GEOGRAPHY AND TOURISM, Vol. 5, No. 2 (2017), 41-49, Semi-Annual Journal
eISSN 2449-9706, ISSN 2353-4524, DOI: 10.5281/zenodo.1118163

Marian S. Varbanov, Kristina M. Gartsiyanova
National Institute of Geophysics, Geodesy and Geography BAS, Bulgaria,e-mail: marian.varbanov@gmail.com

Index assessment of the water quality – a case study of Bulgarian rivers

Abstract: Development and implementation of indexation methods used in the assessment of surface water quality (pollution) is particularly relevant in recent years. Currently, hydrological practice actively uses several dozen indices. The existence of so many indices offers the possibility of testing and choosing those that provide a complete and thorough characterization of the anthropogenic impact as well as the types and forms of pollution inselected rivers in Bulgaria.We calculated four indices: the Water Quality Index – WQI, the Combinatorial Index of Water Pollution – CIP, the Index of Water Pollution – IWP and the Index of Oxygen Balance in river water – IOB for the Bulgarian rivers: the Topolnitsa River, the Vacha River, the Lesnovska River and the Provadiyska River. The results show that complex (index) methods are very effective methods for assessing the quality of river water, especially in the context of anthropogenic impact. Uniform indices also allow to compare the water quality status of different rivers and regions.

Keywords: water quality, index assessments, physicochemical indicators, Bulgaria.

1. Introduction

Systematic research on the surface water quality indicators in Bulgaria has begun in the early 1950s. Basically, they are aimed at determining the main chemical composition of water, the specificity of its formation and spatial distribution of major ions in surface and ground waters. In Bulgaria, the national water quality monitoring system with stations and laboratories for physicochemical and hydrobiological analyses was established following the development of industry, the water supply for housing and the increased irrigation of agricultural areas. A gradual increase in the range of monitored water quality indicators and over 80 physical and chemical parameters monitored in accordance with the national legislation resulted in a complete system being built in the mid-1970s.

The preparation and accession of Bulgaria to the European Union in 2007 required the unification of Bulgarian and European environmental standards. Following the adoption of the Water Act (2000), developed on the basis of the EU Water Framework Directive (60/2000), a comprehensive package of legislative documents on water quality has been designed, complaint with different water users and protection of aquatic ecosystems from harmful impact of man. The "ecological approach" based on three groups of indicators –biological, physicochemical and hydromorphological, has been adopted in the water quality assessment (*Ordinance N-4/2012*). The physicochemical indicators used for surface water quality assessment are divided into basic, priority and specific, adapted to the EU legislation requirements.

The status of water in terms of physicochemical indicators relate to two categories: "good" and "very good". Together with the two other assessments (biological and hydromorphological), they determine the overall condition of a water body at a study site. The general policy objective in the new river basin management plans is to increase the number of river water bodies that should be in "good" and "very good" conditions (http://www5.moew.government.bg/?page_id=24258). At present, two basic approaches to the water quality assessment based on physical and chemical indicators (differentiated and complex, respectively) are applied in hydrological practice.

The differentiated approach provides information about the condition of the research object only on its individual parameters. The result can not be considered representative of the quality status of whole water bodies. Through the integrated approach based on multiple indicators (statutory), a single final assessment of water quality is provided, which can be presented in the form of scores, grades or ranks.

In modern hydrochemical studies, the development and implementation of various methods (complex and differentiated analyses and assessment of the water quality status) play an important role. They determine the forms in which contaminants occur in water and the anthropogenic sources of pollution. The development and implementation of index-ation methods to assess the quality (pollution) of surface water is particularly relevant in recent years. One of the most common reviews includes dozens of indices that differ in the set of indicators, the mathematical algorithm used to calculate the water quality and the choice of reference values. The existence of so many indices provides the possibility of testing and choosing those that, depending on pre-selected criteria, determine the quality of the examined waters in the most complete and objective way.

This paper examines the use of different index assessments of the quality of surface waters in Bulgaria and aimed at providing a comprehensive picture of their status and potential use.

2. Methods - indices of comprehensive river water quality assessment

The four indices, distinguished based on their algorithm, a set of indicators and benchmarks of physical and chemical indicators, have been tested for selected rivers in Bulgaria (Fig. 1). They are commonly used in different regions of the world and in some countries they are the main method of assessing the water status:

1. Water Quality Index – WQI (Canada, recommended by UNEP);
2. Combinatorial Index of Water Pollution – CIP (Russia);
3. Index of Water Pollution – IWP (Russia);
4. Index of Oxygen Balance in river water – IOB (Belgium, the Netherlands, Luxembourg).

