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Assessment of Water Quality as a Key Component in the Water–Energy–Food Nexus

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Abstract: The intensive economic activity along the Bulgarian Black Sea coast is causing serious changes in the quality of the river water. In view of the topicality of the problem, the main goal of this article is to emphasize the water quality as a necessary key component in the water–energy–food nexus by determining the status of the surface waters of selected Bulgarian Black Sea tributaries from the point of view of their physicochemical characteristics. The research is based on the Water Framework Directive (WFD)—2000/60/EU and the relevant national legislation. In the present study, the Canadian Complex Water Quality Index (CCME, WQI) was applied to determine the quality of river waters. The novelty in the present study is a definite and necessary emphasis on the opinion that the analysis and assessment of water quality should become an integral part of all studies of the water–energy–food nexus.

Keywords: water–energy–food nexus; water quality; Black Sea tributaries

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1. Introduction

The role of water as a component of the global ecosystem is becoming increasingly important. It is a resource that sustains life on earth, provides the basic needs of the population, and is a major factor in the development of the economy—agriculture, energy production, industry, transport and tourism, fish trade, etc. A wide range of factors (natural and anthropogenic) influence the quality of water bodies. Deterioration of the quality characteristics of water (including river water) has a negative impact on its economic, social, and ecological role [1]. For this, it is necessary to prepare and utilize a comprehensive multi-level policy between the responsible institutions, identifying the common factors that allow integrated management of the water–energy–food components.

When preparing the nexus assessments, the two main components of the sustainable development of society must be taken into account—human well-being and environmental protection. A nexus concept, which combines management and governance across sectors and scales, can lead to improved water, energy, and food security. A nexus approach can additionally help with the shift to a green economy, which aspires for resource efficiency and increased coordination of policies [2]. However, synergies between the achievement of economic, water, energy, and food security goals and the related role of water quality are still less prominent in national policies and laws. Nowadays, protecting the quality of water sources in Europe is a key priority for the European Union (EU). A fundamental document in the field of water policies is the Water Framework Directive, which establishes the legal framework for protecting and restoring the purity of water bodies in Europe and ensuring their long-term and sustainable use. The Directive creates an innovative approach to water sector management based on river basins.

Rivers are the most important water resource for domestic, industrial, and irrigation purposes, which are fundamental to human development. However, rivers are polluted due to the discharge of sewage and industrial waste and the implementation of various human activities that affect their physicochemical quality. The protection of the natural ecological environment, including the quality of flowing surface water and the creation of favorable conditions for meeting water needs, are determined by the goals of water consumption and the requirements of water users. This applies to the waters of all rivers in the Republic of Bulgaria, including the Bulgarian Black Sea tributaries. With connection to that mentioned above and the lack of many analyses about the physicochemical status for the Black Sea tributaries and the novelty of the nexus approach for our country, the present analysis is needed.

The main goal of this article is to emphasize water quality as a key component in the water–energy–food nexus by determining the status of the surface waters of selected Bulgarian Black Sea tributaries (Batova, Dvoinitsa, Aheloy, Dyavolska, and Rezovska rivers) from the point of view of their physicochemical characteristics for the period from 2015 to 2021.

The quality of water in river basins reflects to a significant extent the origin, intensity, and extent of anthropogenic impact on the environment. The rivers subject to the present research fall within the scope of the Black Sea Basin Management Region in the country. It is characterized by the developed economic activity, the diverse characteristics of land use, the different methods of discharge of untreated or insufficiently treated wastewater from the settlements, etc. In this sense, in order to have the maximum benefit from water as a natural resource, it is necessary to use and manage it in a sustainable way.

2. Materials, Data and Methods

2.1. Study Area

The Black Sea is a natural inland water basin located between Europe and Asia. The catchment area of the Black Sea is about 2.5 million km^2, and about 160 million people, almost half of them from offshore countries, indirectly and even unconsciously influence the Black Sea ecosystem [3].

Along the Bulgarian Black Sea coast, a well-defined economic zone has been formed, in which agriculture, industry, energy, tourism, etc., are developed. Intensive human activity adversely affects the natural environment, and river discharges are a critical factor influencing the functioning of the marine ecosystem.

The coastal marine environment is rapidly changing in space and time. The rivers selected for analysis in the present study—Batova, Dvoinitsa, Aheloy, Dyavolska, and Rezovska—in a territorial aspect are part of the Black Sea Basin Management Region, which covers about 15% of the land territory of the Republic of Bulgaria and 100% of its water area (Figure 1).

The Batova River is located in northeastern Bulgaria, within the borders of the Varna and Dobrich regions. It has a length of 38.7 km. The valley at its mouth is occupied by the "Baltata" forest and the Batovsko Blato estuary. The Batova River is the only Dobrudja river with a permanent outflow. The catchment area of the river is 338.8 km^2. There are five villages located along the river—Dolishte, Batovo, Tsarkva, Obrochishte, and Kranevo. The waters of the river in the lower reaches are mainly used for irrigation.

The Dvoinitsa River is a river in eastern Bulgaria and flows through the Varna and Burgas regions. Its length is 52 km. The catchment area of the river is 479 km^2. Along the course of the river are located one town, Obzor, and two villages, Koznitsa and Popovich. In the middle and lower reaches, the waters of the river are used for irrigation.

