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# Hydro-ecological trends of the Chepelarska River (Western Rhodope Mountains, Bulgaria)

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**Abstract**

Significant anthropogenic impacts and climate change are putting the hydro-ecological conditions in river systems at risk of deterioration. It is crucial to record long-term trends for both an objective assessment during the planning process and the development of a methodological basis for further scientific investigations. This article analyzes human pressure and changes in the hydro-ecological status of the Chepelarska River (Southern Bulgaria), making recommendations for its improvement. The study relies on long-term hydrological data about registered runoff for 74 years from 1950 to 2023, information regarding hydro-morphological changes (regulated river sections and constructed hydropower plants), and dataset from monitoring of biological (phytobenthos, phytoplankton, fish fauna, macrophytes, and macrozoobenthos), physicochemical (pH, $DO_2$, $BOD_5$, Total N, Total P, $NH_4$, $NO_3$, $NO_2$, and $PO_4$), and specific chemical (Al, Cd, Cu, Pb, Mn, and Zn) water quality elements collected for 14 years between 2010 and 2023. The resulting information show a rising variability of runoff and a statistically significant tendency toward a flow volume decline, increasing morphological pressure from hydropower construction and aquaculture farming, and despite the overall positive hydro-ecological trend – constant deviations in some biological (macrozoobenthos), physicochemical (Total N, Total P, $NH_4$, $NO_2$, $PO_4$), and specific chemical (Cd, Mn, Pb, Zn) water quality elements. The achievement of better hydro-ecological conditions requires the application of a complex of environmental, engineering, and legislative measures.
**Keywords:** *anthropogenic pressure, hydrological trend, hydro-ecological status, surface water quality, Chepelarska River*

## Introduction

River water plays a key role in ecosystems' protection and development, offering vital services, such as potable freshwater provision, biodiversity maintenance, and regulation of local climatic conditions and processes (Watson, 2017). However, under the existing circumstances of dynamically changing natural and anthropogenic factors, the hydro-ecological state of river systems worsens (Rose et al., 2023; Tang, 2020). This is due, on the one hand, to water pollution from industry, agriculture, and expanding urbanization, and, on the other hand, to changes in the river runoff regime, including as a result of the influence of extreme phenomena, related to climate change, such as floods and droughts (Asadieh & Krakauer, 2017; Blöschl et al., 2019; Vigiak et al., 2018).

The transition of the Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Water Framework Directive – WFD) into an integrated river basin management paradigm requires a comprehensive approach when assessing the state of surface water, which includes a wide range of criteria and indicators (Giakoumis et al., 2018; Howarth, 2018).

Performed during the process of river basin planning, the assessment of the waters' hydro-ecological state using biological, physicochemical, and hydro-morphological, including hydrological parameters, based on an established anthropogenic pressure, data from conducted monitoring and on an adopted for individual elements classification scale (Kolcheva et al., 2023), presents the general trends in the time and the possible effects on aquatic ecosystems (Karr, 2020). The variations in the hydro-ecological conditions enable the definition of recurring causes of pollution or shortage of water and reassessment of the planned measures.

In the spirit of the implementation of the WFD 2000/60/EC, numerous studies were being conducted in European countries, including Bulgaria, aimed at analyzing the adverse effects of changing natural and anthropogenic factors on hydro-ecological conditions in river systems. Catianis et al. (2012) assesed the hydro-ecological conditions in the region of the Danube Delta (Eastern Romania), using physicochemical parameters (pH, dissolved oxygen, electrical conductivity, total dissolved solids, sulfates, etc.), litological samples of sediments (total organic matter, carbonates and siliciclastic fraction), and biological assay (identification of benthic communities), and reported that due to the upstream anthropogenic activities, delta water is subjected to susceptible chemical loading and traces of metalloids and heavy metals are found in bottom fauna, taking into account that the Danube River is receiving large amounts of industrial, agricultural, and urban wastewater. Štefunková et al. (2020), using the River Basin Habitat Simulation System (RHABSIM), investigated the hydro-ecological impact of a cascade of dams and hydroelectric power plants built on the Váh River (Western Slovakia) and established a significant reduction in ichthyofauna due to failure to ensure the minimum ecological flow. Ligorini et al. (2023) estimated the influence of multiple and increasing threats (demographic pressures, eutrophication, climate change) on the hydro-ecological status of 95 Mediterranean coastal lagoons and their adjacent connected drainage basins in the Corsica Island (France) and founded that increasing air temperatures and anthtopogenic pollution due to urbanization negatively affected seasonal biogeochemical cycles, disrupted photosynthetic efficiency, produced higher phytoplankton biomass, and provoked blooms of potentially harmful dinoflagellates. Malovanyy et al. (2025), using methods of mathematical modelling, the Spearman's and the Pearson's rank correlation coefficients, as well as the Macrophyte Index of Rivers (MIR), focused on the ecological sustainability of landscapes on the formation of the hydro-ecological state of water in the upper part of the Prypiat River Basin (Southern Belarus and Northern Ukraine) under conditions of climate change and human activities, and concluded that the areas with a higher coefficient of ecological sustainability of landscapes have better water quality indicators, which implies a lower rate of erosion, a weaker anthropogenic impact, and a stronger hydro-ecological potential. These complex relationships between climate change, human pressure, and hydro-ecological processes in rivers were also demonstrated by Radeva & Seymenov (2019) for the Lom River Basin (Northwest Bulgaria). Using information about registered river flow, hydro-morphological parameters, physicochemical (pH, dissolved oxygen, biochemical oxygen demand, ammonia, nitrates, and phosphates) and biological (macrophytes, macrozoobenthos, and phytobenthos) water quality elements, the authors found significant deviations from the reference conditions. The flow regime is altered, and the hydro-morphological status is graded as "poor" due to the effect of hydropower plants and water abstraction facilities. The physicochemical state is "moderate", resulting from constant exceedances in values of key biogenic components, while the biological quality elements showed a relatively "good" state with periodic deviations (Radeva & Seymenov, 2019). The authors summarized that the overall hydro-ecological status could be assessed as "moderate", resulting from organic and biogenic water pollution by agriculture and domestic sources, as well as the various types of hydro-morphological pressures.

The Chepelarska River is another example of a river in the Republic of Bulgaria, subjected to diverse human impacts, disrupting the natural hydro-ecological status and hindering the implementation of the objective ‘all water bodies to achieve good status’ following the guidelines of WFD 2000/60/EC. The selected river basin is characterized by a lot of settlements without urban sewage systems, dozens of unregulated landfills for solid household wastes, an increasing number of hydropower facilities, as well as developed industrial production associated with two of the largest lead-zinc ore mines in the country. As a result of uncontrolled discharge of untreated industrial and domestic wastewater, water is polluted with substances of various origins and compositions like heavy metals, metalloids, and nutrient components (Dospatliev et al., 2015; Gartsiyanova, 2022; Gartsiyanova et al., 2023; Pencheva et al., 2002; Radeva & Seymenov, 2021). T

he deteriorated physicochemical state of river water and the constructed hydroelectric plants negatively affected aquatic ecosystems, disrupting fish migration and reducing biodiversity (Gecheva et al., 2023; Patronov & Kirin, 2024). Parasites and parasite communities have also been established (Zaharieva, 2023).