Figure 1. Location of the researched catchments against the background of the river network in Bulgaria

The CCME Water Quality Index (1.0) (CCME, 2001) is based on a formula developed by the British Columbia Ministry of Environment, Lands and Parks and modified by Alberta Environment and Parks, and officially used in all its provinces from the late 1990s. In 2006, the program was recommended by UNEP UN for general use in the assessment of surface water quality (http://www.unep.org/). The Index incorporates three elements: scope (F1) – the number of variables not meeting the water quality objectives; frequency (F2) – the number of times these objectives are not met; and amplitude (F3) – the amount by which the objectives are not met. After determining the values of individual components of the integrated formula, the index of water quality is calculated, using the following formula:

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

The divisor of 1.732 normalises the obtained values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality. Once the CCME WQI value is determined, water quality is classified by referring to one of the following categories (Table 1).

It is not advisable to manually calculate the index for a large amount of data. For this purpose, an Excel macro has been developed, which enables fast handling of large data sets (without much preparation) for a significant range of physicochemical parameters, because reference values can be set depending on the purpose of the study and specific legislation in a country.

The second presented index is known as a Combinatorial Index of Water Pollution (CIP), developed by the State Hydrochemical Institute of the Russian Federation and is now widely used to assess the quality of river water (Nikanorova, 1984; Vasilieva et al., 1998; Venitsianov et al., 2003). It assess how much and how many times the limit concentrations (LC) for selected elements were exceeded. It is calculated as follows:

$$H_i = \frac{\mathrm{N}_{\mathrm{LC_i}}}{\mathrm{N_i}} \times 100\%,$$

where *Hi* is a repeated exceedance of the limit concentration for the *i*th element, N_{LCi} is the number of analytical results, in which the content of the *i*th element exceeds the limit concentration, *Ni* is the total number of the result analysis for the *i*th element.

The exceedance of the limit concentration is determined by the relationship:

$$K_i = \frac{C_i}{LC_i},$$

where *Ki* indicates how much the limit concentration was exceeded, *Ci* is the concentration of the *i*th element in the analysed water expressed in $mg{\cdot}dm^{-3}$.

Table 1. Interval scheme for the classification of waters in relation to their quality based on WQI

CATEGORIES	RANK	WATER QUALITY
Excellent	95–100	water quality is protected; basically no threat or deterioration; conditions very close to natural or pristine levels
Good (very good)	80–94	water quality is protected; minor threats or deterioration; conditions rarely depart from natural or desirable levels
Fair (good)	65–79	water quality is usually protected but occasionally threatened or deteriorated; conditions sometimes depart from natural or desirable levels, slightly polluted
Marginal (critical)	45–64	water quality is frequently threatened or deteriorated; conditions often depart from natural or desirable levels, polluted water
Poor (bad)	0–44	water quality is almost always threatened or deteriorated; conditions usually depart from natural or desirable levels, heavily polluted water

The total assessment score Si for each of the selected components is calculated as follows:

$$S_i = H_i \times K_i$$

and the final formula of CIP is:

$$CIP = \sum_{i=1}^{n} S_i .$$

For each indicator, a rating scale was created. The final assessmentis based on 5 classes, ranging from "clean" to "extremely dirty" waters. The high value of CIP means "bad" water. The main objective of this method is to arrive at definite assessment of water quality and its classification for different uses (Emelianonova et al.,1983).

Very often quick assessments of the water quality status are required in hydrological practice, using a limited number of physical and chemical indicators. The Index of Water Pollution (IWP) (Gagarina, 2012) and the Index of Oxygen Balance in river water (IOB) (Colombo, 1992) are such indices.

IWP is calculated based on a number of indicators. In the classic case, 6 physicochemical indicators are used, of which "dissolved oxygen" and "BOD_5" (biochemical oxygen demand) are mandatory. This is due to the fact that these indicators are particularly sensitive to human impact. BOD_5 is an integral indicator of readily oxidisable organic substances. Water quality deteriorates rapidly with their increasing content, which results in a rapid reduction in dissolved oxygen in the water. Amodified version of the index was used in this study. The indicators used are those with complete and representative data. The average annual values for the period of 2000–2014 are used in the calculations. The index formula is as follows:

$$IWP = \frac{1}{8} * \sum_{i=1}^{n=8} \frac{C_i}{SWQ_i},$$

where C_i average annual concentration of indicator *i*, SWQ_i is the value of the water quality standard for this indicator.

