Temporal Patterns of Quality Surface Water Changes

Olena Mitryasova[1], Volodymyr Pohrebennyk[2*], Ivan Salamon[3],
Alina Oleksiuk[1], Andrii Mats[4]

[1] Department of Ecology, Petro Mohyla Black Sea National University, 10, 68-Desantnykiv Steet, Mykolayiv oblast 54003, Ukraine

[2] Department of Ecological Safety and Nature Protection Activity, Lviv Polytechnic National University, Stepana Bandery Str., 12, Lviv, 79013, Ukraine

[3] Department of Ecology, Preshov University, 17. novembra 3724/15, 080 01 Prešov, Slovakia

[4] Maria Curie-Sklodowska University, 20-400 Lublin, Poland, Poland

* Corresponding author's email: vpohreb@gmail.com

ABSTRACT

The dynamics of hydrochemical parameters of surface waters from the upper, middle and lower reaches of the river was analyzed. On the basis of the analysis of temporal and spatial monitoring data, a comprehensive assessment of the environmental status of the Inhulets river (Ukraine) waters by hydrochemical indicators was carried out. The study performed a comparative analysis of the river water quality assessment using different methods: an integrated assessment based on the calculation of water pollution indexes, pollution rate. A result of the evaluation of water quality in certain classes: in terms of ammonium ions and BOD_5 – III quality class, the water is slightly polluted; phosphate content – V quality class, water is very low in the bottom; according to the content of suspended solids, in phosphates and BOD_5 – III class of water quality, water is polluted; by a concentration of chlorides – V class of quality, degree of purity – very dirty; the value of suspended solids and chlorides – III class; in terms of the sulfate content – IV class. In general, the very excessive concentration of substances in the middle course remains stable, the environmental state is poor (quality class IV).

Keywords: surface water quality, water security, hydrochemical indicators, level of pollution, resistance degree of pollution, Inhulets river.

INTRODUCTION

Water resources are limited and vulnerable as natural objects. Among the 17 global sustainable development goals, two are directly related to water security. The growth of anthropogenic activity leads to excessive pollution of water resources (Bharti et al. 2011, Mitryasova et al. 2017, Coirolo t al., Jepson et al. 2017, Pohrebennyk et al. 2017, Staddon et al. 2017, Mitryasova et al. 2018). The proceeds of the untreated or inadequately treated industrial, municipal and domestic wastewater reduces the possibility of their use for drinking and household needs (Petrov et al. 2020, Barakat 2011, Pohrebennyk et al. 2019, Casal-Campos et al. 2015, NRDC 2013, Mitryasova and Pohrebennyk

2017, Wang et al. 2018). The urgent tasks to ensure water security are to reduce the pollution of water basins, ensure the sustainable use of water resources, the introduction of effective regulation of extraction of aquatic resources (De Haan et al. 2015, Butler et al. 2016, Ishchenko et al. 2019, Mitryasova et al. 2020, Bezsonov et al. 2017, Banjaw et al. 2017).

The majority of the population of Ukraine uses low-quality water, which poses a danger to health. The problem of the environmental state of water objects is important for all pools and rivers in Ukraine. One of the main components of environmental security towards sustainable development is monitoring the quality of water (Abbasi et al. 2012, Byrne et al. 2017, Gersonius

et al. 2013, Mitryasova et al. 2019). Ukraine is one of the few water resources countries in Europe. Under the influence of economic load, about 70% of surface and part of groundwater in Ukraine have lost their importance as sources of drinking water supply.

The assessment of the surface water quality takes into account in time and space the state of the water body, which allows identifying the trends in water quality, helps to determine the anthropogenic pressure and the consequences of water conservation measures (Farrelly and Brown 2011, Ward et al. 2019, Fernandez et al. 2012). The study of correlations between chemical components, as well as the patterns of pollutants distribution in the aquatic environment, the study of small rivers pollution problems are presented in works (Meyer et al. 2019, Mitryasova and Pohrebennyk 2017, Schickele et al. 2020, Karpinski et al. 2018).

Ukraine is the largest country in Europe, but it is one of the poorest countries in terms of the water content. Therefore, the issue of water quality, especially surface water for the country is extremely relevant. The problem of limited local water resources and uneven distribution is extremely relevant for the Mykolaiv region. The area is located in the South of Ukraine and belongs to the arid regions of the country. According to the «National Program of Water Management Development» per 1 person, the average local river runoff was 0.450 thousand m^3/year, and 23.2 thousand m^3/year (per 1 km^2 area) (https://zakon.rada.gov.ua/laws/show/4836-17). The Mykolaiv area is low-water, insufficiently supplied with water.

