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Transboundary river water quality as a core indicator for sustainable environmental development in Europe: A case study between republics of Bulgaria and Serbia

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ABSTRACT
In recent years, the issue of the sustainable management and protection of water resources has gained increasing emphasis in environmental policies at the local, national and supranational levels. The goal of the present study is the analysis and assessment of water quality in the Bulgarian section of the Timok, Nishava and Erma (Jerma) rivers for the period 2015-2021. The quality status of the studied river courses was assessed by the values of ten physicochemical indicators and the concentrations of eight heavy metals. The analysis and assessment performed were based on the Water Act (WA) in accordance with the criteria by Directive 2000/60/EC or so called Water Framework Directive. The Canadian Water Quality Index (CWQI) was applied for the analysis. Achieving the goal formulated in the study could serve as a good basis for making informed management decisions.

Keywords: Transboundary waters, Water quality, Sustainable development.
Article type: Research Article.

INTRODUCTION
Water, energy, food and ecosystems form a special interrelationship which plays a fundamental role in providing the resources and services necessary to sustain human activity. This relationship is affected both by changes in climate, precipitation and land cover on one hand, and by economic development, agriculture and population growth on the other. A wide range of experts are working to determine how the water-energy-food nexus fosters the coherence of water, energy and food policies, supporting the transition to a circular and low-carbon economy in Europe (Internet 1). In many ways, water is a local resource. Changes in the quantity or quality of water have a direct impact on the local environment and the local population (Omidi & Shariati 2021; Fatih Ali *et al.* 2021; Heidari *et al.* 2022; Abdulkareem Hussein *et al.* 2022). Water in general is also a global resource and a common good, shared by all people and all living creatures on the planet. It moves across borders connecting countries both physically and culturally (UNEP 2016). In recent years, the issue of the sustainable management and protection of water resources has gained increasing emphasis in environmental policies at the local, national and supranational levels. The activities for protection from pollution and for restoration of the quality of water bodies offer opportunities in cooperation and assistance to overcome the challenges by using a multidisciplinary and cross-sectoral approach - both in the interest of the economic and ecological needs of the society (UNEC 2015). The European policy in the field of environment is also based on the principle of precautionary measures, preventive actions and elimination of pollution at the source, as well as on the principle "the polluter pays". The multi-annual programs set the framework for future action in all areas of environmental policy. They are part of the horizontal strategies and are taken into account in the framework of international negotiations in relation to environmental protection (Internet 2). Transboundary waters represent 60% of the world's freshwater flows, and

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153 countries have territory within at least one of 286 transboundary river and lake basins and 592 transboundary aquifers. Only 32 countries have 90% or more of their transboundary basin area covered by operational agreements. Only 24 countries reported that all of their transboundary basins were covered by cooperative agreements (Kolcheva 2020; Internet 3). Both Republic of Bulgaria and Republic of Serbia are good examples of such cooperation. Bilateral cooperation is presented both within the framework of European programs such as – "INTERREG-IPA Cross-border Cooperation Bulgaria-Serbia Programme, adopted by the European Commission with Decision No C (2015) 5444 on 30 July 2015 and financing projects related to development of sustainable tourism, youth and environment", as well as in interdepartmental agreements such as the "Memorandum of Understanding between the Ministry of Environment and Water of the Republic of Bulgaria and the Ministry of Environmental Protection of the Republic of Serbia on cooperation in the field of environmental protection" signed in Dimitrovgrad on 22.01.2019" (Internet 4 and Internet 5). The main goal of the present study is the analysis and assessment of water quality in the Bulgarian section of the Timok, Nishava and Erma (Jerma) rivers for the period 2015-2021. Achieving the goal formulated in that way could serve as a good basis for making informed management decisions – a necessity for the resolution of important environmental problems and societal challenges corresponding to human health and societal needs (Fig. 1).
In order to realize the goal set that way, the following tasks have been completed:
– a database was created containing information on the values of selected physicochemical quality indicators, including heavy metals;
– an assessment of the water quality status was made, by using a complex water quality index (WQI);
– an analysis of the values of the studied qualitative parameters was carried out.