Depending on the measured values of BOD5, dissolved oxygen and pH as required by the IWP and specific meanings of SWQ ("rules") are introduced. In this case, they replace statutory values of the analysed indicators. The obtained results of IWP under that formula are compared with the tabular evidence and the class of water quality is determined. The degrees of contamination are presented in 7 classes from "very clean" to "extremely dirty".

The last index tested for Bulgarian rivers provides a comprehensive assessment of the river water quality using several physical and chemical indicators. The Index of Oxygen Balance in water without load (Colombo, 1992) is a fast integral assessment of the surface water quality status through the use of physical and chemical indicators, evaluating self-cleaning ability of water bodies and determining their organic load. This index has been developed in the Benelux countries (Belgium, the Netherlands and Luxembourg). It uses a dissolved oxygen concentration expressed in % (in Bulgarian legislation referred to as "oxygen saturation"), biochemical oxygen demand (BOD5) and the content of ammonia nitrogen (N-NO4). The assessment of IOB at a monitoring point of a water body is carried out for each of the indicators according to a scale of scores depending on their concentration. The final assessment is the sum of scores and can be allocated to one of the five classes, ranging from "very poor" to "very good".

3. Results

3.1. Application of the Water Quality Index (WQI)

The water quality in the basin of the Topolnitsa (Fig. 1), a left tributary of the Maritsa River, was assessed based on WQI. Many of the settlements in the catchment of the studied river have no sewage systems and wastewater treatment plants. The discharge of wastewater takes place directly into watercourses or "septic tanks" from where it re-enters the rivers through the groundwater. The application of WQI reveals trends in water quality changes under the influence of wastewater from the municipal sector. The following parameters were analysed – oxygen, pH, conductivity, ammonia nitrogen, nitrite and nitrate ions, total nitrogen, total phosphorus, orthophosphate and BOD5. They are defined in the Bulgarian legislation for the classification of surface waters. It appears from the WQI estimates and studies of the river water quality in the surveyed area that between 1981 and the early 1990s, the waters were largely or continuously subject to anthropogenic loads, hence they can be classified as "marginal" or "poor" (Table 1, Fig. 2) in relation to its bad and very bad quality.

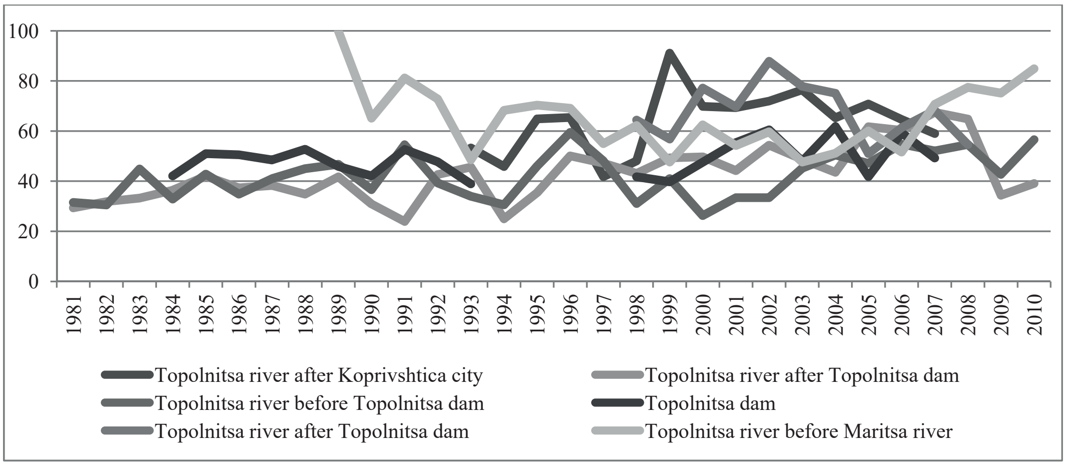


Figure 2. WQI Index in different parts of the Topolnitsa River for the period of 1981–2010

At some points (e.g. at the Topolnitsa River in the mouth section), the value of the WQI slightly increases. The main source of pollutants in surface water bodies in the western part of Pazardzhik-Plovdiv Field is untreated household sewage from the settlements (without a sewage system) and wastewater treatment plants (WWTP).