The Aheloy River is a river in southeast Bulgaria in the Burgas region. It is 39.9 km long. It flows into the Black Sea at the Aheloy campsite, 1.2 km south of the town of Aheloy. The catchment area of the river is 141 km^2. Along the course of the river are located one town, Aheloy, and three villages, Draganovo, Medovo, and Aleksandrovo. The river waters are mainly used for irrigation, with the Aheloy Dam built along the river.

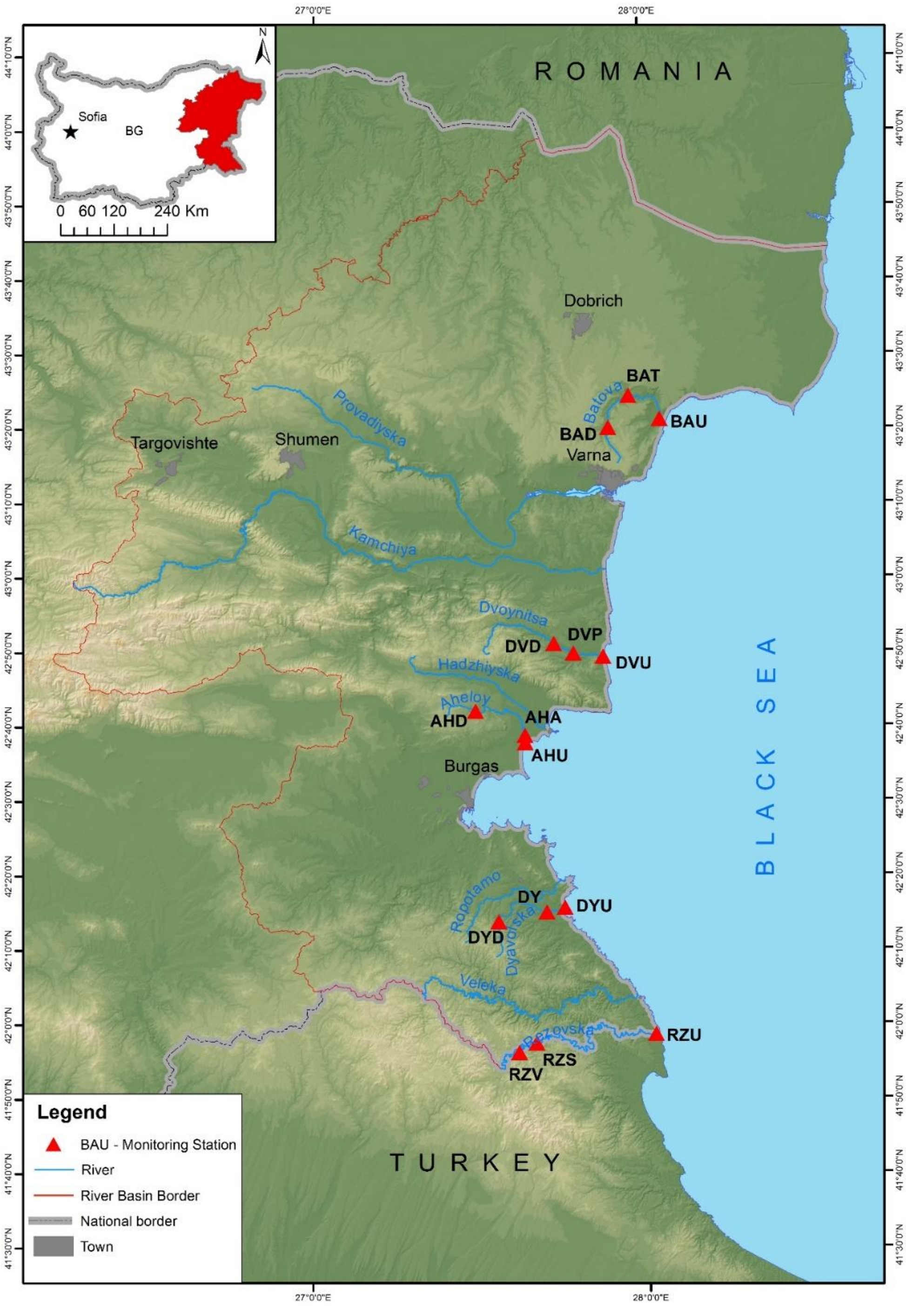

Figure 1. Map of the study area.

Dyavolska is a river in southeast Bulgaria in the Burgas region, flowing into the Devil's Bay on the Black Sea. Its length is 37 km. The catchment area is 133 km^2. One village, Yasna Polyana, and one town, Primorsko, are located along the course of the river. A dam called "Yasna Polyana" was built along the course of the river, the waters of which are used for drinking water supply and for irrigation of agricultural lands.

The Rezovska River flows through Turkey and Bulgaria, its length is 112 km, and almost along its entire length, it serves as a border between the two countries. Its catchment area is 738 km^2, of which 183 km^2 is on Bulgarian territory. In general, the river flows through uninhabited territories, and the Bulgarian village of Rezovo is located at its mouth [4].

2.2. Materials

In the present article, in the relevant sections, literary sources are used for the theoretical part, and in the analytical section, several administrative-legal documents are used. Literature sources are scientific articles and publications with an emphasis on the water–energy–food concept. Regarding the determination of water quality, the analysis and assessment are based on the requirements for achieving "good" river water status as defined in the Water Framework Directive (WFD)—2000/60/EU, and at the national level, the current topic of discussion is aligned with the Water Act. Announcement, SG No. 67 of 27 July 1999, in force since 28 January 2000.