MATERIALS AND METHODS

Study area

The negative impact of anthropogenic activity on the natural environment, including water, is primarily expressed in concentration change of the imported pollutants (also contained in the natural state of the environment). Pollution as a result of adverse anthropogenic impacts is directly related to the disruption or suspension of the normal functioning of water ecosystems, including river ones. Nowadays, anthropogenic impacts on water quality are diverse, dynamic, and significant in quantitative terms. In the modern development of the economy, the issue of protecting water bodies from pollution is gaining more and more importance. The hydro-ecological problems arising as a result of the change in the quality of the waters could expand their territorial scope and grow from local to regional (Gartsiyanova 2022). The choice of the research area in the present article is justified by the diverse natural conditions in combination with the various anthropogenic activities, which have a parallel and interconnected effect in the process of formation and change in the quality of river waters. Timok River is the largest river in Eastern Serbia (202 km, 16 km common border between Serbia and Bulgaria) and the last tributary of the Danube River on Serbian territory. Its river basin is located between 43°15' and 44°15' N, and 21°30' and 22°45' E, and covers an area of 4,547 km² - 132 km² in Bulgaria. The largest tributary of the Timok River is the Borska River with a length of 47 km and an area of 364 km². Borska River is one of the most polluted river courses in Serbia and in Europe in general. Mining and ore processing enterprises have been operating in the river basin for years. In addition, the waters of the Borska River are subjected to pollution of a communal and domestic nature (Brankov *et al.* 2012). Nishava River springs east of Kom Peak in Mount Stara Planina and is a right tributary of the South Morava River. In Berkovska mountain and in its upper reaches it is called Ginska River. Nishava River leaves the territory of Bulgaria western of Kalotina vilage and passes through Tsaribrodsko and Pirotsko fields, where the river Temska flows into it. After the area of Bela Palanka, it forms the impressive Sichevska Gorge. In Serbia, Nišava passes through the cities of Tsaribrod, Pirot, Bela Palanka, Niška Banya and Niš. The catchment area of the river in Bulgaria and its length are 659 km² and 52 km respectively. The length of the river on Serbian territory is 166 km and the total catchment area of the river covers 3950 km². In Bulgaria, the Nishava catchment covers the north-western parts of the Sofia region and the northern parts of the Pernik region. The waters of the Nishava River are mainly used for water supply, agriculture, fishing and recreation. The quality of river waters is a result of the impact of not many sources of pollution and the lack of treatment facilities (Nikolić *et al.* 2006). Erma (Jerma) River collects its waters on the north-western slope of the village of Tsvetkov Grob (1489 m) in the westernmost branches of Karvav kamak mountain on the territory of Serbia. The river flows in a north-northeast direction, taking in numerous small left and right tributaries. Its length is 74 km, 25 km of which are in Bulgaria. It crosses the Serbian-Bulgarian border close to the village of Strezimirovtsi. There are no significant settlements or industrial sites in the Serbian section of the watershed. The several hamlets and villages in this section are sparsely populated with mostly elderly people. Most of the settlements have no sewage systems and waste water is discharged into septic tanks. The catchment area of the river in Bulgaria is 430 km². Passing through the Bulgarian territory, in the area of the village of Bogoyna, Erma (Jerma) River enters again in Serbia, and in the area of the village of Gradishte, it flows into the Nishava River (Internet 6).

Fig. 1. Study area.

River water monitoring points, study period and samples.

The analysis and assessment of the quality of the river waters for the period 2015-2021 in selected points of the studied watersheds are based on data provided by the Environmental Executive Agency (ExEA) part of the Ministry of Environment and Water (MOEW). Due to the specificity of the sampling and the completeness of the data, to achieve the goal of the present study, the monitoring points presented on Fig. 1 and Table 1 were selected. The quality status of the studied river courses was assessed by the values of the physicochemical indicators including pH, electrical conductivity, dissolved oxygen, ammonium nitrogen ($N\text{-}NH_4$), nitrates ($N\text{-}NO_3$) and nitrites ($N\text{-}NO_2$), orthophosphates ($P\text{-}ortho\text{-}PO_4$), total nitrogen and phosphorus content, BOD_5 and the concentration of the following heavy metals including iron (Fe), manganese (Mn), cadmium (Cd), lead (Pb), arsenic (As), copper (Cu), nickel (Ni), zinc (Zn).