3.1. Application of the Combinatorial Index of Water Pollution (CIP)

The CIP index was tested on the waters of the Vacha River in the Rhodopes and the Lesnovska River in the Sofia Valley (Fig. 1). The former is characterized by a relatively smaller anthropogenic impact due to the absence of large settlements, industrial sites and developed agriculture. The latter flows through a heavily developed industrial area, agricultural lands and a large number of settlements. The Vacha River has a relatively good status of wateralong its entire course (Fig. 3). The water quality deteriorated at the beginning of the study period (the 1980s), and major pollutants included: BOD5, nitrate nitrogen and, to a lesser extent, suspended matter. The load is more sustainable throughout the year and falls into the category of sustainable contamination with a moderate overshoot.

After 1990, the anthropogenic impact apparently subsided and the river reaches the status of "uncontaminated water". Based on this index, the quality of waters in the Lesnovska River (Fig. 4) is critical throughout the study period. Till 1995, the status of the river's waters can be defined as "good", while in 1995-2003 the conditions deteriorated to "critical" or even "bad".

The main pollutants are ammonia and nitrite ions, dissolved and suspended matter, and sulphates in different years. The limit concentrations for ammonium, nitrite ions and suspended matter were in many cases exceeded up to 30 times.

The anthropogenic load is carried by industrial and household wastewater from the region around the town of Elin Pelin, as well as by drainage water from the cinder depots of Kremikovtzi Metallurgical Works. According to the assessmentindex, waters of the Lesnovska River can not be used because they are in critical conditions.

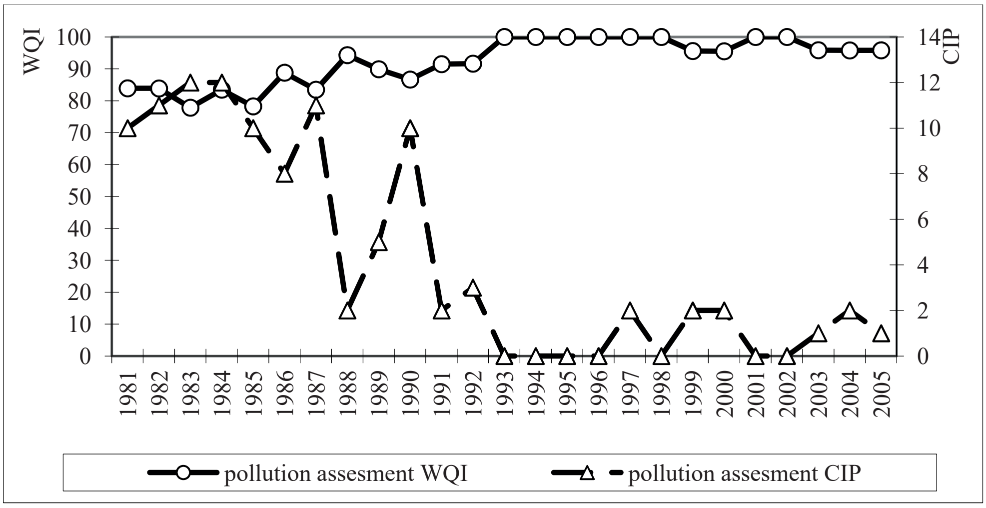


Figure 3. Assessment of pollution in the waters of the lower Vachareaches by the Water Quality Index (WQI) and the Combinatorial Index of Pollution (CIP) for the period of 1981–2005