In this context, the present study aims to analyse the anthropogenic impact on the surface water quality, as well as the hydro-ecological trends of the Chepelarska River, based on statistical data about specific periods, provided by the National Institute of Meteorology and Hydrology (NIMH) and the Eastern Aegean Basin Directorate (EABD). In the spirit of sustainable development, the implementation of this task is important for achieving the good-water-state aim and expanding the research activities to increase the level of objectivity during the planning process.

## Study area

The Chepelarska River has a length of 85.9 km. Its catchment drains an area of 1051.39 km$^2$ with a mean altitude of 1143 m a.s.l. (River Basin Management Plans – RBMP, 2022–2027; Tcherkezova et al., 2023) (Fig. 1).

The source of the river is on the western foothills of the Rozhen Peak at an altitude of 1550 m a.s.l. Farther, the river flows north and northeast in a deep narrow gorge valley between the ridges of Chernatitsa, Dobrostan, and Radyuva Mountain: constituent units within the Western Rhodopes. Downstream the river leaves the mountainous environment, enters the Upper Thracian Lowland, and flows from the right into the Maritsa River after the village of Katunitsa at an altitude of 148 m a.s.l. (Hristova, 2012).

The climate is transitional continental with mountainous influences. The mean annual air temperature increases from 7.3°C for the city of Chepelare up to 12.3°C by the town of Sadovo. July is the hottest month with mean air temperatures between 16°C and 24°C, while January is the coldest one with -2.5°C and 1.0°C, respectively (Plan for Integrated Municipal Development, 2021–2027). The annual amount of precipitation rises from 550–650 mm (in the lowland) up to 750–1100 mm (in the mountain) with two maximums in May/June and November/December, and two minimums during February/March and August/September (Velev, 2010). The climate scenarios Representative Concentration Pathways (RCP) for the territory of the EABD predict a rise in the mean annual air temperatures by 2.79°C (RCP 4.5) and 3.76°C (RCP 8.5) for 2071–2100 compared to the reference period 1976–2005. Warming is expected for all seasons. The mean annual sum of precipitation is also predicted to increase – by 1.17% (RCP 4.5) and 3.31% (RCP 8.5), especially in autumn by 24.8%, but to decrease in summer by 9.1% (RBMP, 2022–2027).

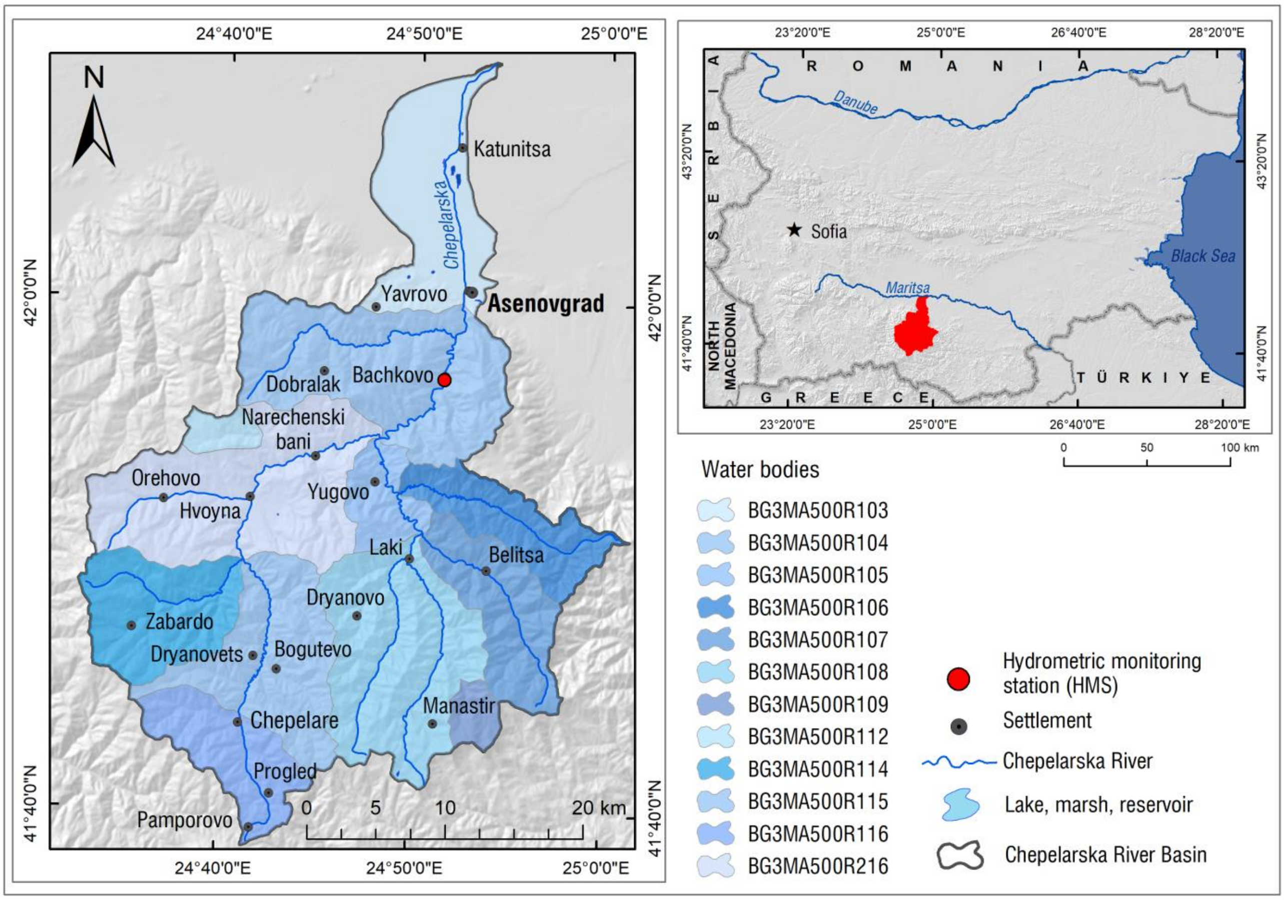


**Figure 1. Study area**

The Chepelarska River Basin is divided into 12 surface water bodies (SWBs) of types R3 (Mountainous rivers in an Ecoregion 7: Eastern Balkans) and R5 (Semi-mountainous rivers in an Ecoregion 7: Eastern Balkans) (Table 1). Most of these SWBs are classified as ''natural'', excluding a water body BG3MA500R103, which belongs to category ''highly modified'', and another two are "drinking water bodies" (DWB).

Based on the List of complex and significant reservoirs under Appendix No 1 to the Water Act (2000), published by the Ministry of Environment and Water (MOEW), no dams are of national importance in the studied river basin. The anthropogenic impact on the drainage system is presented by water intakes for electro-production, aquaculture farming, drinking, household, and industrial needs, as well as by flood protection dykes and irrigation channels near the mouth (RBMP, 2022–2027).

Following the administrative division of the Republic of Bulgaria, the Chepelarska River Basin includes parts of nine municipalities (Asenovgrad, Banite, Chepelare, Devin, Kuklen, Laki, Rodopi, Sadovo, and Smolyan), which are distributed over two districts (Plovdiv and Smolyan). The main economic branches include wood-processing and ore-mining industries, ski- and spa-tourism for the municipalities in the Western Rhodopes, while crop cultivation and livestock farming are among the crucial activities for the municipalities in the Upper Thracian Lowland (Plans for Integrated Municipal Development, 2021–2027).