Table 1. Information for the selected monitoring points.

Name of the monitoring point	Code of the water body	Code of the type of the water body	Period of the study	Code on the map
Timok River at the point near	BG1WO100R001	R8*	2015-2021	T1
Nishava River at the point near Kalotina	BG1NV200R1001	R2**	2015-2021	N1
Erma River at the point near the village of Strezimirovtsi	BG1ER100R001	R2	2015-2019	E1
River Erma at the point after Tran	BG1ER100R001	R2	2015-2021	E2

Note: ***Plane type of the water body; ****Mountain type of the water body.

Legislation

Human activities can exhibit an adverse impact on the environment and in particular on water. Such negative impact subsequently affects people’s well-being. Given the primary importance of water in nature, its management and rational use at the European Union level, a key element of water legislation in the European Union is Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 or so called Water Framework Directive, Directive 2000/60/EC (Internet 7). This directive is setting out the framework for action in the field of water policy. Member States should strive to achieve at least "good" ecological and chemical status of water bodies, take preventive actions, apply the "polluter pays" principle as well as ensure dialogue and cooperation regarding the use and protection of waters in the international river basins. Very often, policies regarding water conservation and management transcend national boundaries. In that sense, as an EU member Bulgaria is a party to the ratification in a number of international conventions, among which, in direct connection with this study, are: Convention on the Conservation and Use of Transboundary Watercourses and International Lakes Done at (Helsinki, 17 March 1992) and Convention on cooperation for the protection and sustainable use of the Danube River (29 June 1994, Sofia, Bulgaria State Gazette № 30/1999; Internet 8 and Internet 9). In addition, on 06.05.2022, the Republic of Bulgaria and the Republic of Serbia signed a bilateral "Agreement on Environmental Impact Assessment and Strategic Environmental Assessment in a Cross-Border Context". In connection with the sustainable development of society and acceleration of the transition to low-carbon emissions in all sectors of the economy in Europe, in many European countries, including Serbia, special attention is paid to issues related to environmental protection, including water resources (Brankov *et al.* 2021). Since 2007, Republic of Serbia has been working intensively to improve its legal and political framework, and in 2009 the country adopted the basic package of laws governing the use and protection of natural components. On the basis of these laws, more than 300 by-laws were subsequently adopted. A fundamental strategic document in the water sector in Republic of Serbia is the adopted 10-year general water plan from 2002 (OB 11/02). With regard to modern Bulgarian legislation, the issue of state water management finds expression and a normative solution initially in the country's Constitution, and in 1999 a new Water Act (WA) was adopted. Currently, many laws, acts, regulations, rules, decrees, decisions, etc. are changed in accordance with European requirements. In the present study, the hydro-chemical analysis and assessment performed are based on Ordinance N-4 on surface water characterization (2012) and Ordinance on environmental quality standards for priority substances and some other pollutants (2010; (Internet 5; Tables 2-3).

Table 2. Physicochemical elements for quality (category “River”) according to Ordinance N-4 on surface water characterization (2012).

Status	River Type	Dissolved oxigen (mg L^{-1})	pH	Electroconductivity (µS sm^{-1})	$N\text{-}NH_4$ (mg L^{-1})	$N\text{-}NO_3$ (mg L^{-1})	$N\text{-}NO_2$ (mg L^{-1})	Total N (mg L^{-1})	$P\text{-}PO_4$ (mg L^{-1})	Total P (mg L^{-1})	BOD^5 (mg L^{-1})
Fair	Mountain	6.00-8.00	6.5-8.5	750	0.04-0.4	0.2-0.5	0.01-0.025	0.2-0.8	0.01-0.02	0.012-0.03	1-2.5
	Semimountain	6.00-8.00	6.5-8.5	750	0.04-0.4	0.5-1.5	0.01-0.03	0.5-1.5	0.02-0.04	0.025-0.075	1.2-3
	Plane	6.00-7.00	6.5-8.5	750	0.1-0.3	0.7-2	0.03-0.06	0.7-2.5	0.07-0.15	0.15-0.3	2-4

Table 3. Chemical elements and priority substances and their quality standards of the environment (Ordinance on environmental quality standards for priority substances and some other pollutants (2010) and Ordinance H-4 on surface water characterization (2012).