2.3. Data and Legislation

For determining the water quality of the selected study area, the present study was based on the analysis of the values of 10 parameters: pH, electrical conductivity (EC), dissolved oxygen (DO), ammonium nitrogen (N-NH_4), nitrate nitrogen (N-NO_3), nitrite nitrogen (N-NO_2), total nitrogen (N-Total), total phosphorus (P-Total), orthophosphates (P-PO_4), and BOD_5.

The study used verified data from the National Monitoring Network provided by the Executive Environmental Agency (ExEA) to the Ministry of Environment and Water (MOEW) for fourteen monitoring points of five Bulgarian Black Sea tributaries. According to national legislation requirements, all analyses were performed in accredited laboratories every month. The sampling stations presented in Table 1 and Figure 1 were initially selected to achieve the purpose of the present study. After that, due to the review of specificity and the completeness of the primary source data, the sampling station RZV was not taken into account during the analysis process.

Table 1. Information for the selected monitoring points.

Monitoring Points	Code of the Sampling Stations	Coordinates	Type of Water Body	Code on the Map
Batova River—before Batovo village	BG2DO01835MS269	27.9466 43.4038	R11	BAT
Batova River—Dolishte village	BG2DO08399MS201	27.8975 43.3401	R11	BAD
Batova River—mouth	BG2DO00831MS001	28.0564 43.3578	R11	BAU
Dvoinitsa River—before Popovich village	BG2SE400R006RP08	27.7763 42.8397	R11	DVP
Dvoinitsa River—after Dulino village	BG2SE04519MS230	27.7406 42.8486	R4	DVD
Dvoinitsa River—before flowing into the Black Sea	BG2SE00041MS003	27.8768 42.8264	R16	DVU
Aheloy River—before the Aheloy Dam	BG2SE00859MS236	27.4428 42.7189	R4	AHD
Aheloy River—before Aheloy village	BG2SE00081MS237	27.6376 42.6547	R11	AHA
Aheloy River—Aheloy camp	BG2SE81MS008	27.6405 42.6341	R16	AHU
Dyavolska River—before the Yasna Polyana Dam	BG2IU49159MS252	27.5524 42.2419	R4	DYD
Dyavolska River—5 km before Primorsko	BG2IU411MS001	27.6649 42.2689	R11	DY
Dyavolska River—before its mouth, Primorsko town	BG2IU07411MS408	27.75058 42.26008	R16	DYU
Rezovska River—Slivarovo village	BG2RE855MS001	27.6595 41.9606	R4	RZS
Rezovska River—mouth	BG2RE855MS002	28.0246 41.805	R16	RZU

In the studied area are developed agricultural activity and animal husbandry, tourism, and industrial production. The types of the relevant water bodies are presented on Table 2 [5]. The period of the study was 2015–2021. The complex and differentiated evaluation of the physicochemical status of studied river basins was based on Ordinance No. N-4/14.09.2012 (concerning the characterization of surface waters) in accordance with Directive 2000/60/EU (Water Framework Directive) [6,7]. The obtained results for water quality are considered key components in the water–energy–food nexus.

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

Types of Rivers	Dissolved Oxygen, mg/L	pH	Electrical Conductivity µS/cm	$N\text{-}NH_4$, mg/L	$N\text{-}NO_3$, mg/L	$N\text{-}NO_2$, mg/L	Total Nitrogen mg/L	P-Ortho-Po_4, Mg/L	P-Total Phosphorus mg/L	Bod_5, Mg/L
R4	8.00–6.00	6.5–8.5	650–750	0.04–0.2	0.4–1.4	0.01–0.03	0.5–1.5	0.02–0.04	0.025–0.075	1.2–3
R11 R16	6.00–5.00	6.5–8.5	650–750	0.2–0.3	0.9–2.0	0.03–0.06	1.0–2.5	0.07–0.15	0.15–0.3	2–5

2.4. Methods

In this scientific article, the analysis and synthesis of literary sources and cartographic and mathematical-statistical methods are applied. The collection, accumulation, and preliminary processing of the information received from scientific publications, manual documents, official sources of information, as well as the familiarization and application of the necessary administrative documents, i.e., directives, laws, and regulations from the legislation in force in the EU and Bulgaria, represent the initial methodical stage in the development of the problem set. To visualize the study area, the cartographic method was applied, which provided up-to-date and qualitative information about the formed natural-anthropogenic systems [8].

The Canadian Complex Water Quality Index was used to determine the quality status of the selected Black Sea tributary rivers. The CCME WQI is a science-based communication tool that tests multivariate water quality data against certain user-defined criteria. The CCME WQI model does not specify exactly which parameters should be applied. The CCME WQI mathematically combines three variables characterizing the impact on water quality (range, frequency, and amplitude). The impact range (F_1) expresses the range of quality indicators whose values do not correspond to the normatively determined equation below:

$$F_1 = \left[\frac{m}{M}\right] \times 100$$

Here, m is the number of quality indicators with cases of deviation from the norms, and M is the total number of quality indicators used in the calculation of the index.

The frequency (F_2) shows the ratio between the number of so-called "bad samples" (samples in which the content of a potential pollutant with a content above the reference values was detected) and the total number of samples:

$$F_2 = \left[\frac{n}{N}\right] \times 100$$

where n is the number of all samples deviating from the reference values, and N is the total number of samples used in the calculation of the index.