**Table 1. Surface water bodies in the Chepelarska River Basin (RBMP, 2022–2027)**

| Number | Name | Type | Length of river (km) | Catchment area (km²) |
|---|---|---|---|---|
| BG3MA500R103 | The Chepelarska River from the town of Asenovgrad to its mouth | R5 | 19.31 | 109.84 |
| BG3MA500R104 | The Chepelarska River from the Yugovska River to the town of Asenovgrad | R3 | 16.54 | 165.69 |
| BG3MA500R105 | The Yugovska River from the Sushitsa River to its mouth | R3 | 10.91 | 33.79 |
| BG3MA500R106 | The Sushitsa River | R3 | 20.80 | 62.25 |
| BG3MA500R107 | The Belishka River | R3 | 17.75 | 74.49 |
| BG3MA500R108 | The Manastirska River and the Dzhurkovska River | R3 | 22.81 | 148.64 |
| BG3MA500R109 | The Krushovska River – DWB | R3 | 4.76 | 14.71 |
| BG3MA500R216 | The Chepelarska River from the Zabardovska River to the confluence of the Yugovska River and the Oreshitsa River | R3 | 18.20 | 171.66 |
| BG3MA500R112 | The Ledenitsa River – DWB | R3 | 5.48 | 14.53 |
| BG3MA500R114 | The Zabardovska River | R3 | 15.14 | 85.37 |
| BG3MA500R115 | The Chepelarska River from the town of Chepelare to the Zabardovska River | R3 | 14.61 | 107.29 |
| BG3MA500R116 | The Chepelarska River from its source to the town of Chepelare | R3 | 11.03 | 63.14 |

## Methodology

In each river basin planning period (the first one for the Republic of Bulgaria being 2010–2015) relationships analysis between anthropogenic pressure and impact and assessment the degree of the impact on waters through the conceptual model "Driving Force–Pressure–Impact–Answer" (DFPIA), according to Guide No. 3 - Analysis of pressures and impacts of the General strategy for the implementation of the WFD. The updated assessment of the pressures in the RBMP for the planning period 2022–2027, the following categories of pressure on surface water bodies has been identified: from point and diffuse sources of pollution and from hydro-morphological changes. And if the impact determines the negative changes of individual quantitative and qualitative parameters of the water body, then the monitoring (hydrobiological, physicochemical, and chemical) data is the basis for assessing the degree of impact of the pressure and the general ecological and chemical state of the surface water bodies.

Monitoring (control, operational, and research) of surface waters is implemented with the necessary scope and frequency using standardized methods, in accordance with current European and national standards. The NIMH maintains the national hydrometric network and provides operational information about river runoff since the beginning of the 20$^{th}$ century, and the Executive Environment Agency (ExEA) administers the surface water quality monitoring networks.

The frequency of the operative monitoring for biological elements of water quality (BEQ) is once a year, with the exception of phytoplankton, monitored twice a year, and for the physicochemical ones, incl. specific pollutants is four times a year (once every three months). River morphology and continuity are surveyed once every six years.

The classification for the assessment of quality elements, according to Annex V of the WFD and Guideline No. 6 in five, three, and two classes, respectively, is presented in Table 2.

**Table 2. Classification and designations of ecological status (Ordinance No H-4 of September 14 2012)**

| Ecological status - water quality elements | | |
|---|---|---|
| **Biological** | **Physicochemical** | **Hydro-morphological** |
| Excellent | Excellent | Excellent |
| Good | Good | Good |
| Moderate | Moderate | |
| Poor | | |
| Bad | | |

An updated "General approach to evaluating the environmental status and potential of surface water bodies in the Republic of Bulgaria" has been attached to the RBMP (2022–2027), considering the general patterns in the state changes and the specifics of interpretation of the monitoring data. The final evaluation is determined by the water quality element in the worst status, according to the "one out–all out" rule (Annex V of the WFD). All requirements regarding the classification and presentation of the studied status are enshrined in Ordinance No H-4 of September 14 2012 for surface water characterization.

*Hydro-morphological elements of water quality (HMEQ)* – these elements, in support of Biological elements of water quality (BEQ), are studied in two directions: hydrological, related to quantitative changes in the hydrological regime (e.g. after a dam or due to water intakes), changes in the speed of the river velocity, level, and continuity (number and types of barriers and ensuring the passage of aquatic organisms), and *morphological*, related to physical changes in the riverbed, including in its profile, in the transport of sediments, and in erosion processes.

*Hydrological parameters* – Statistical information provided by the NIMH, responsible for conducting the quantitative monitoring of surface water, according to the letter No. OD-03-994-1/09.01.2025 is used to assess the hydrological characteristics of the Chepelarska River. The study includes 74 years from 1949/1950 to 2022/2023. The hydrometric observations are conducted at the stream gauging station No. 72460 (latitude 41.9498° N; longitude 24.8580° E), located in the village of Bachkovo. The mean elevation of the drainage basin to the station is 1241 m a.s.l., and its area is 824.9 $km^2$ (78.4% of the total catchment area) (Hydrological Reference Book, 1981). Flow variabilities are evaluated at three time-scales: annual, monthly, and seasonal. The analysis is conducted for hydrological years, lasting from November of the previous calendar year to October of the following calendar year, and including three seasons: winter (XI–II), spring (III–VI), and summer-autumn (VII–X) (Panayotov, 1972).

Initially, the data set is checked for homogeneity through double mass curves. Then, descriptive statistical characteristics, such as minima, maxima, and mean values, and a coefficient of variation (Cv) are calculated.

*Water withdrawal* from surface water bodies with an annual limit ≥ $150x10^3$ $m^3/y$ is significant, and the pressure from it on the available resource is distinguished as: weak (0–15%), moderate (15–30%), and significant (>30%).

*River continuity and morphology* – Standardized field protocols and concepts are used to assess the morphological conditions under the WFD 2000/60/EC, in accordance with the guidelines of the Guidance standard for assessing the hydro-morphological features and Ordinance No H-4 of September 14 2012 for surface water characterization. Significant hydro-morphological changes (corrected and affected by the extracting of inert materials river sections) are those that change the ecological status of water from "good" to "poor" based on BEC data and the relationship between BEC and hydro-morphological quality elements. For example, the River Habitats Survey Protocol used in Europe aims to provide reliable information on hydro-morphological quality elements in a standard section of 500 m in length. The morphological pressure in the second planning cycle is expertly accepted as significant, when the length of the affected river section compared to that of research is as follows: corrected or with extraction of inert materials and bank protection facilities more than 70%, with migration barriers over 50%, and regulated over 30%.

*Biological elements of water quality (BEQ)* – In the RBMP all mandatory are covered five BEQs (phytoplankton, macrophyte flora, phytobenthos, benthic macroinvertebrate fauna, and fish fauna) required for the determination of the ecological status and potential of rivers/lakes. The methods for BEQ assessment in Bulgaria are based on the requirements of WFD 2000/60/EC and Ordinance No H-4 of September 14 2012 for surface water characterization. The comparative assessment of observed biological data with reference conditions is presented by the Ecological Quality Ratio (EQR).

The estimation of phytoplankton (for lakes/dams), considered the most important biological quality element in assessing the ecological status or potential of lakes and reservoirs, is based on one-time sampling and subsequent analysis, carried out in accordance with the following guidance documents for water quality: Guidance on the design of sampling programmes and sampling techniques ISO 5667-1:2006/AC:2007, Guidance on the preservation and handling of water samples ISO 5667-3:2003/AC:2007, Guidance standard on the enumeration of phytoplankton using inverted microscopy (Utermöhl technique) EN 15204:2006 by the Utermöhl method and calculation of the biovolume by taxon-specific cell volumes of planktonic algae, and Spectrometric determination of the chlorophyll-a concentration ISO 10260:1992. Phytoplankton is the most sensitive element to nutrient pollution (eutrophication).