After analyzing the data of the Mykolaiv Regional Department of Water Resources, there is a gradual decrease in water intake by 76.2% (from 1125.5 million m^3 to 267.6 million m^3). The volume of surface water discharges to the surface also decreased by 43% (http://mk-vodres.davr.gov.ua/water_resources). The dynamics of water use and sewerage indicate the irrational use of resources, the deterioration of the environmental condition of water bodies and the inefficiency of treatment facilities (Figure 1). Water abstraction and resource use decreased due to the reduced water use for production and irrigation.

In 2019, 64.90 mln. m^3 wastewater (32% contaminated, 66% pure without purification regulatory, legislative 2% purified) was discharged to the water bodies in the Mykolaiv region(http://www.niklib.com/eco/dop.pdf). The Mykolaiv area is considered a zone of risky agriculture; therefore, there is a need for irrigation.

The problem of pollution of water resources in the Mykolaiv area owing to the dumping of highly mineralized mine waters of the Kryvyi Rih enterprises to the Inhulets River is aggravated. The Inhulets River is extremely polluted by the discharges of polluted waters of the Kryvyi Rih mining iron ore basin.

The result of the planned annual discharge of highly mineralized mine waters of the mining enterprises of Kryvbas to Ingulets is a significant deterioration of the ecological condition of the river surface waters and damage to irrigated lands. In particular, the residents of the Snihuriv district are provided with low-quality drinking water from spring floods.

Annually, about 12 million m^3 of Kryvbas mine water (mineralization reaches 4000 mg/l is discharged into the Ingulets river basin (https://adm.dp.gov.ua/pro-oblast/rozvitok-regionu/ekologiya, Lykhovyd and Kozlenko 2018, Yurasov et al. 2012). The excess of return water occurs in a clearly defined intervegetation period (February-November). After the discharge of highly mineralized waters, the measures to eliminate the consequences of the discharge are introduced through the washing of the Inhulets
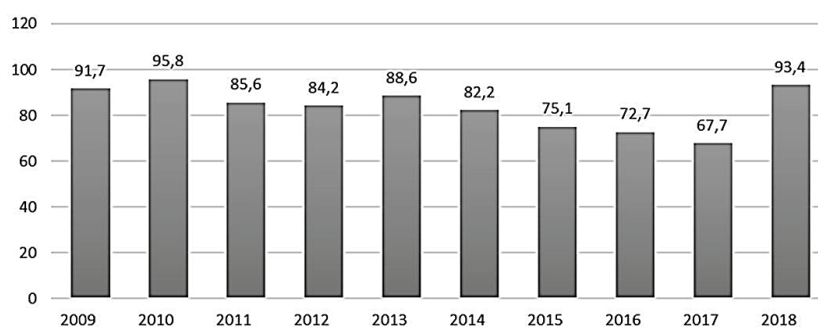

Fig. 1. Volumes of discharges of return waters to surface water bodies of the region, million m^3

riverbed. At the same time, there is a dilution of water to the normalized levels of water quality in the control areas below the release. Since 2010, following the regulations of riverbed washing and ecological rehabilitation of the Inhulets River, improvement of its water quality health washing is carried out the Inhulets River bed due to constant discharges of fresh Dnieper water. Wellness and technological rinsing make it possible to improve the quality of water in the river during the irrigation period and is carried out to displace the salt prism.

The dynamics of the Dnieper water supply over the years are shown in Figure 2. As a result of the implementation of the Flushing Regulations, the water quality has slightly improved. The hardness of water was 9.4 mg-eq/l, chlorides – 109.6 mg/l, sulfates – 448.4 mg/l, dry residue – 1064.6 mg/l, but in terms of hardness and dry residue of normative indicators could not be reached. However, this type of activity is potentially dangerous for the environment, because with the periodic discharge of highly mineralized excess return water, it is impossible to comply with the current surface water quality standards. Thus, a comprehensive analysis of the ecological condition of the river by hydrochemical parameters is relevant.

The *object* of the work is a study based on the analysis of temporal and spatial monitoring data, a comprehensive assessment of the environmental status of the Inhulets River waters according to the hydrochemical indicators.