The amplitude (F_3) represents the degree or multiplicity of deviation of the values of the "bad sample" from the corresponding normative values and is calculated by a three-step algorithm as follows: at the beginning, the magnitude of the deviations E_i of the so-called "bad samples" from relevant regulated meanings:

$$\text{(a) } E_i = \left[\frac{v_i}{V_{PL_i}}\right] - 1$$

or

$$(\text{b})\ E_i = \left[\frac{\text{V}_{\text{PL}i}}{\text{v}_i}\right] - 1$$

v_i denotes the value of the "bad" sample, and $\text{V}_{\text{PL}i}$ is the reference value of the maximum permissible concentration (norm) for the corresponding quality indicator. The second formula (b) is applied to calculate the amplitude of indicators whose reference values decrease when moving to a worse category (for example, dissolved oxygen content). The normalized sum of deviations NSE is then calculated:

$$NSE = \frac{\sum_{i=1}^{n} \text{E}_\text{i}}{\text{N}},$$

where the corresponding symbols match those of the above formulas. The final formula for determining the amplitude F_3 is calculated as follows:

$$F_3 = \left(\frac{\text{NSE}}{0.01 \times \text{NSE} + 0.01}\right)$$

After obtaining the values of the individual components of the integrated formula, the calculation of the water quality index (WQI) itself is performed by means of the following:

$$WQI = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$$

Here, the divisor 1.732 normalizes the obtained value in the interval from 0 to 100, where 0 means the "worst quality" and 100 the "best quality" of water.

According to the water quality, its status was differentiated into the following groups: excellent (WQI = 95–100, the waters are in a natural state); good (WQI = 80–94, single cases of contamination are registered); fair (WQI = 65–79, waters are defined as lightly polluted); marginal (WQI = 45–64, water quality is often recorded as deteriorating); and poor (WQI = 0–44, the water quality is not suitable for use for any purpose) [9].

According to Bulgarian legislation, harmonized with the European legislation through the WFD, the characterization of the state of river waters based on physicochemical parameters was carried out in three categories—moderate, good, and very good. In the subsequent calculations, the standard approach of the CCME-WQI was comparable to the adopted reference values set out in the Bulgarian regulatory documents for "good" condition of river waters.

The Canadian Water Quality Index (CCME, WQI) has a number of application advantages, including the relative simplicity of application, the flexibility provided in both the selection of water quality parameters, and the ability of the index to represent measurements of different variables in one number, the possibility to combine different measurements with different measurement units, tolerance in cases of missing data, the establishment of a general status of water bodies, the easily comparable results for separate periods and sections and entire river basins, information on the leading polluting substances, and the extent and intensity of pollution and how it spreads in time and space as derived from intermediate results. Essentially, the index is not designed to replace detailed analysis of variables but rather serves as an aid to management decision making and representation of overall water quality.

3. Results and Discussion

3.1. Water–Food–Energy Concept—A Brief Overview

The water–energy–food nexus is a framework increasingly used by researchers to promote policy making to address global, national, and regional challenges that require a multidisciplinary and cross-sectoral approach [10,11]. The water–energy–food relationship is not static and must take into account the needs of the ever-changing global world, which reflect on the demand for the three components. The achievement of Sustainable Development Goals (SDGs)—specifically SDG 2 in the achievement of zero hunger, SDG 6 in the provision of clean water and sanitation, and SDG 7 in affordable and clean energy—represent in practice the degree of the development and realization of nexus thinking [12]. The water–energy–food concept describes interactions among domains that yield gains or trade-offs when analyzed together rather than independently [13]. In the modern world, economic benefits drive the design and implementation of policies for the management and use of resources in the water–energy–food nexus. Although the current thinking of society supports the notion that money is the basis of its development, having a balanced, functioning water–energy–food nexus is the indispensable and necessary condition for its existence, not the other way around [14]. The case studies of the water–energy–food nexus reviewed in the scientific literature show that it has different scales (household, catchment area, and region) and impacts from different point and diffuse sources. This defines it as markedly transdisciplinary and dynamic, developing in time and space. The main objective of the nexus concept is to increase the net benefits of using water resources for food production, water supply, and energy provision while minimizing trade-offs in the relationships between the three components of the nexus. The main goal of the nexus concept is to maximize the net benefits of using water resources for water production, water supply and energy generation, while minimizing compromise is in the relationships between the three components [15].

3.2. Consideration of Water Quality as a Key Point within Water–Energy–Food Nexus Analyses

The importance of water quality to human health, the state of the environment, and societal well-being are rarely addressed specifically in discussions of the water–energy–food nexus. In recent years, there has been a worldwide increase in the number of the studies regarding the adverse effects of degraded water quality [16,17]. Hydrological and transdisciplinary sciences offer enough tools, models, platforms, etc., to address challenges in the water–energy–food nexus, but they do not explicitly cover "water quality" [10,18–21].

One of the leading reasons for insufficient research on water quality in the water–energy–food nexus is the existence of many different conceptualizations, including different number of sectors falling into the framework, also the scale and time of manifestation and analysis of interactions, etc. [22]. Another difficulty for the perception of water quality as an essential component in the described relationship is the lack of a suitable and generally available set of data on the state of surface and underground waters, mainly in terms of their quality. Without such a set, adequate assessments can hardly be conducted [23].