The assessment of macrophytes is based primarily on careful selection of a "macrophyte" river section (up to 100 m long) or "macrophyte" lake belt transects, as initially using the results of the Reference Index (RI), successfully applied in Germany (Bavaria). For the analysis, the following international standards for surface water quality are also applied: Guidance standard for the surveying of macrophytes in lakes EN 15460:2007 and Guidance standard for the surveying of aquatic macrophytes in running waters EN 14184:2003. Macrophytes are an indicator of water pollution with biogenic components and some specific pollutants.

Phytobenthos (rivers) assessment is related to estimation of periphyton diatoms (diatoms) in accordance with two standards from 2003 and 2004 for water quality: Guidance standard for the routine sampling and pretreatment of benthic diatoms from rivers and Guidance standard for identification, enumeration and interpretation of benthic diatom samples from rivers.

About macrozoobenthos at the national level only benthic (bottom-dwelling) invertebrates (for rivers), assessed according to an adapted Irish Biotic Index (IBI), are studied. Both elements are indicators of organic and toxic water pollution. For the fish fauna, the European Fish Index EFI+ method, developed at the European level, is applied.

*Physicochemical elements of water quality (PCEQ)* – This type of assessment includes three groups of indicators – general, biogenic, and specific chemical pollutants. In this study, the following elements with statistically confirmed representativeness of the "pressure-impact" relationship are used: hydrogen indicator (pH), dissolved oxygen ($DO_2$), biochemical oxygen demand ($BOD_5$), total nitrogen (TN), total phosphorus (TP), ammonia ($NH_4$), nitrates ($NO_3$), nitrites ($NO_2$), and phosphates ($PO_4$), as well as the elements: aluminium (Al), cadmium (Cd), copper (Cu), lead (Pb), manganese (Mn), and zinc (Zn) from the third group. The assessment of each one of the physicochemical elements is based on the available monitoring data and the rules specified in Annex No. 6 to Article 12, paragraph 4, part B. Physicochemical quality elements in Ordinance No H-4/September 14 2012 for surface water characterization.

In the planning process, the assessment of ecological status/potential of surface water bodies by the specified quality elements is improved with the implementation of research projects. For example, in the current RBMP, the assessment is based on an updated "General approach for assessment of the ecological status/ecological potential of surface water bodies in the Republic of Bulgaria", aiming the greatest possible objectivity, taking into account both the general patterns in changes in the ecological status and the specifics in the interpretation of monitoring data.

Summarized data from annual reports on the surface water status on the territory of the EABD region for the period 2010÷2023 have been used to assessing the BEQ and PCEQ, and the parameters with an exceedance, defining state, different from the "good" hydro-ecological state, have been considered.

To find tendencies, a linear trend is applied. The statistical significance of the regression line is estimated by the Mann-Kendall Test. If the *p-value* is less than the critical level of 0.05, the non-parametric estimator determines the trend as monotonic.

Additionally, the following spatial data were also used: Digital Terrain Model (DTM) for Continental Europe with a grid size of 30 m (Hengl et al., 2020) and Open Street Map Project (OSM): settlements, roads, railroads (2025).

## Results and discussion

Changes in the general hydro-ecological state are determined by an analysis of the information collected for two main periods: the first – hydrological (1949/1950–2022/2023) and the second for assessing the ecological state (2010–2023), according to the planning periods.

*Hydro-morphological elements of water quality (HMEQ)* – The following parameters are considered in this study: hydrological, including water withdrawal, and river continuity and morphology.

*Hydrological parameters* – The initial statistical analysis shows that the time-series data are not homogeneous. The double-mass curve demonstrates a break in the slope of the cumulative function in the mid-1980s (Fig. 2). Then, due to rising air temperatures and scanty precipitation, the Chepelarska River Basin experienced a severe hydro-meteorological drought, which was especially pronounced from 1982/1983 until 1993/1994 (Gerasimov et al., 2001).

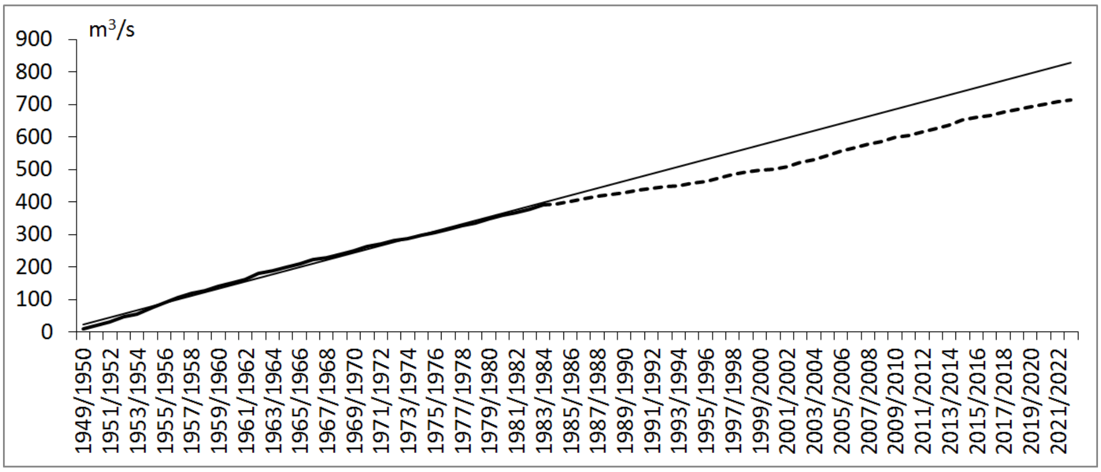


**Figure 2. Double mass curve of the annual streamflow in the Chepelarska River Basin at Bachkovo**

The obtained result gives a reason to divide the observation period into two sub-periods with a homogeneous data set and an approximately equal length. The 1984/1985 hydrological year is taken as the boundary. Henceforth, the descriptive statistical measures of river flow for the two sub-periods will be calculated and presented.

The average annual streamflow of the Chepelarska River at the gauging station of Bachkovo for 1984/1985–2022/2023 is 8.33 $m^3/s$ (from 3.71 $m^3/s$ in 1993/1994 to 16.97 $m^3/s$ in 2014/2015) or less than the mean annual flow for 1949/1950–1983/1984: 11.15 $m^3/s$ (between 5.38 $m^3/s$ in 1967/1968 and 18.99 $m^3/s$ in 1962/1963) (Fig. 3). The annual streamflow increases its fluctuations around the norm during the last four decades: Cv is 0.37 (1984/1985–2022/2023) compared to 0.28 (1949/1950–1983/1984). The decrease in the annual streamflow volumes is confirmed by the linear hydrological trend. The slope of the regression line is statistically significant (Fig. 3, Table 3).