№	Chemical Element (Specific pollutants)	AAV* - EQS*** (µg L^{-1})	MPC** - EQS*** (µg L^{-1})
1.	Arsenic (As)	10	25
2.	Copper (Cu)	1 ($CaCO_3$ 0-50 mg L^{-1}) 6 ($CaCO_3$ 50-100 mg L^{-1}) 10 ($CaCO_3$ 100-250 mg L^{-1}) 22 ($CaCO_3$ > 250 mg L^{-1})	not applicable
3.	Iron (Fe)	100	not applicable
4.	Manganese (Mn)	50	not applicable
5.	Zinc (Zn)	8 ($CaCO_3$ 0-50 mg L^{-1}) 40 ($CaCO_3$ 50-100 mg L^{-1}) 75 ($CaCO_3$ 100-250 mg L^{-1}) 100 ($CaCO_3$ > 250 mg L^{-1})	not applicable
	Priority substances		
6.	Lead (Pb)	1.2	14
7.	Cadmium (Cd)	0.25	1.5
8.	Nickel (Ni)	4	34

*Average annual value **Maximum permissible concentration *** Environmental quality standards

Applied methods

Water quality testing requires the measurement of its physicochemical and biological properties against a certain set of standards. It plays a key role in cases where an assessment has to be made if the water quality is high enough so the water could be used for consumption, irrigation or other purposes, or to be assessed if the water content is perilous or not for the existence of aquatic ecosystems, etc. Nowadays, dozens of indices are used and developed worldwide for a complex assessment of water quality or degree of pollution (Uddin *et al.* 2021; Sutadian *et al*. 2016; Feng *et al.* 2016). Some of them are internationally applied, some are specific for particular country, and others are designed to solve a specific task. Complex index evaluations provide a general idea of the overall state of water quality by obtaining a score or rank value. At the same time, however, it is possible to determine the degree of pollution of water systems by individual components. The Canadian Water Quality Index (WQI, CCME 2001) applied in the present study refers to the group of so-called "open" assessments, where the user chooses the set of physicochemical indicators, applies the relevant reference values depending on the legislation, determines the volume of available information, etc. WQI, CCME 2001 is accepted as one of the eight basic complex indices on the basis of which the others are developed and is recommended by UNEP (United Nations Environment Programme). It has a number of advantages compared to other complex index assessments. CCME WQI is relatively easy to use. It is flexible both in the selection of water quality parameters and in its ability to represent measurements of different variables in a single number. The index also has the ability to combine various measurements with different units. The mathematical algorithm itself is briefly presented below. In practice, the index is a result of three main components: F1 (impact range), F2 (frequency) and F3 (amplitude). F1 expresses the range of quality indicators, the values of which do not meet the normatively determined ones. F2 shows the proportion of samples in which the content of a potential pollutant above the reference values was found, compared to the total number of samples. F3 represents the degree of deviation or the multiplicity of the so-called "bad samples" of the quality ingredients, which are divided into three groups. The first group includes the values with registered deviations up to 10 times the norms. In the second group are those between 10 and 25 times, and in the third the amplitude "bounces" more than 25 times from the regulated values. The applied model CCME, WQI also offers a differentiation of the quality state of the waters in the following categories: excellent (WQI = 95 – 100); good (WQI = 80 – 94); fair (WQI = 65 – 79); marginal (WQI = 45 – 64); poor (WQI = 0 – 44). The index itself is calculated by the following formula:

$$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1{,}732}\right)$$

The application of the complex methods for assessment and analysis of the state of surface water bodies in Bulgaria, and in general the issues related to the quality of river waters in our country, have become more relevant since the 1990s. For the first time, CCME, WQI was applied by Varbanov M. (2007) as a result, the scientific developments of Varbanov & Gartsiyanova (2017), Varbanov & Gartsiyanova (2015), Gartsiyanova & Varbanov (2015), Gartsiyanova (2018), Gartsiyanova *et al.* (2021), Gartsiyanova *et al.* (2022) and others, have made a significant contribution on that field of science. The results obtained from the conducted research and the accumulated empirical material by the authors are a good basis for the preparation of a regional qualitative categorization of surface waters in the country. In order to realize the set goal in the present study, mathematical-statistical, comparative, chamber, graphic and cartographic methods were also applied.