The Inhulets River is large with the length of 549 km. The area of the basin is 14870 thousand km. On the territory of the basin, there is one of the largest Precambrian iron ore regions in the world, the main mining center of Ukraine – Kryvyi Rih iron ore basin. Due to the intensive development of anthropogenic activity, the vegetation of the Inhulets basin was transformed. As a result of agricultural land development, almost 85% of the territory has been plowed. Natural landscapes are partially located and preserved only in a very small part of the territory (0.5%). In the northern part, there are remnants of forest, steppe, meadows, and water, rocky and sandy vegetation. Almost the entire length of the river is under man-made load, especially in the middle reaches.

MATERIALS AND METHODS

Two groups of methods were used in the work: theoretical and mathematical. The theoretical methods included: analysis, synthesis, systematization, and generalization in the process of studying the literature on the topic of research and hydrochemical indicators of the water status in the Inhulets river. In turn, the mathematical methods involved: statistical data processing, the method of averages in determining the level of pollution, graphical display of the results of work performed, correlation, and regression analysis of hydrochemical parameters and time trends quantity; the calculations were performed using the MS Excel software package, schemes were created in MapInfo,.

During the assessment of the environmental condition of the river, the pollution coefficient (PC) was determined according to the method (Shakhman and Bystriantseva 2017, Mitryasova and Pohrebennyk 2020).

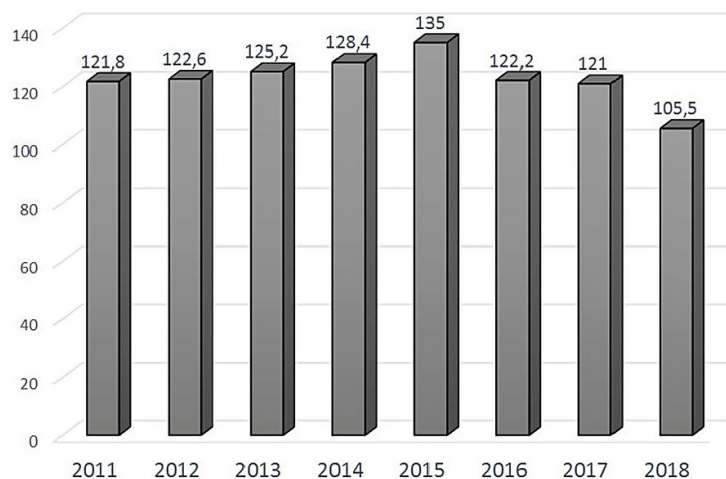The pollution coefficient is a generalized indicator and characterizes the level of pollution

Fig. 2. Changes in the supply of Dnieper water, million m^3

in general according to the list of water quality indicators. The values of multi-year measurements at several observation points of the water body ere used for assessment. The value of the pollution coefficient characterizes the multiplicity of exceeding the MPC standards. When assessing the environmental state of water body, the sanitary-toxicological properties of water were taken into account. The PC values were calculated by formulas 1 and 2:

$$\gamma = 0{,}1 \sum_{i=1}^{10} \left(\frac{1}{N} \sum_{j=1}^{J} \sum_{n=1}^{N_{ij}} \gamma_{ijn} \right); \qquad (1)$$

$$\gamma_{ijn} = \begin{cases} \dfrac{C_{ijn}}{MPC_i}, & f \ MPC_i \ violated \ (C_{ijn} \geq MPC_i), \\ 1, & f \ MPC_i \ satisfies \ (C_{ijn} \leq MPC_i), \end{cases} \qquad (2)$$

where: i, 10 – serial number and the total number of controlled indicators; j, J – ordinal number and a total number of observation points; n, Nij – ordinal number and the total number of measurements of the i-th indicator in the j-th point for the period of time being analyzed; Ni – the total number of measurements of the i-th indicator in all observation points; g_{ijn} is the multiplicity of exceeding the MPC at the n-th measurement of the i-th indicator at the j-th observation point.

The value of the short circuit is calculated only for ten indicators. These indicators include those indicators that exceed the value of the MPC. If the number of indicators exceeding the MPC is less than ten in the formula, the value of g_{ijn} for the remaining indicators is taken equal to one (Vasenko et al. 2017).

According to the value of the pollution coefficient classify the level of water pollution according to Table 1.

The classification of waters is based on the establishment of a resistance measure to pollution (recurrence of P cases of exceeding the MPC) by formula 3 (Bashynska 2018).

$$P_i = \frac{N_{MPC_i}}{N_i}, \qquad (3)$$

where: N_{MPCi} is the number of analysis results in which the content of the i-th ingredient exceeds its MPC, N_i is the total number of analysis results of the i-th ingredient.