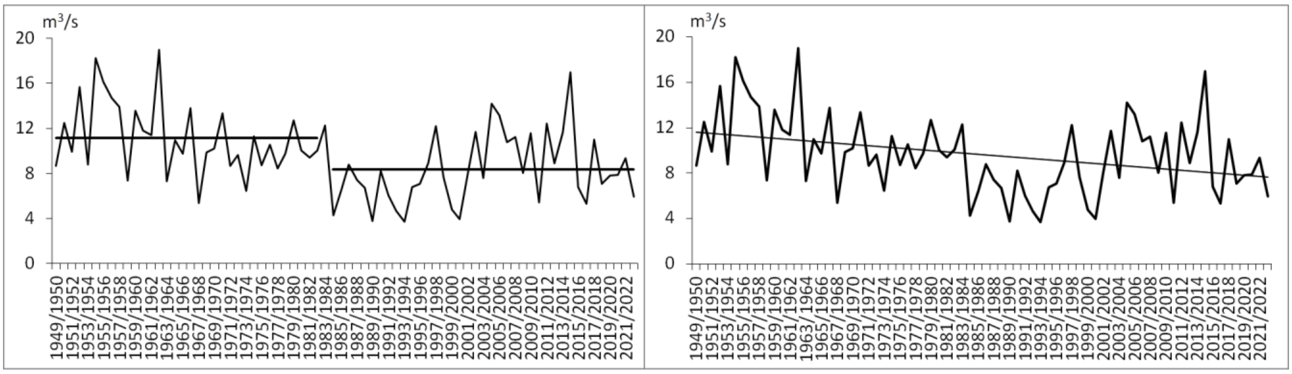

**Figure 3. Long-term fluctuations with average values (on the left) and linear trend (on the right) of the annual streamflow in the Chepelarska River Basin at Bachkovo**

**Table 3. Flow trends in the Chepelarska River Basin at Bachkovo according to the Mann-Kendall test**

| **Time scales** | | **Mann-Kendall's test parameters** | | |
|---|---|---|---|---|
| | | ***p-value*** | ***Kendall's tau*** | ***Sen's slope*** |
| Annual | | 0.004 | -0.246 | -0.018 |
| Seasonal | Winter | 0.001 | -0.332 | -0.015 |
| | Spring | 0.007 | -0.241 | -0.013 |
| | Summer-autumn | 0.084 | -0.067 | -0.001 |

The intra-annual runoff distribution of the Chepelarska River belongs to the moderate-continental type: the period of high-water levels is during the spring months, while the low-flow phase occurs in the summer-autumn months (Fig. 4, Table 4). In general terms, the monthly runoff increases from October to April and decreases from May to September. The highest streamflow is observed in April, while the lowest flow is measured in September. There is no change in the configuration of the monthly and seasonal maxima and minima for the studied two sub-periods, which indicates a relatively stable runoff regime.

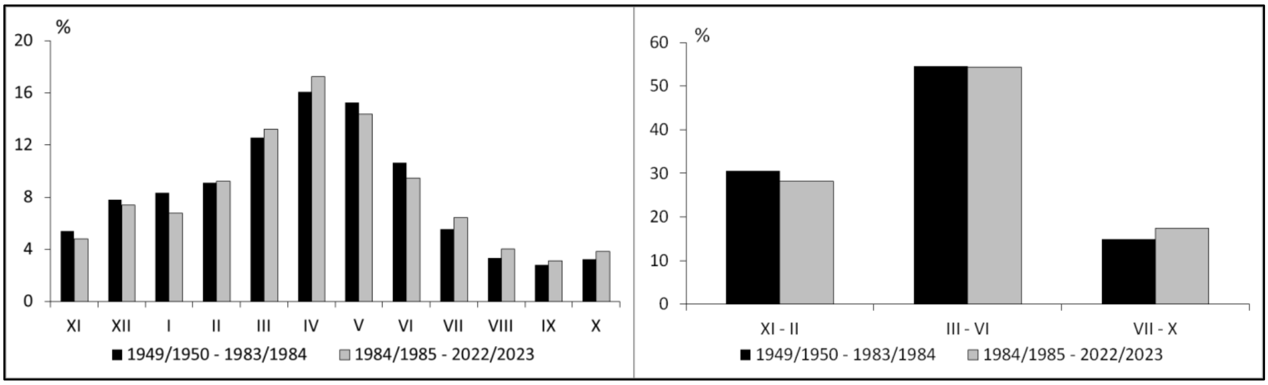

**Figure 4. Monthly and seasonal streamflow distribution (% of the annual volume) in the Chepelarska River Basin at Bachkovo**

**Table 4. Descriptive statistics of the monthly streamflow in the Chepelarska River Basin at Bachkovo**

| **Period** | **Indicators** | **Months** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **XI** | **XII** | **I** | **II** | **III** | **IV** | **V** | **VI** | **VII** | **VIII** | **IX** | **X** |
| 1949/1950–1983/1984 | $Q_{min.}$, m³/s | 1.49 | 1.78 | 2.97 | 2.64 | 4.37 | 6.54 | 5.90 | 3.49 | 2.15 | 1.49 | 1.02 | 1.30 |
| | $Q_{av.}$, m³/s | 7.20 | 10.43 | 11.14 | 12.15 | 16.84 | 21.49 | 20.39 | 14.22 | 7.39 | 4.43 | 3.78 | 4.32 |
| | $Q_{max.}$, m³/s | 24.10 | 30.30 | 36.40 | 44.40 | 42.00 | 44.00 | 40.70 | 43.80 | 20.00 | 24.60 | 13.10 | 17.00 |
| | $C_v$ | 0.73 | 0.69 | 0.76 | 0.68 | 0.52 | 0.45 | 0.46 | 0.63 | 0.61 | 0.93 | 0.74 | 0.85 |
| 1984/1985–2022/2023 | $Q_{min.}$, m³/s | 1.37 | 1.39 | 1.81 | 1.66 | 3.87 | 4.48 | 5.42 | 2.86 | 1.46 | 1.13 | 0.96 | 1.11 |
| | $Q_{av.}$, m³/s | 4.76 | 7.33 | 6.80 | 9.22 | 13.21 | 17.28 | 14.36 | 9.50 | 6.45 | 4.05 | 3.14 | 3.86 |
| | $Q_{max.}$, m³/s | 29.45 | 25.17 | 16.03 | 26.78 | 34.59 | 33.53 | 50.83 | 23.42 | 21.85 | 18.08 | 23.41 | 22.10 |
| | $C_v$ | 1.18 | 0.80 | 0.61 | 0.63 | 0.58 | 0.43 | 0.67 | 0.50 | 0.75 | 0.93 | 1.14 | 1.02 |

The average monthly flow decreases during the 1984/1985–2022/2023 period compared to the earlier one (Table 4). This decrease is larger (exceeding 20%) from November to June, especially in January (39%), November (34%), and June (33%) and closely correlates with the significant air temperature increase, whereas it is barely influenced by precipitation, which has slightly changed. In other months, the decrease is less than 20%.

The seasonal flow distribution (%) is 30.6/54.5/14.9 (1949/1950–1983/84) and 28.2/54.3/17.5 (1984/1985–2022/2023) for a winter, spring, and summer-autumn hydrological season, respectively. The declining share of winter runoff is probably due to the lower snow cover height. On the other side, the rising relative share of summer-autumn river flow reflects the increasing autumn precipitation.

The average seasonal flow also declines for 1984/1985–2022/2023 compared to 1949/1950–1983/1984. This change is expressed for winter (31%), followed by spring (25%), and summer-autumn (12%) hydrological seasons (Table 5). There is a statistically significant negative trend for all hydrological seasons, excepting summer-autumn (Fig. 5, Table 3). Torrential and intense summer-autumn precipitation caused sharp peaks in hydrographs and increased flow variability in last years, especially during the summers of 2005 and 2014. That to some extent explains the lack of a significant decrease in runoff for the summer-autumn hydrological season, regardless of rising air temperatures.