RESULTS AND DISCUSSION

The results obtained for the quality of surface waters of *Timok River at the point beside Bregovo* are defined as "polluted" and "heavily polluted", which is the reason why the river in this section does not fulfil the conditions for "good" physicochemical condition in any year of the study period (2015-2021). The lowest WQI score was recorded in 2018 and was only 30.2, while the highest (still in the critical range) was 57.8 in 2015 (Figs. 2-3). It is clear from the component analysis that the deteriorated condition of the river waters is mainly due to the "bad" values of the heavy metal content. The recorded pollution with heavy metals at the mouth of the studied river is characterized by the high concentration, especially of copper (Cu), zinc (Zn) and cadmium (Cd). Values that exceed the standards by more than 25 times for the above-listed metals remain constant over time. The recorded values of copper (Cu) are particularly impressive. During the studied seven-year period, they exceeded the regulated standards 25 times. For example, on September 12, 2017, an extreme value of 480 µg L-1 was recorded. According to the same indicator, deviations from the norms up to 10 times and between 10 and 25 times are not detected. The results obtained on the basis of the processed available data, shows that during the study period the concentrations of zinc (Zn) and cadmium (Cd), which exceed the quality standards, vary in the entire range of non-compliance (up to 10 times, from 10 to 25 times and over 25 times). The analysis shows that while at the beginning of the period (13.09.2016) according to the cadmium (Cd), a single value was registered that deviated from the quality criteria more than 25 times, in the following years the number of these values gradually increased and they became predominant at the end of the study period. The highest content was registered on 13.11.2018: 630 µg L-1 for zinc (Zn) and on 15.10.2019: 43.80 µg L-1 for cadmium (Cd). From the results obtained for the physicochemical pollution of the surface waters by components including electrical conductivity, total nitrogen (N), total phosphorus (P), nitrate (N-NO3) and ammonium (N-NO3) nitrogen, orthophosphates (P-PO4) and BOD5, it becomes clear that the excesses of the registered values are non-permanent or episodic up to 10 times above the normatively determined ones.

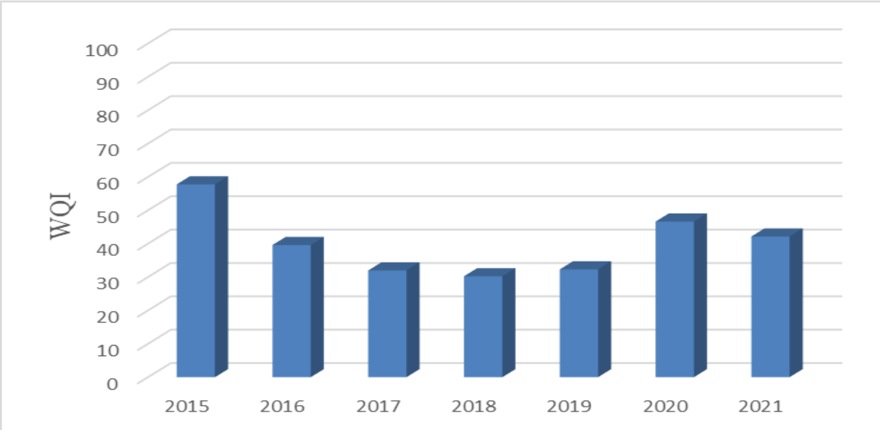

Fig. 2. Change in WQI values calculated for the Timok River at the point beside Bregovo in the period 2015-2021.