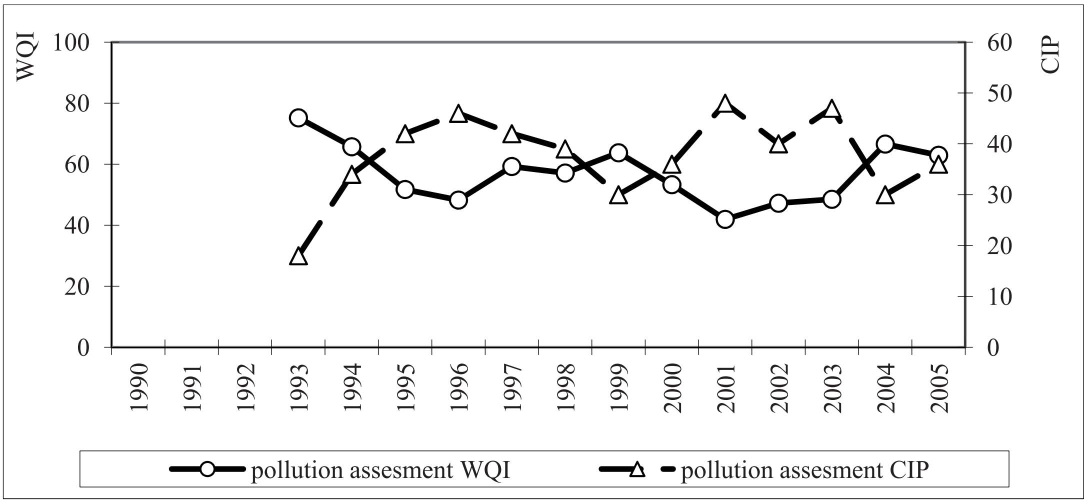
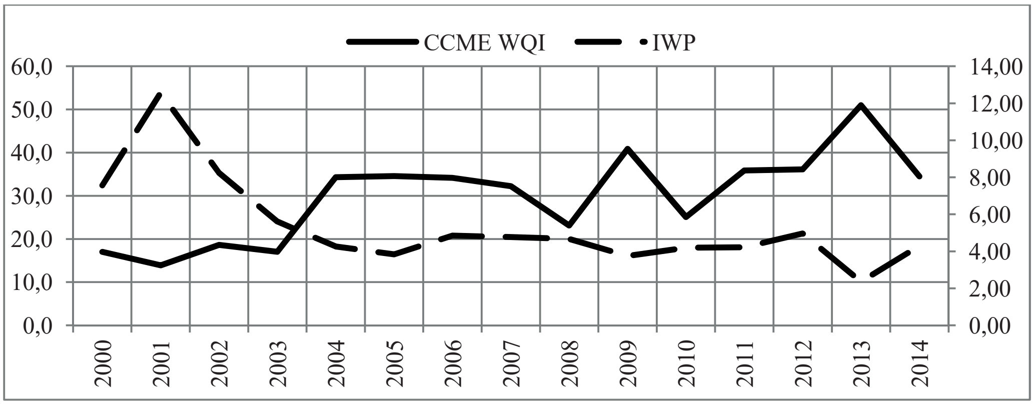


Figure 4. Assessment of pollution in the waters of the Lesnovska River by the Water Quality Index (WQI) and the Combinatorial Index of Water Pollution (CIP) for the period of 1993-2005

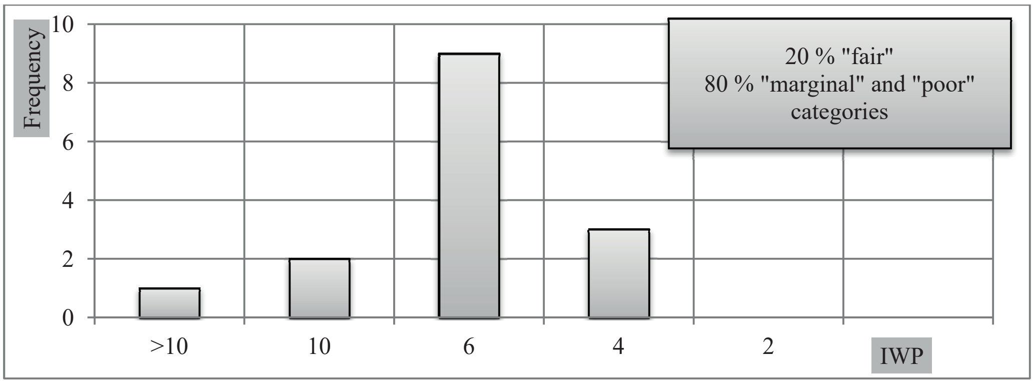
3.3. Application of the Index of Water Pollution (IWP)