**Table 5. Descriptive statistics of the seasonal streamflow in the Chepelarska River Basin at Bachkovo**

| Period | Indicators | Hydrological seasons | | |
|---|---|---|---|---|
| | | Winter | Spring | Summer-autumn |
| 1949/1950–1983/1984 | $Q_{min.}$, m$^3$/s | 2.66 | 7.37 | 1.79 |
| | $Q_{av.}$, m$^3$/s | 10.23 | 18.24 | 4.98 |
| | $Q_{max.}$, m$^3$/s | 23.50 | 29.78 | 11.51 |
| | $C_v$ | 0.53 | 0.29 | 0.55 |
| 1984/1985–2022/2023 | $Q_{min.}$, m$^3$/s | 2.04 | 5.60 | 1.26 |
| | $Q_{av.}$, m$^3$/s | 7.03 | 13.58 | 4.38 |
| | $Q_{max.}$, m$^3$/s | 22.01 | 29.19 | 16.50 |
| | $C_v$ | 0.60 | 0.38 | 0.74 |

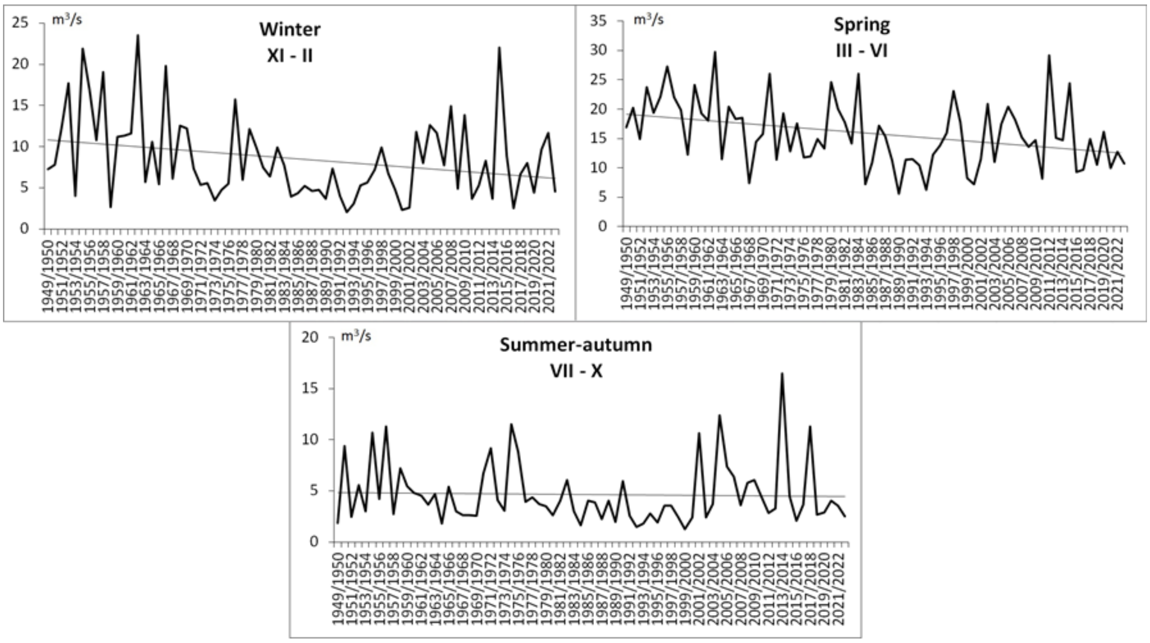


**Figure 5. Linear trend of the seasonal streamflow in the Chepelarska River Basin at Bachkovo**

The ratio between winter and spring streamflow ranges from 0.21 to 1.32 (1949/1950–1983/1984) and from 0.18 to 0.97 (1984/1985–2022/2023). The mean annual values are 0.57 and 0.52, respectively. The ratio exceeds the critical value of 1.00 only for two hydrological years (1966/1967 and 1976/1977), which confirms the moderate-continental type of the seasonal flow distribution. The variability in ratio values over the past decades is evidence of changing seasonal patterns of streamflow.

*Water withdrawal, river continuity and morphology* – The main activities generating hydro-morphological

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pressure on SWBs in the Chepelarska River Basin are: water withdrawal (including the constructed water intake facilities), electricity production through small hydropower plants (SHPPs), flood protection dykes, migration barriers, and the extraction of inert materials (sands and gravels).

The general structure of water use by 2025, without intakes for electricity production, is presented in Figure 6.

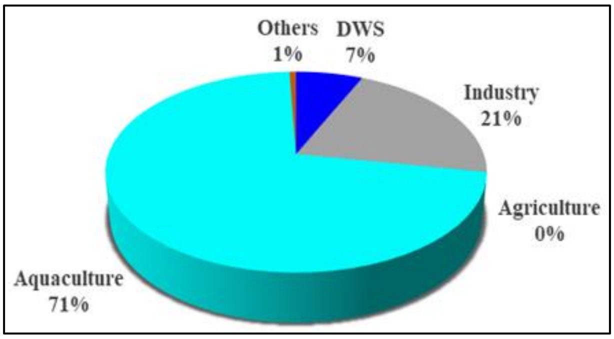


**Figure 6. Structure of water use without electricity production in the Chepelarska River Basin**

Considering the overall water use in the studied river basin, the leading sector is the hydropower, presented by multiple operating and under construction SHPPs (Figure 7). Two SHPPs – "Asenitsa" 1 and "Asenitsa" 2 with a derivation channel (L = 5.0 km, Q average = 12 $m^3$/s) for electricity production and irrigation have been built along the stream of the Chepelarska River from the town of Asenovgrad to the village of Bachkovo. Two more SHPPs – "Tunela" and "Lukovitsa" (along the Lukovitsa River) are under construction. In the river section from the village of Bachkovo to the village of Narechen, the SHPP "Narechen" is operating, and five more ("Asenitsa 3", "Bukov dol", "Konsort", "Hana", and "Laki") are under construction. From the village of Narechen to the town of Chepelare, the SHPPs "Hvoyna", "Pavelsko", "Chaya", "Desislava", and "Persenk" are in operation (Fig. 7 ). On the feeder of the Zabardovska River, the SHPP "Niki 60" operates, and three more are under construction: "Hlapach", "Zabardo", and "Chudnite Mostove". Four SHPPs are in operation in the catchment of the Yugovska River, and six more are being constructed. The total permitted water volume for electricity production by February 2025 is 5380.661*$10^6 m^3$. Water intake facilities for SHPPs are barriers that disrupt the continuity of the river and impede the free migration of fish and their reproduction. Additionally, most of these SHPPs are derivational and can cause drying of river sections, not ensuring the minimum ecological flow. In the pilot river basin, this pressure is significant along the main river course in the section from the confluence of the Zabardovska River to the mouth of the Chepelarska River.