Incorporating water quality assessments into the water–energy–food nexus is important for addressing transboundary issues where ecosystems are added to the nexus, suggesting that efforts to collect water quality data and analyze interactions in the water–energy–food tri-sector framework should initially be focused on the so-called "hot spots" where the fastest tensions are expected to rise [24–26]. In addition to the data mentioned above, it is useful to provide data describing ambient water quality, domestic and industrial wastewater quality, agricultural runoff, drinking water sources, wet atmospheric deposition, urban rainwater, etc. Water quality and its impact on the environment can be harmful and cumulative in both underground and surface water bodies, namely rivers, lakes, artificial ponds, and coastal areas. That, in turn, affects the livelihood of the population concentrated in the scope of these areas. Studies of the interactions in the three-sector relationship are numerous, but in summary, they always follow the impact vectors as follows: water–energy, water–food, energy–water, energy–food, food–water, and food–energy.

3.3. Assessment of the Water Quality in Selected Bulgarian Black Sea Tributaries

The qualitative status of the Bulgarian Black Sea coast is determined by anthropogenic impacts that are different by nature and diverse by effect and scale. Despite the long-term load with various pollutants both on the water area itself and also on the tributary river systems, current research activities on the problem are limited. Regional scientific studies on the hydrochemical status of some of the Bulgarian Black Sea tributaries (Batova, Provadiiska, Kamchiya, Dvoinitsa, Hadjiska, Aheloy, Ropotamo, Diavolska, Veleka, and Rezovska rivers) at different periods were undertaken by [27–30]. The influence of river tributaries on the quality of the sea waters from the adjacent coastal area as well as the general load with various pollutants, including heavy metals, are the subject of research in the works of [31,32]. The Bulgarian Black Sea tributaries and the coastal zone are a subject of scientific analyses and assessments in the works of [33,34], etc.

The monitoring points presented in Table 1 and Figure 1 were selected to determine the quality of the waters of the Batova River. The values obtained for the WQI at the BAT point placed the river in the "good" category for the years 2017 and 2019, and for 2018, the water quality is defined as "poor". According to the norms for a "fair" physicochemical condition set out in Ordinance No. N-4 for characterization of the surface waters, the norms exceeded the registered values by up to 10 times, mainly referring to the following indicators: nitrates ($N\text{-}NO_3$) and total P. During the period 2015–2021, Batova River at the BAD point generally achieved a "fair" state of its waters (Figure 2). The differentiated assessment shows that the usual indicators the values exceeded the regulated ones by up to 10 times, again due to nitrates ($N\text{-}NO_3$) and total P. The results obtained for the surface water quality of the Batova River at the BAU point during the studied seven-year period indicate a markedly deteriorated physicochemical condition Figure 2. From the analysis by components, it is clear that the results of the investigated quality status are due to the "bad" values of the following indicators: electrical conductivity, nitrate nitrogen ($N\text{-}NO_3$), total N, and total P. The discrepancies exceed the norms by up to 10 times.

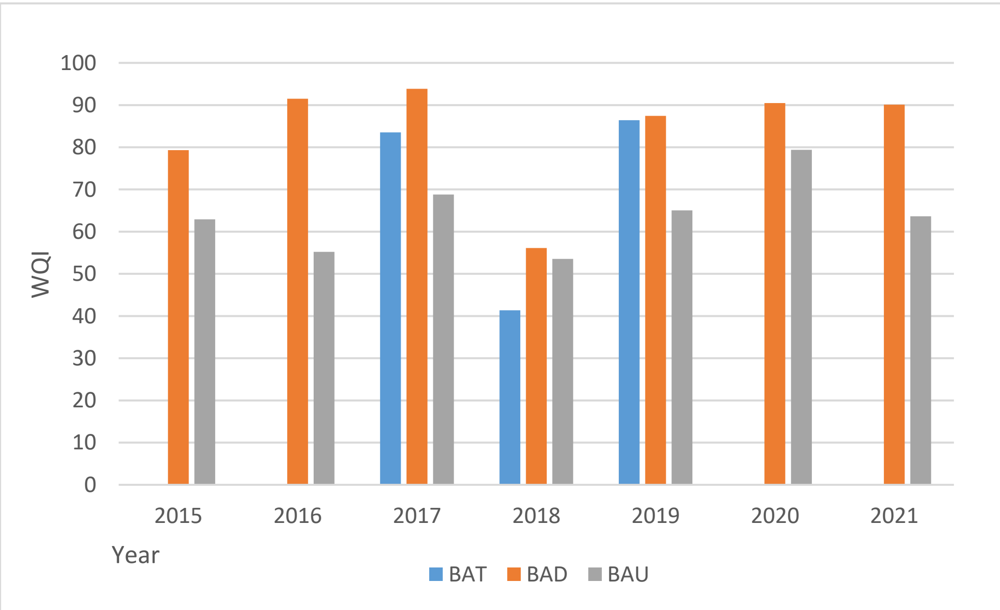

Figure 2. Change in WQI values calculated for Batova River in the period 2015–2021.