The index was tested to determine the water quality for the Provadiyska River (Fig. 1). The WQI presented in this paper is used for reference and comparison. The Provadiyska is one of the largest rivers in the Black Sea drainage area. It flows into Lake Beloslavsko, west of Varna. The river flows through a large industrial area with developed chemical, cement and sugar industries. In the river basin management plans and many analytical works, the Provadiyska is referred to as a "hot spot" because of the poor water quality. In the Provadiyska river mouth, a very strong technogenic impact was registered in terms of both the volume and quality of simulated wastewater as well as in the values of the integral indicators. The results of both indices, IWP and WQI, correlate very well in terms of the time and the assessment of critical water quality status (Fig. 5a, b, c).

a



b



c

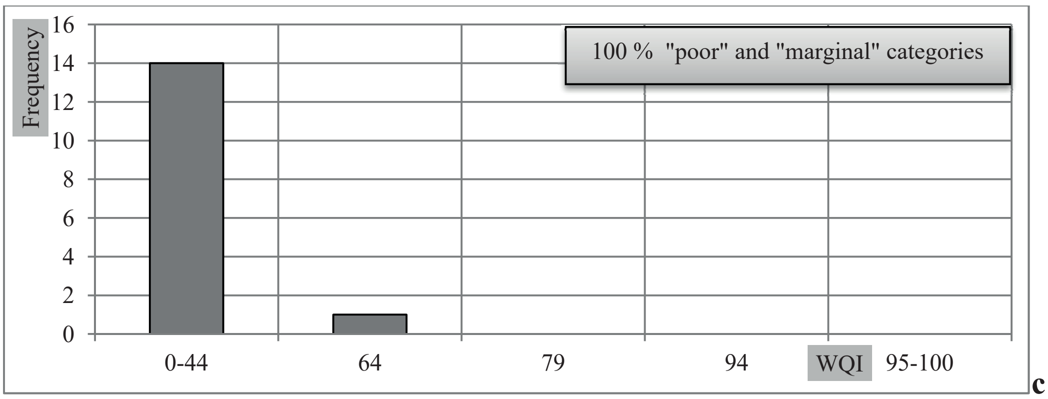


Figure 5a, b, c. Changes in WQI and IWP values for the Provadiyska River for the period of 2000-2014

3.4. Application of the Index of Oxygen Balance in water (IOB)

In the sensitivity check of the index, the information about the Provadiyska River has been used for the period of 1992-2015. The conducted assessment of the condition of the Provadiyska River at its mouth through IOB confirm the findings for the same river by WQI and IWP presented in this paper (Fig. 6).

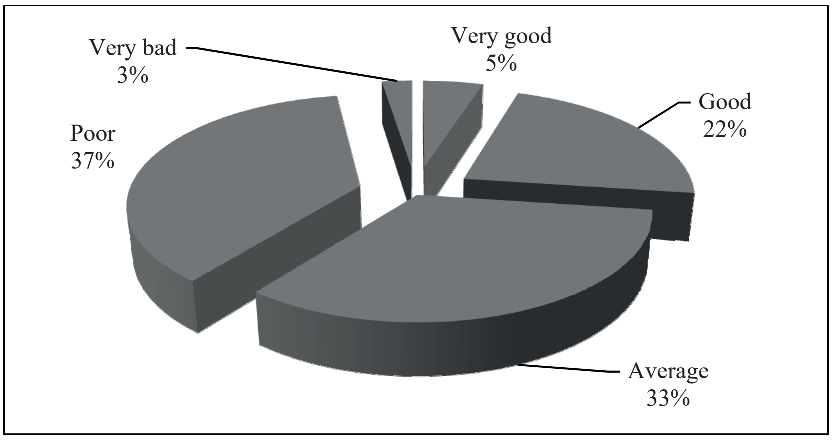


Figure 6. Assessment of the water conditions in the Provadiyska mouth according to IOB (in percentage)

According to the above chart, just over ¼ of the sampling can be assessed as "good" and "very good". This result demonstrates very high contributionof "bad" and "very bad" status of the water. The critical condition is typical for the first 10 years of the study period. A steady trend towards a slow improvement of the water in the rivers has been observed. The average score for the water status assessment period is "medium" (Fig. 7).