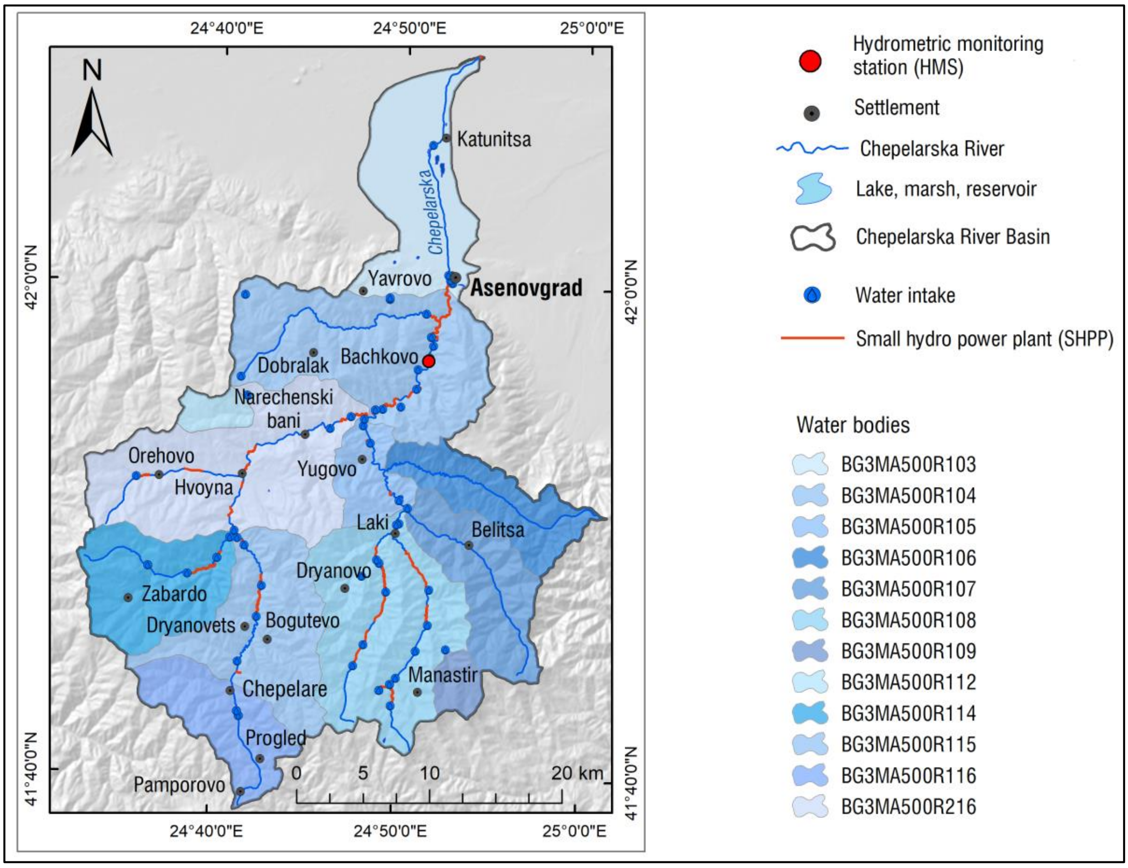


**Figure 7. Map of the Chepelarska River Basin with surface water bodies, water intakes, and small hydro power plants**

The next significant activity in the studied drainage basin is the aquaculture farming in artificially created flow-through basins (fisheries), located near to the town of Asenovgrad and the villages of Hvoyna, Bachkovo, Zabardo, and Dryanovo. The total permitted water volume for aquaculture by February 2025 is estimated at $769.680 * 10^3 m^3$. The permitted annual limit for each of the SWBs with aquaculture farming (BG3MA500R104, BG3MA500R108, and BG3MA500R216) is over $150 * 10^3 m^3/y$.

The industry is mainly represented by water intakes related to the extraction of polymetallic lead-and-zinc ore in the mines of "Dzhurkovo" and "Druzhba", and the "Tailings Pond Laki-2 Complex" with an operator "Laki Invest" AD near to the town of Laki, which is classified as an "enterprise with a high-risk potential". Representatives of other industrial sectors are: Rosa Impex Cosmetic Factory and Production Base in the village of Yagodovo; Fish processing workshop "Sinite hancheta" between the villages of Pavelsko and Hvoyna; a dairy farm in the village of Zabardo; a recreation base within the Resort Complex "Pamporovo", a shopping complex, a car-wash, etc. (RBMP, 2022–2027).

The drinking water supply (DWS), which is represented by local water intakes near to the larger settlements, has a relatively smaller share. The share of agriculture and other economic sectors in the overall structure of water use is negligible (Fig. 6).

The calculations on the degree of hydro-morphological pressure shows that it is moderate from flood protection dykes for one SWB (BG3MA500R103) with a share of the affected river section of 62%, from migration barriers it is significant for two SWBs (BG3MA500R103 and BG3MA500R104), from drying out from the constructed derivational SHPPs it is significant for one SWB (BG3MA500R103) with a share of the affected river section of 56%, and from the extraction of inert materials (sands and gravels) for seven SWBs it is weak, varying from 1.3% (BG3MA500R108) to 20% (BG3MA500R103).

In summary, the assessment of the *HMEQ*, carried out through an analysis of hydrological parameters, including water withdrawal, and river continuity and morphology, establishes: declining annual streamflow volume without significant change in its monthly and seasonal distribution, predominant water use for electricity production and aquaculture farming, absence of hydro-morphological pressure from the targeted water abstraction permitted by 2025, and disturbances in river morphology from barrier facilities, given the construction of derivational SHPPs and flood protection dykes.

*Biological and physicochemical elements of water quality (BEQ and PCEQ)* – Changes in the general hydro-ecological status of the Chepelarska River for the period 2010÷2023, and separately, on the number of SWBs in a "poor" status, are presented in Figures 8 and 9.

The general tendency is toward improving the water quality state, with an increasing number of water bodies in a "good" status and a decreasing number of these reported to have retained a "poor" status.

The observed peak in the number of SWBs in a "good" status in 2020 and 2021 can be explained by: improved monitoring methods, assessment of water bodies that were previously in "unknown" status, improved analysis of the spread of specific chemical pollutants, and possibly lower sampling frequency during the COVID-19 pandemic.

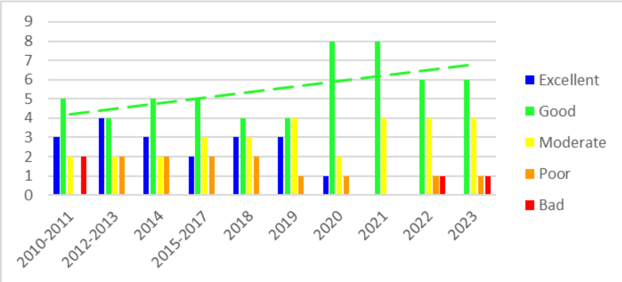


**Figure 8. General hydro-ecological trend in the period 2010-2023**

Despite the observed positive trend, water bodies in a "poor" status continue to be identified, which necessitates a reassessment of measures for water quality protection. In the current edition of the RBMP (2022–2027), six SWBs (BG3MA500R103, BG3MA500R104, BG3MA500R105, BG3MA500R108, BG3MA500R115, and BG3MA500R216) are assessed at risk regarding the general ecological state, and respecting the chemical state three SWBs (BG3MA500R103, BG3MA500R104, and BG3MA500R108) are defined as not achieving a "good" status, with a decline in the number of parameters with deviations compared to previous years.