The comprehensive quality assessment of Dvoinitsa River was carried out in the points presented in the Table 1 and Figure 1. According to the obtained WQI results calculated for the DVP point, the river flow fell into "fair", "poor", and "marginal" categories (Figure 3). As a result of the differentiated assessment, deviations (up to 10 times above the norms) from the reference values were determined for all the investigated parameters (pH, electrical conductivity (EC), dissolved oxygen (DO), ammonium nitrogen ($N\text{-}NH_4$), nitrate nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total nitrogen (N-Total), total phosphorus (P-Total), and orthophosphates ($P\text{-}PO_4$)) with the exception of BOD_5, for which source data were too scarce. For the P-Total indicator from 2019 until the end of the study period, one-time exceedances of more than 25 times the limit concentrations were registered. According to the WQI, Dvoinitsa River in terms of its water quality at the DVD point was in "excellent", "good", "fair", and "marginal" categories. Since 2018 up and to 2021, the river gradually improved in the quality of its water (Figure 3). All values of the studied indicators for the physicochemical state of the river were out of the limit, except for pH. The waters of the Dvoinitsa River at the DVU point in the period from 2015 to 2021 did not meet the criteria to achieve "good" status as set out in Ordinance No. N-4 for characterization of surface waters. The WQI values measured in this section of the river marked the water body as polluted and highly polluted, falling into the "marginal" and "poor" categories, respectively (Figure 3). The worst was the water quality in 2021, when the largest exceedances of the norms (between 10 and 25 times and more than 25 times) were registered. These were one-time exceedances for the following indicators: nitrites ($N\text{-}NO_2$), total P, and ammonium nitrogen ($N\text{-}NH_4$).

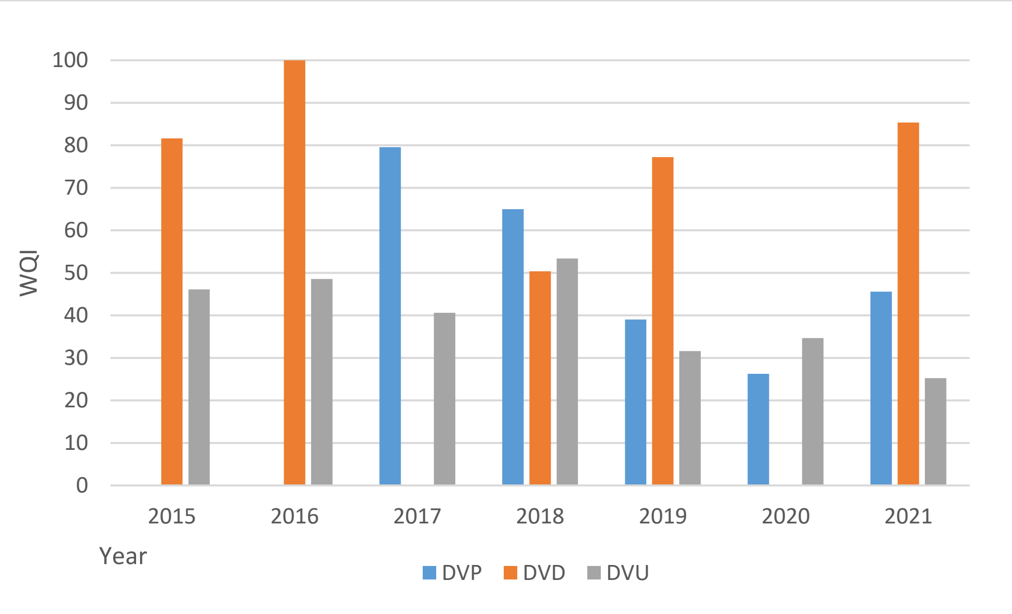

Figure 3. Change in WQI values calculated for Dvoinitsa River in the period 2015–2021.

During the research period, the waters of Aheloy River at the AHD point were in the "marginal" and "poor" categories in terms of quality, (Figure 4) although they did not fulfill the regulatory requirements for "fair" physicochemical condition as determined in Ordinance No. N-4 for the characterization of surface waters. Instances of exceeding (by up to 10 times) the regulated values were registered for all the investigated indicators, the most frequent being for nitrate nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total nitrogen (N-Total), total phosphorus (P-Total), and orthophosphates ($P\text{-}PO_4$). The obtained results indicate that the waters of the Aheloy River at the AHA point were polluted and highly polluted, placing the river course in this section in the "fair" and "marginal" categories (Figure 4). Instances of exceeding (by up to 10 times) the regulated values were registered for all the studied indicators, the most frequent being for nitrate nitrogen ($N\text{-}NO_3$), nitrite nitrogen ($N\text{-}NO_2$), total nitrogen (N-Total), total phosphorus (P-Total), and orthophosphates ($P\text{-}PO_4$). The obtained results indicate that the waters of the Aheloy River at the AHA point were polluted and highly polluted, placing the river course in this section in the "fair" and "marginal" categories (Figure 4).