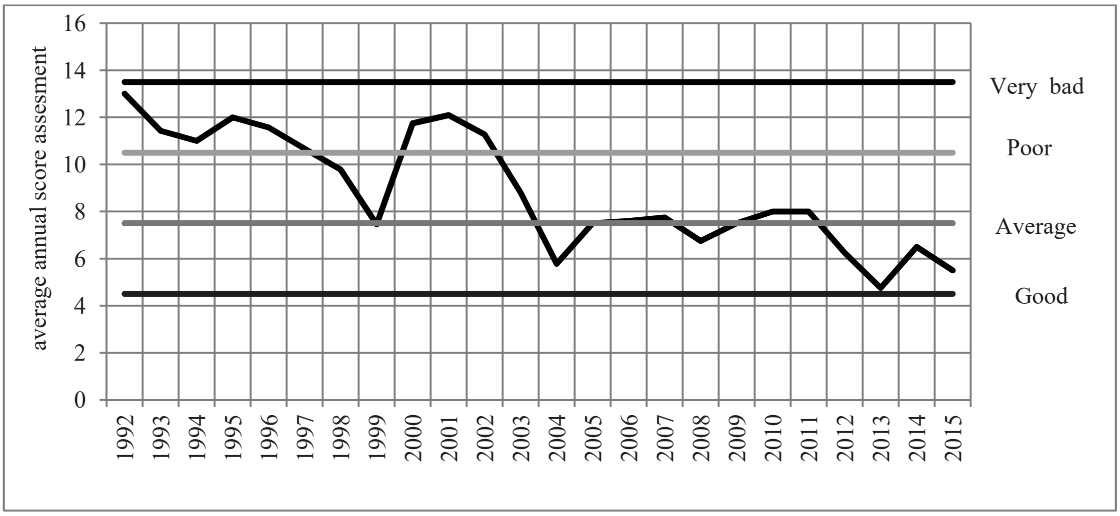


Figure 7. Average annual score assessment of waters (IOB) of the Provadiyska River mouth for the period of 1992-2015 (Reference values for the conditions: 1 – "very good"/"good"; 2 – "good"/"medium"; 3 – "medium"/"bad"; 4 – "bad"/"very bad")

The disadvantage of this index is the limited number of indicators used and the benchmarks for the strictly defined reference values of the physicochemical indicators. It can be used for a preliminary assessment of the river water quality status or in combination with other indices.

4. Conclusions

Based on the results obtained from the application of the indices in assessing the quality of water in the Bulgarian rivers, the following conclusions can be drawn:

– The advantages of using the complex (index) methods of assessing the quality of river water based on physical and chemical indicators have been demonstrated. They provide a more complete and thorough characterization of the anthropogenic impact as well as the types and forms of pollution in water bodies.

- The definite result, which can be in the form of a score, rank, class, etc., allows to determine the quality status of the whole river course or its individual sections. Assessments provide an opportunity to make a comparative characterization between different river basins and territories.
- The indices can be used to determine the quality status of rivers for different purposes, mainly for the management of water resources, for the science and to provide information for the population and local authorities.

References

CCME, 2001. Canadian water quality guidelines for the protection of aquatic life. Canadian Water Quality Index 1.0 Technical Report. Canadian Council of Ministers of the Environment 2001, Excerpt from Publication No. 1299.

Emelianonova V.P., Danilova G.N, Kolesnikova T.H., 1983. Evaluation of the quality of surface water on hydrochemical indicators. Hydrochemical materials 88, 119-129 [In Russian with English abstract].

Gagarina O., 2012. Evaluation and standardization of the quality of natural waters: the criteria, methods, existing problems. Udmurtia University, Izhevsk [In Russian].

Nikanorova, A.M., 1984. Complex evaluation of the quality of surface water. Gidrometeoizdat, Leningrad [In Russian].

Colombo A.G. (Eds.), 1992. Environmental Impact Assessment, Vol. 1. Kluwer Academic Publishers, Netherlands.

Vasilieva E.A., Vinichenko V.N., Guseva T.V., Zaika E.A., Krasney E.V., Molchanova Ya.P., Pechnikov A.V., Hotuleva M.V., Cherp O. M., 1998. How to organize public environmental monitoring, Guide for NGOs. [In:] Hotulevoy M.V. (Eds.), Ecoline [In Russian with English abstract].

Venitsianov E,V., Stutterer E.A., Mendeleev, D.I., 2003. Environmental monitoring: a step-by-step [In Russian].

Ordinance N-4/2012 on the characterization of surface water, MEWB.

Internet sources

www5.moew.government.bg/?page_id=24258 (Plans for river basin management) (date of access 01/11/2016)

www.unep.org/gemswater/Default.aspx?tabid=101094 (Water Quality Index and Indicators – UNEP) (date of access 01/11/2016)