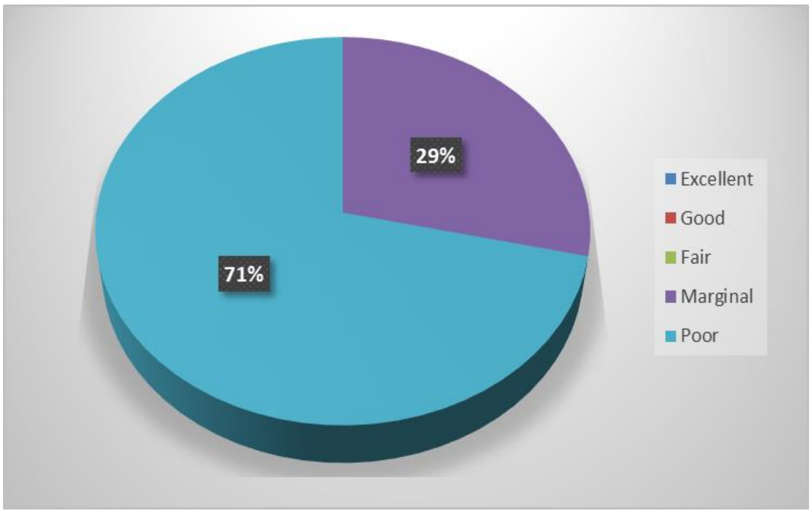

Fig. 3. Distribution of the water quality status of the Timok River at the point beside Bregovo by categories (in %).

The WQI values calculated for *Nishava River at the point beside Kalotina* place the river course in the category "very good". In that way, the waters there during the studied period fully meet the criteria for achieving a "good" quality status (Figs. 4 - 5). As a result of the differentiated assessment, the main inconsistencies from the reference values (up to 10 times above the norms) were detected for pH, nitrites ($N\text{-}NO_2$), total phosphorus (P), total nitrogen (N) and orthophosphates ($P\text{-}PO_4$). The values of these indicators during the studied period lead to a conclusion that the quality of the river waters is formed under the impact of single isolated cases of anthropogenic pressure. Regarding the heavy metals, calculations show that only the content of Cu (in each of the studied years) exceeded (up to 10 times) the quality standards, with the highest concentration recorded on 15.04.2021: 10 µg L^{-1}. During the study period, the waters of Erma (Jerma) River at the point beside the village of Strezimirovtsi (Figs. 6-7) were in "very good" quality condition. Individual cases of exceeding (up to 10 times) the standards for "good" quality in terms of total nitrogen (N) and total phosphorus (P) were registered. The reported values of the content of heavy metals indicated small and non-permanent exceed of the standards (up to 10 times) for iron (Fe) and manganese (Mn) over time.

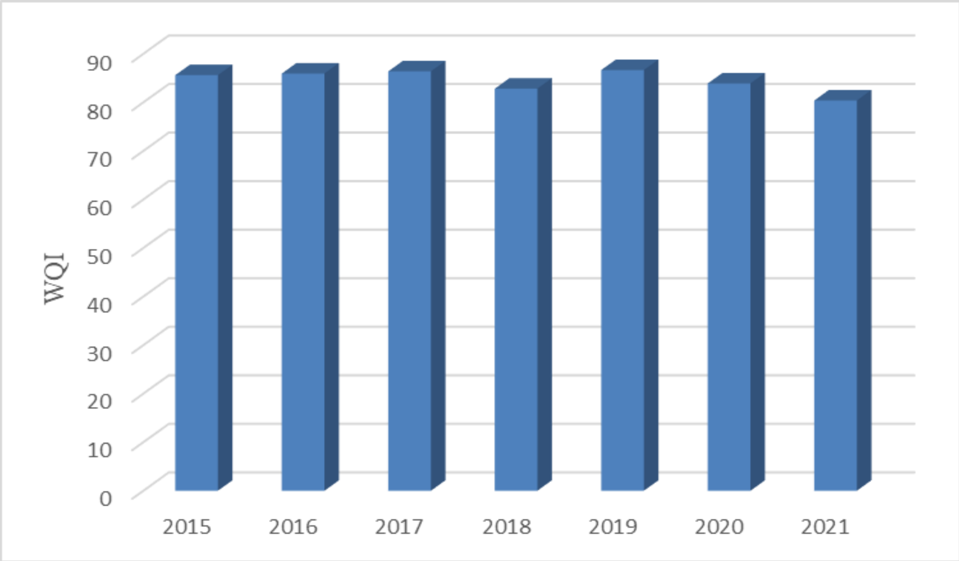

Fig. 4. Change in WQI values calculated for the Nishava River at the point beside Kalotina in the period 2015-2021.

