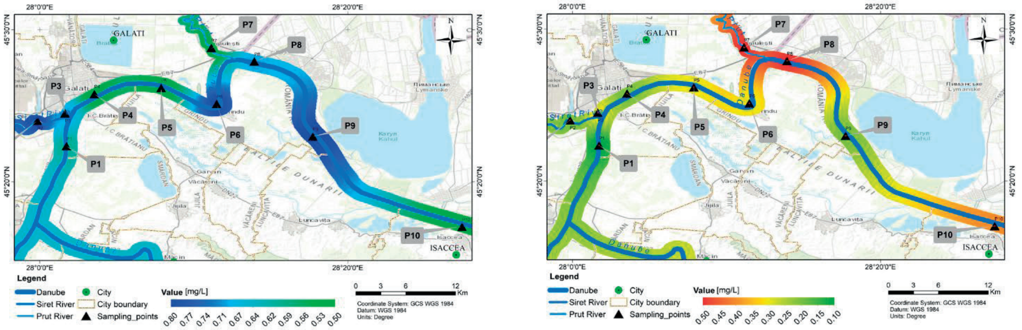


Figure 19. The dispersion map of N-NO_3

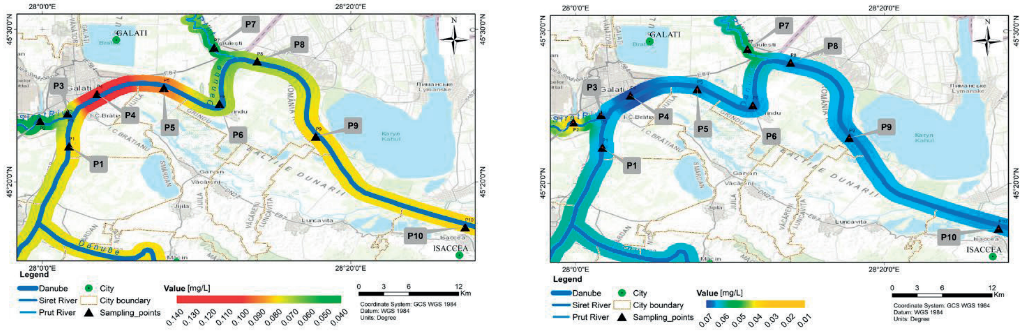


Figure 20. The dispersion map of P-PO_4^-

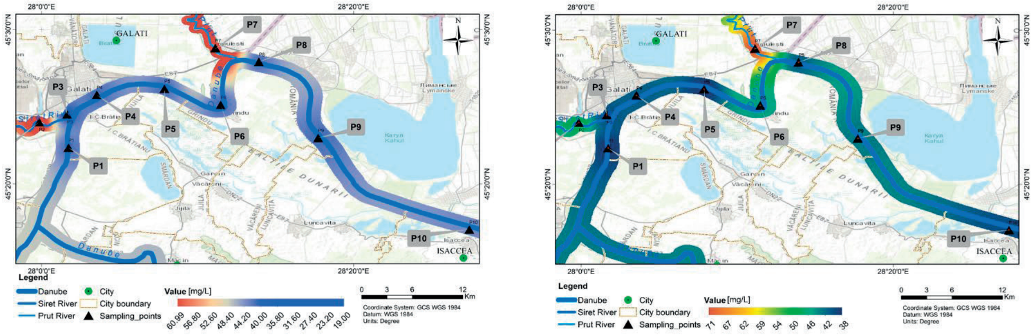


Figure 21. The dispersion map of SO_4^{2-}

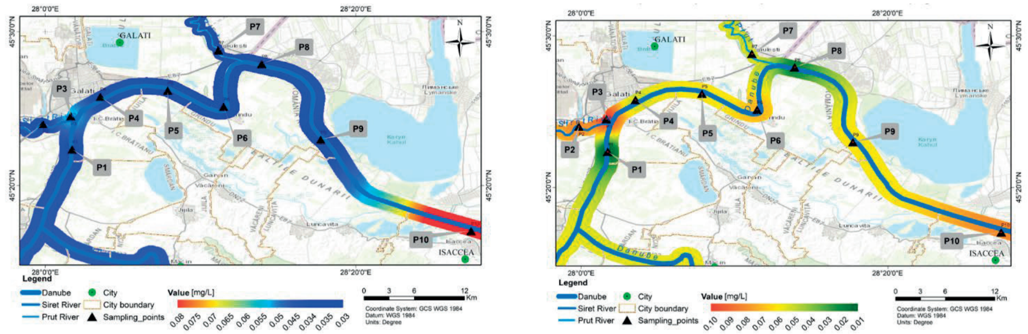


Figure 22. The dispersion map Phenols

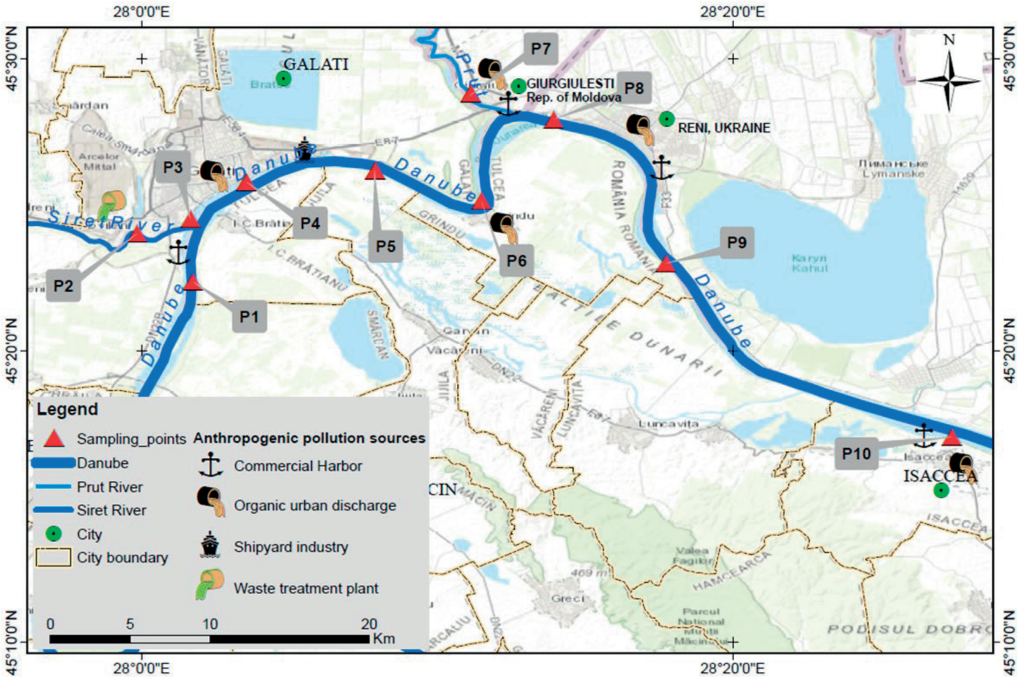


Figure 23. Location map of anthropogenic pollution sources

CONCLUSIONS

By analyzing the deviation of discharge and depth data within each segment, we can identify patterns such as areas of high variability or consistency vertically within the stream. This information can be crucial for understanding the flow dynamics and geomorphology of the stream, which is valuable for various applications such as hydraulic engineering, ecology, and water resource management.

ADCP system can measure water currents at multiple depths simultaneously, providing a comprehensive picture of current profiles over a vertical section. At the same time, it can provide real-time or near-real-time data, allowing researchers and scientists to monitor and respond to changes in current patterns promptly. Calibrating discharge measurements with a speed of sound in a water profiler is essential for improving the accuracy, reliability, and interpretability of hydrological data. From the calibrated results the maximum depth was at cross-section P9 (29.498m). The maximum discharge was recorded at the P9 cross-section in july campaign, and at P8 in october campaign. The hydromorphological form of crossection show that the speed of water deacrease near banks, wich means that the water pollutants accumulates more in these areas.

The dispersion map of physyco-chemical parameters indicates fluctuation of values between station. These are influenced by the anthropogenic activites (Figure 22). At the sime time there are fluctuation between values caused by sesonal time variation. These sesonal variations are influenced by the climate change indicator (Voiculescu et al., 2020), such as water and air temperature, humidity, air pressure.

In conclusion, the dispersion map shows a direct correlation between water velocity and pollutant transport. The slower water velocities result in longer retention times, allowing pollutants more time to settle or be taken up by aquatic organisms, potentially reducing dispersion. However, stagnant or slow-moving water can also lead to localized accumulation of pollutants. On ve over hand higher water velocities can carry pollutants further downstream, increasing the spatial extent of pollution.

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