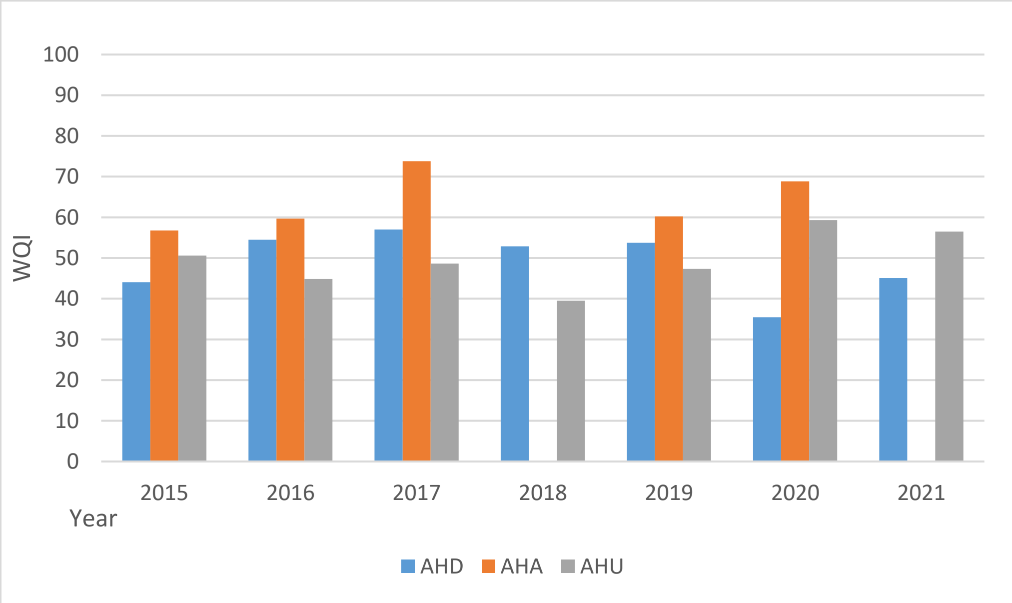

Figure 4. Change in WQI values calculated for Aheloy River in the period 2015–2021.

During the research period, the quality of the river waters of the Dyavolska River at the DYD point fully met the criteria for "fair" physicochemical status. The measured WQI values are presented in Figure 5. The differentiated assessment shows episodic and minor discrepancies from the norms only in some indicators. The analysis carried out for the quality of the waters of the Dyavolska River at the DYP point determined them as unpolluted and slightly polluted, with WQI values as shown in Figure 5. During the studied period, the determined physicochemical condition met the requirements for "fair" conditions of surface waters. The permanent indicator for which excesses (by up to 10 times) of the permissible concentrations were registered was total phosphorus (P-Total); for the other physicochemical indicators, episodic deviations from the norms were noticed. The waters of the Dyavolska River at the point at the mouth of the DYU fell into different categories of quality status, which varied from "excellent" to "marginal". The differentiated assessment proved non-constant over time, with one-time excesses of the permissible concentrations of the following indicators: pH, electrical conductivity (EC), dissolved oxygen (DO), ammonium nitrogen ($N\text{-}NH_4$), total nitrogen (N-Total), total phosphorus (P-Total), orthophosphates ($P\text{-}PO_4$), and BOD_5.

The water quality of the Rezovska River at the RZS point at the beginning of the period was defined as "fair", after which it improved, reaching "good" and in 2020 "excellent"; thus, the river fulfilled the criteria determined by Ordinance No. N-4 for characterization of the surface waters in Bulgaria (Figure 6). The detected inconsistencies were one-time and insignificant, except for nitrate nitrogen ($N\text{-}NO_3$) and nitrite nitrogen ($N\text{-}NO_2$) values, which still remained within the limit values. In the estuary section of the Rezovska River at the RZU point, according to the calculated WQI values during the research period, the river waters were classified as "excellent", "good", and "fair" (Figure 6). The analysis shows episodic excesses (by up to 10 times) of the limit concentrations of some quality parameters: dissolved oxygen (DO), nitrite nitrogen ($N\text{-}NO_2$), total phosphorus (P-Total), and orthophosphates ($P\text{-}PO_4$). The only recorded deviation between 10 and 25 times above the norm was for the nitrite nitrogen ($N\text{-}NO_2$) indicator measured on 28 July 2020.

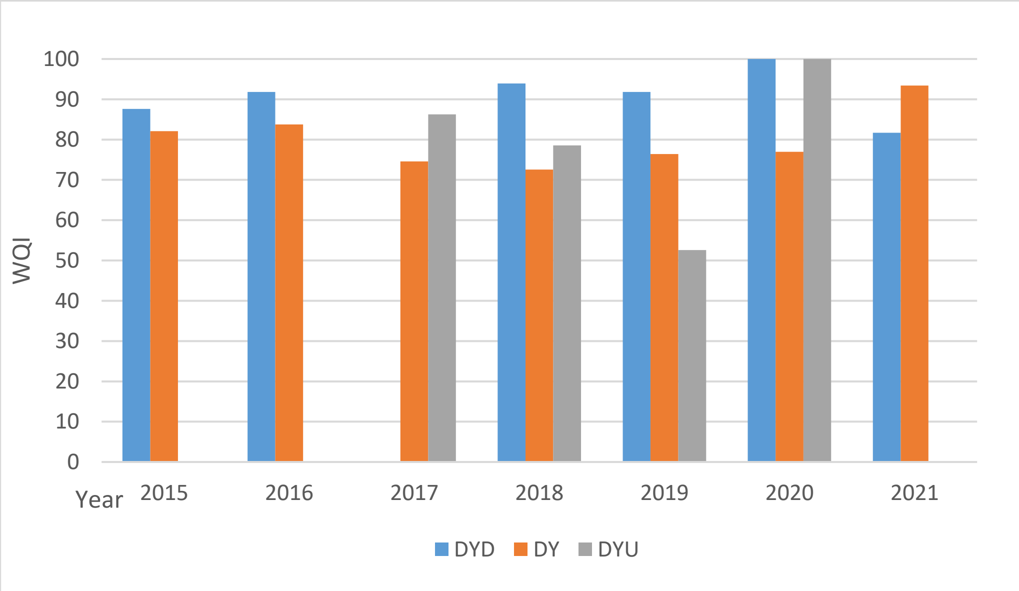

Figure 5. Change in WQI values calculated for Dyavolska River in the period 2015–2021.