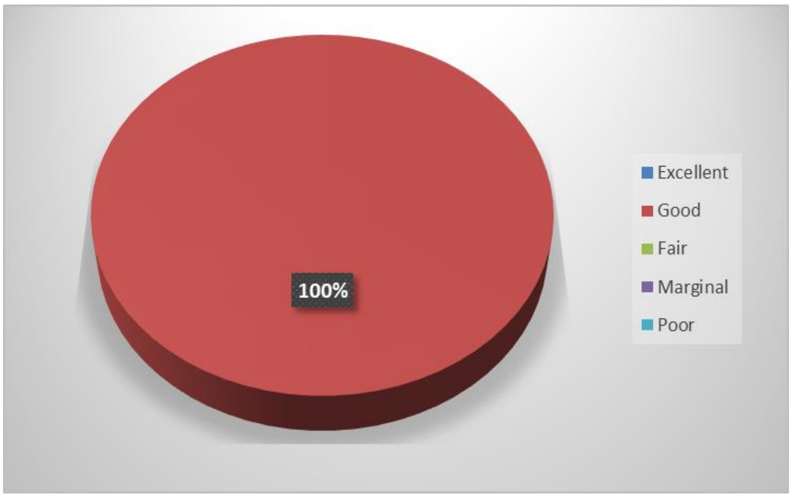

Fig. 5. Distribution of the water quality status of the Nishava River at the point beside Kalotina by categories (in %).

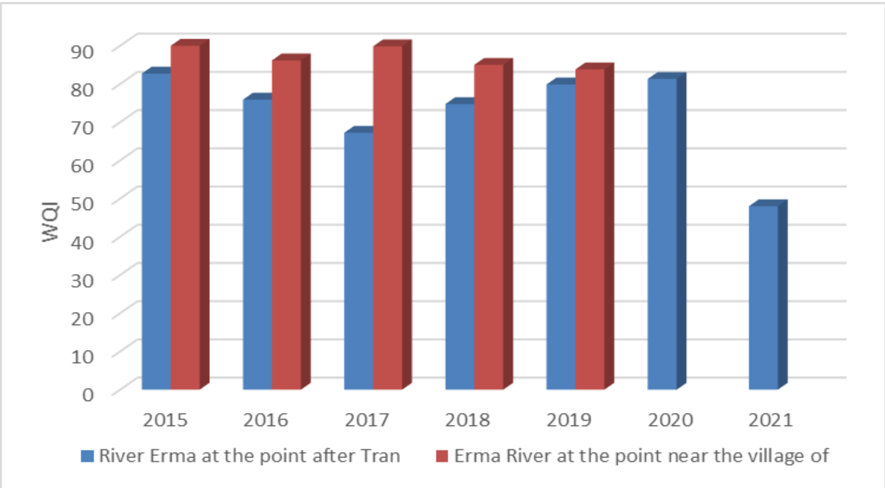

Fig. 6. Change in WQI values calculated for the Erma (Jerma) River at the point beside the village of Strezimirovtsi in the period 2015-2021.

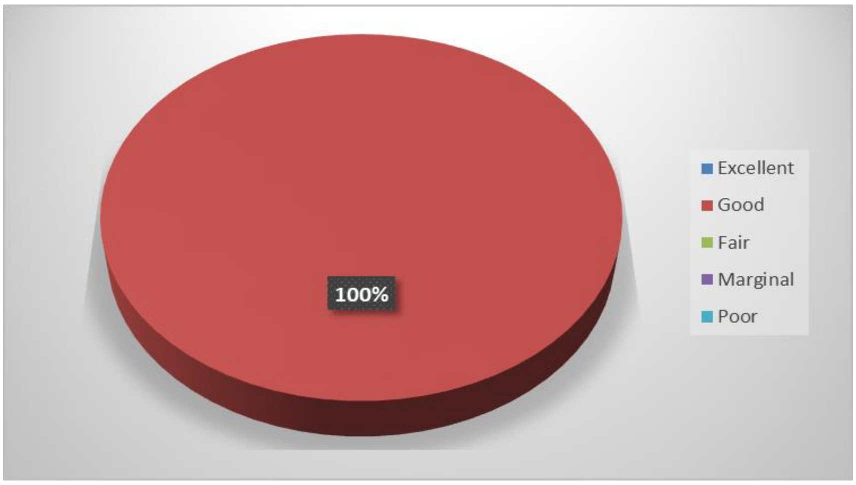

Fig. 7. Distribution of the water quality status of the Erma (Jerma) River at the point beside the village of Strezimirovtsi by categories (in %).