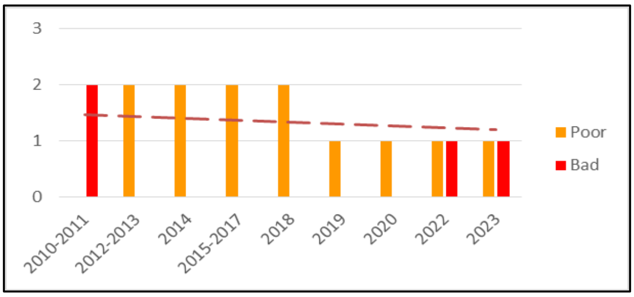


**Figure 9. Poor state change in the period 2010-2023**

Based on the monitoring data, carried out during the period 2012÷2023, exceedances have been found for those parameters shown in Table 6, characterizing the main physicochemical and biological elements of water quality. Regarding physicochemical and specific chemical elements, the most disturbing is heavy metal pollution (Zn, Pb, Cd, Mn, and Cu), typical not only of those SWBs (BG3MA500R105 and BG3MA500R108) that cover the mining-affected areas, but also of downstream SWBs

(BG3MA500R103). Elevated values of metalloids and heavy metals in the lower reaches of the main river were reported in past studies as well (Gartsiyanova, 2022; Gartsiyanova et al., 2023; Radeva & Seymenov, 2021). Unregulated discharges of industrial and mining wastewater from the mines of "Druzhba" and "Dzhurkovo" continue. Water pollution with biogenic components (TN, TP, $NH_4$, $NO_2$, $NO_3$, and $PO_4$) is a widespread problem, which affects both the upper (BG3MA500R115) and lower (BG3MA500R103) reaches of the river. The main reason for this situation is the lack of sewage systems in the settlements and the inflow of untreated domestic and fecal effluents (Radeva & Seymenov, 2021). This requires the implementation of measures related to the construction or modernization of a public sewage network and urban wastewater treatment plants for agglomerations with more than of 2000 population equivalent (p.e.). In the study area, wastewater treatment plants are currently constructed and operated only in the town of Asenovgrad and the village of Progled (Plan for Integrated Municipal Development, 2021–2027).

**Table 6. Parameters with norm exceedances in the period 2012-2023, presented by SWBs**

| Year / SWBs | BG3MA500R103 | BG3MA500R104 | BG3MA500R105 | BG3MA500R108 | BG3MA500R115 |
|---|---|---|---|---|---|
| **2012** | Biotic Index (BI), $NH_4$, $NO_2$, $PO_4$, Zn, Cd, Pb | $NO_3$, $PO_4$, TP, Cd | BI | - | $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP, BI |
| **2013** | $NH_4$, $NO_2$, $PO_4$, Zn, Cd | $PO_4$, TP | - | - | $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2014** | Macrozoobenthos, $NH_4$, $NO_2$, $PO_4$, Cd | $PO_4$, TP | Macrozoobenthos, Zn, Cu | - | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2015** | Chepelarska River after Asenovgrad: $PO_4$; Chepelarska River at the mouth, Kemera station: $PO_4$, Zn, Cd | $PO_4$, TP | Macrozoobenthos | Macrozoobenthos | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2016** | Macrozoobenthos, Chepelarska River after Asenovgrad: $NO_2$, $PO_4$ | TP | Cu | Macrozoobenthos | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2017** | Macrozoobenthos, Chepelarska River after Asenovgrad: $NO_2$, $PO_4$, TP; Chepelarska River at the mouth, Kemera station: $NO_2$, $PO_4$, TN, TP, Mn, Zn, Cd, Pb | TP | Cu, Mn, Pb | Macrozoobenthos, Zn, Pb | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2018** | $NH_4$, $NO_2$, $PO_4$, TN, TP, Mn, Cd, Pb | TP | Zn, Cu, Mn, Cd, Pb | Macrozoobenthos, Zn, Cd | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2019** | Macrozoobenthos, $NH_4$, $NO_2$, $PO_4$, TN, TP, Mn, Cd, Pb | TP | Mn, Cd, Pb | Zn, Cd | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2020** | Macrozoobenthos, electrical conductivity, $NO_3$, $NO_2$, $PO_4$, TN, Mn, Cd, Pb | - | Cd, Pb | Zn, Cd | Macrozoobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2021** | Macrozoobenthos, Phytobenthos, $NO_2$, PO4, TN, TP, Cd, Pb | Fishes, $PO_4$, TP | Cd, Pb | Zn, Cd | Macrozoobenthos, Phytobenthos, $BOD_5$, $NH_4$, $NO_3$, $NO_2$, TN, $PO_4$, TP |
| **2022** | Phytobenthos, Macrozoobenthos, TP | Fishes, TP | Zn, Cu | Al, Zn, Cu | Phytobenthos, Macrozoobenthos, Fishes, TN, TP, $BOD_5$ |
| **2023** | Phytobenthos, Macrozoobenthos, TP, Zn | Fishes, TP | Zn | Zn | Fishes, Phytobenthos, Macroinvertebrates, TN, TP |

Respecting biological elements, the largest and persistent deviations from reference conditions are found for the Macrozoobenthos indicator, especially for two SWBs (BG3MA500R105 and BG3MA500R108), which are exposed to toxic pollution with heavy metals from mining activities (Table 6). Deviations for this element were also established by Patronov & Kirin (2024). After 2021, the Phytobenthos and Fishes indicators also do not meet the requirements. And if for Phytobenthos, deviations are related to organic and biogenic water pollution, for Fishes, the most critical are river sections with built SHPPs (Fig. 7, Table 6). The changes in hydro-morphological conditions negatively affected fish and benthic invertebrates (Gecheva et al., 2023). In this sense, ensuring minimum ecological flow after water abstraction facilities, the construction or reconstruction of fish passes, and the modernization of aquaculture farms by using sensors for real-time monitoring of indicators such as dissolved oxygen are measures that should be taken into account. And last but not least, the objective analysis of the causes of water pollution and the availability of indicators with norm exceedances requires additional research like these carried out by Chunchukova et al. (2020) and Zaharieva & Kirin (2020).

## Conclusion

The results obtained in this study, dedicated to current tendencies in hydro-ecological conditions of a river system facing to climate change and anthropogenic impacts, reported: alternation in hydrological regime with an increasing variability and declining volume of annual runoff, relatively stable monthly and seasonal streamflow distribution, a rising hydro-morphological pressure from hydropower construction, riverbanks correction, and aquaculture farming, and despite the overall positive hydro-ecological trend – water pollution, given the registered deviations in biological and physicochemical quality elements.

The improvement of the general hydro-ecological status and river water protection requires the application of a complex of environmental, engineering, and legislative measures, as well as measures for climate change mitigation. The environmental-friendly measures, that are possible to take, are related to the afforestation of riverside zones to reduce erosion and improve water retention, protection and restoration of wetlands as natural filters for pollution, and biodiversity improvement with exercising control over the invasive species. The measures with an engineering character are: a development and modernization of the water supply, sewerage, and treatment infrastructure with reduction of losses and increase of the purification effect; green infrastructure introduction (green roofs, rain gardens, and special pavements for natural water retention); introduction of energy and water-securing technologies, including water collection and turnover cycles for water reuse; construction of fish passages to maintain the natural migration roads, etc. In the context of sustainable management, the following activities are of great importance: development of integrated water resources management strategies, including for the cases of drought; reassessment of the regulations with stricter control over pollution and water abstraction, environmental standards for the industry and agriculture; introduction of incentives and sanctions such as "the pollutant pays"; optimization and/or expanding the monitoring networks with an introduction of new technologies to improve information security; environmental education and involvement of the local communities; and last but not least, expansion of the methodological and pilot scientific investigations to increase the objectivity of the assessed current and prognostic state, taking into account the dynamic changes, including climate change.

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## Author contribution

Conceptualization, methodology, writing – original draft, MM, GB. All authors have read and agreed to the published.

## Conflicts of interest

The authors declare no conflict of interest.

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