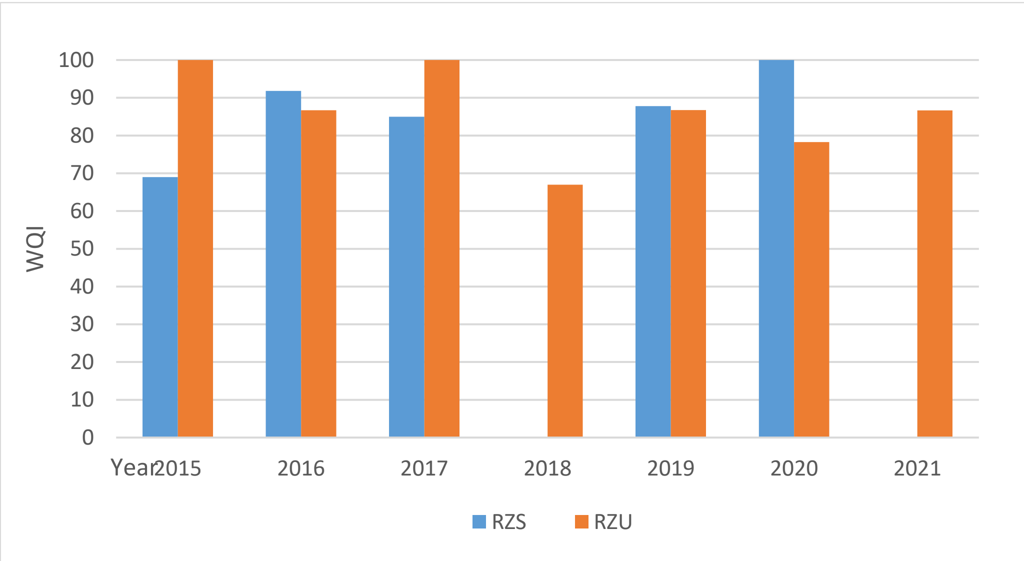

Figure 6. Change in WQI values calculated for Rezovska River in the period 2015–2021.

Based on the results obtained from the applied CCME-WQI, the following conclusions can be made:

- For the Batova River, the waters in the BAD point have the most favorable quality characteristics, and the waters in the estuary section BAU have the worst;
- For the Dvoinitsa River, the river waters at the point DVD are defined as the cleanest, and the most polluted are those immediately before entering the Black Sea-the point DVD;
- The quality condition in the river of Aheloy is most favorable at the AHA point, and the river waters at the AHD and AHU points have markedly deteriorated physicochemical characteristics that do not meet the criteria for "fair" quality condition laid down in Ordinance No. H-4 for the characterization of surface waters;
- The best-quality waters in the Dyavolska River are the waters at the point DYD, and the most polluted is the river section at the point DYU;

- The surface waters of the Rezovska River in both research points-RZS and RZU—hold a satisfactory quality status according to the norms;
- The quality of the river waters in the studied watersheds varies both in the individual years of the analysis period and also in the different points of the river systems, with no deterioration or improvement in their quality status;
- Most often, in almost all studied points, the leading and constant exceedances are usually 10 times the norm for the indicators total phosphorus (P-Total), orthophosphates ($P\text{-}PO_4$), nitrite nitrogen ($N\text{-}NO_2$), and nitrogen (N-Total). The deviations from the norms for the other physicochemical indicators are not defined as so frequent.

The deviations from the normative requirements for these indicators leads to a conclusion that the main potential sources of pollution are the following:

- Agricultural activities carried out in the watersheds of the studied river basins through the excessive or incorrect use and storage of organic and mineral fertilizers as well as waste water from the operation of, albeit small, livestock complexes and farms, mainly poultry farms and pig farms, located in the study area;
- Discharge of untreated waste water from the sewers of populated areas and insufficiently treated domestic waste water from urban, resort, and industrial WWTPs;
- Regulated and unregulated landfills, the seepage of wastewater from the septic tanks of the settlements into the aquifers of the river basins, as well as the lack of treatment plants and sewerage networks.

An important tool for achieving the main objectives of the Water Framework Directive on maintaining or improving the quality of water bodies is the development and implementation of a program of certain measures.

Taking into account the specificity of the anthropogenic load on the waters of the Batova, Dvoinitsa, Aheloy, Dyavolska, and Rezovska rivers as well as the nature of the polluting substances and the possible sources of pollution, some basic and effective measures are as follows:

- Construction of new and reconstruction of existing WWTPs and the provision of biological wastewater treatment;
- Control over the fulfillment of the conditions in the complex permits and, if necessary, revision of the conditions;
- Implementation of good farming and agricultural practices;
- Planting intermediate crops in cultivated areas and increasing diversity in crop rotations;
- Closure and reclamation of municipal landfills;
- Reducing the phosphorus load by introducing additional measures such as switching to phosphate-free detergents and optimizing the use of sewage sludge, as a result of which the application of artificial fertilizers in agriculture will be reduced.

4. Conclusions

The overview of the nexus concept in the tripartite relationship water–energy–food reveals the key role played by the water sector. It highlights the need to apply a multi-sector approach in the process of achieving synergies and mitigating trade-offs involving multiple interested parties—government agencies, the private sector, academia, and civil society.

As a result of the application of the CCME-WQI, the advantages of the used index were revealed, allowing us to obtain complex and differentiated assessments for different temporal and spatial summaries. The performed analysis and the obtained assessment of the quality of the river waters along the Bulgarian Black Sea coast serve as a basis for future studies in the same model area for the remaining two components in the energy and food relationship.

This research provides new knowledge about this concept in the country and provides regional water quality assessments. The authors of the present study strongly express the opinion that research on the quality of water should become an integral part of research on the water–energy–food relationship.

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