River Erma (Jerma) at the point after Tran in the period 2015-2021 generally achieved "good" water status, except for 2021, when according to the WQI, the river course in this section was characterized by "polluted" waters and significant anthropogenic impact. As a result, the stream in this section does not meet the requirements to achieve "good" quality status (Figs. 6 and 8).

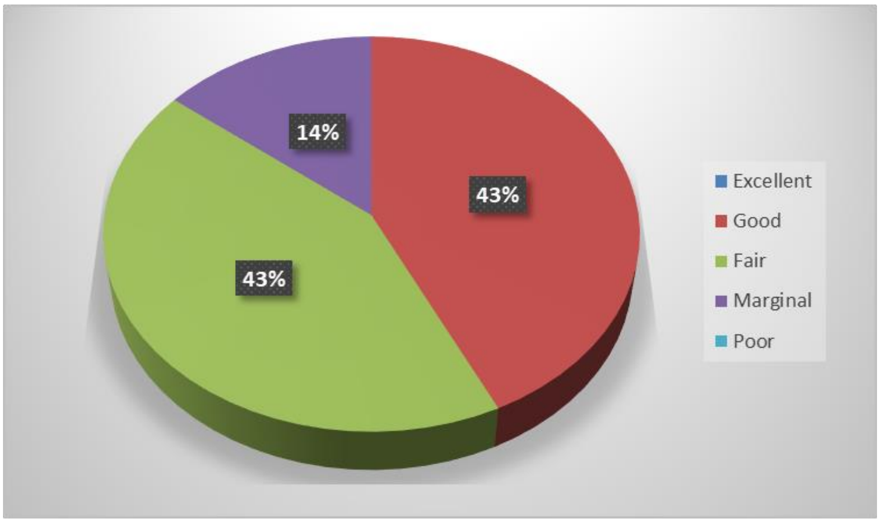

Fig. 8. Distribution of the water quality status of River Erma (Jerma) at the point after Tran by categories (in %).

The differentiated assessment shows that the usual indicators, the values of which exceed the regulated norms up to 10 times, are total nitrogen (N), total phosphorus (P), orthophosphates ($P\text{-}PO_4$) and BOD_5. To these excesses can be added the one-off discrepancies detected during the period (again up to 10 times) of ammonium ($N\text{-}NH_4$), nitrate ($N\text{-}NO_3$) and nitrite ($N\text{-}NO_2$). Rare but still present are concentrations of copper (Cu) and zinc (Zn) that exceed quality standards typically up to 10 times, and in isolated cases from 10 to 25 times or more. For example, on 11.01.2021 a maximum content of copper (Cu) and zinc (Zn) amounting to 36 and 113 $\mu g\ L^{-1}$ were recorded respectively.

CONCLUSION

The waters of the Nishava River beside the village of Kalotina exhibited the most favourable quality characteristics, and the Timok River at the point beside Bregovo was the most polluted. In almost all of the studied points in the river courses, the most frequently recorded exceedances of the norms (usually up to 10 times) were for total nitrogen (N), total phosphorus (P), orthophosphates ($P\text{-}PO_4$) and less often for dissolved oxygen, BOD_5, ammonium nitrogen ($N\text{-}NH_4$) and nitrates ($N\text{-}NO_3$). The extremely poor quality of the river waters in Timok River at the mouth was determined by the extreme content of copper (Cu): more than 25 times the standards (over the entire 7-year study period). Values exceeding standards up to 10 times above norms were relatively constant over time, and very often between 10 and 25 times for cadmium (Cd) and zinc (Zn). In conclusion, it can be noted that heavy metals are very important group of pollutants that can cause significant damage to the environment, if they are above the permissible concentration. The main mission of the mining industry should be efficient and sustainable extraction, processing and beneficiation of raw metals in strict compliance with the regulatory requirements for healthy and safe working conditions and environmental protection. Unfortunately, in a number of mining areas, for one reason or another, the quality of surface water has drastically deteriorated. The results of the present study would be useful to the local authorities in the Republic of Serbia and the Republic of Bulgaria for conducting future studies and adequate control of transboundary surface waters.

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