Hydrochemical monitoring of surface waters of the Inhulets River at the observation point – Inhulets Irrigation System, Snihurivka was carried out during the irrigation period (May – September) during 2011–2018.

The characteristics of water pollution were determined accordingly and presented in Table 2.

RESULTS

The results of monitoring for the period from 2011 to 2018 of indicators exceeding the MPC have been studied, namely: pH; Chemical oxygen demand (COD); Biological oxygen demand (BOD); Water hardness, Dry residue; Magnesium and Sodium. Characteristics of indicator measurements are specified in Table 3.

The average monthly values of substance concentrations were selected for analysis. For, example, the dynamics of indicator concentrations are graphically shown in Figs. 3–9.

The hydrogen index during the study period varied in the range of 7.29–8.48. The pH indicator is integral because its value is influenced by the content of all soluble substances and the nature of intermolecular interactions. The highest pH value was recorded in 2011. During 2014–2016, the indicator was observed at a stable level. In 2018, the pH value decreased (Fig. 3). The trend line of the dynamics is presented in the form of a polynomial line. The correlation coefficient is 0.6 and indicates a significant link between pH and time values.

The dynamics of the value of COD at the observation point – Inhulets irrigation system is shown in Figure 4. The COD index varied uniformly in the range of 28–36 mgO_2/dm^3 (MPC = 15 mgO_2/dm^3).

Chemical oxygen demand (COD) is also an integrated indicator that shows the content of organic matter in water. Currently, COD is considered one of the most informative indicators of the anthropogenic water pollution. The value of

Table 1. Indicators of water pollution by PC

The value of the PC	1	1.1…2.5	2.5…5.0	5.1…10.0	10.1…
The level of pollution	unpolluted (pure)	slightly polluted	moderately polluted	dirty	very dirty

Table 2. Classification of water bodies by pollution recurrence

Repeatability,%	Characteristics of water pollution
0 – 10	single
10 – 30	unstable
30 – 50	stable
50 – 100	characteristic

Table 3. Characteristics of indicator measurements

Indicator	Units of measurement	MPC
pH	units pH	6.5 – 8.5
COD	mg O_2/dm^3	15.00
BOD	mg O_2/dm^3	3.00
Water hardness	mg-eq/dm^3	7.00
Dry residue	mg/dm^3	1000.0
Magnesium	mg/dm^3	40.0
Sodium	mg/dm^3	200.0

COD is the amount of oxygen (or other oxidants in terms of oxygen) required for complete oxidation of the organic compounds present in the sample, or rather all oxidizable elements from the composition of organic components. Thus, carbon is theoretically oxidized quantitatively to CO_2, and sulfur and phosphorus (if present in the compound) to SO_2 and P_2O_5. Nitrogen is converted into an ammonium salt, and oxygen is the basis for the oxidation products, while hydrogen is converted into the structure of H_2O or ammonium salt.

The trend line shows a decrease in the value of COD in time. The highest COD indicator was recorded in 2015. The high value of oxidation indicates a high content of organic matter and pollution by wastewater and poor general condition of the reservoir (algae overgrowth, lowering the water level, etc.). Such water is usually contaminated with microorganisms, causes foaming, indicates the possibility of organic fouling.
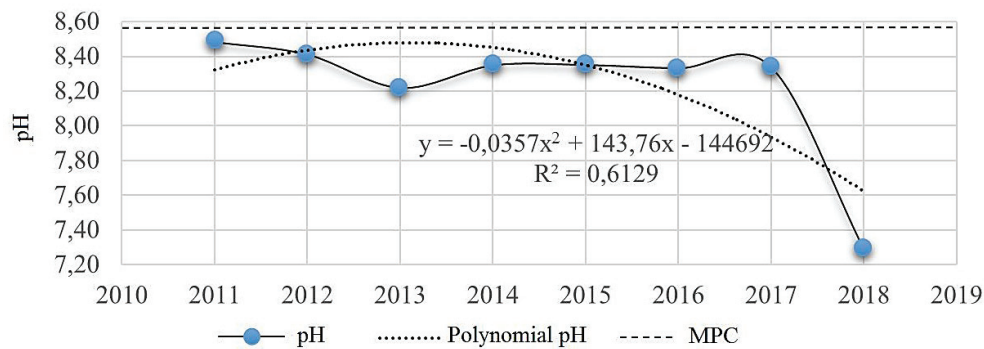

$$y = -0,0357x^2 + 143,76x - 144692$$
$$R^2 = 0,6129$$

Fig. 3. Changes in pH value on the sampling point – Inhulets irrigation system (Snigurivka)

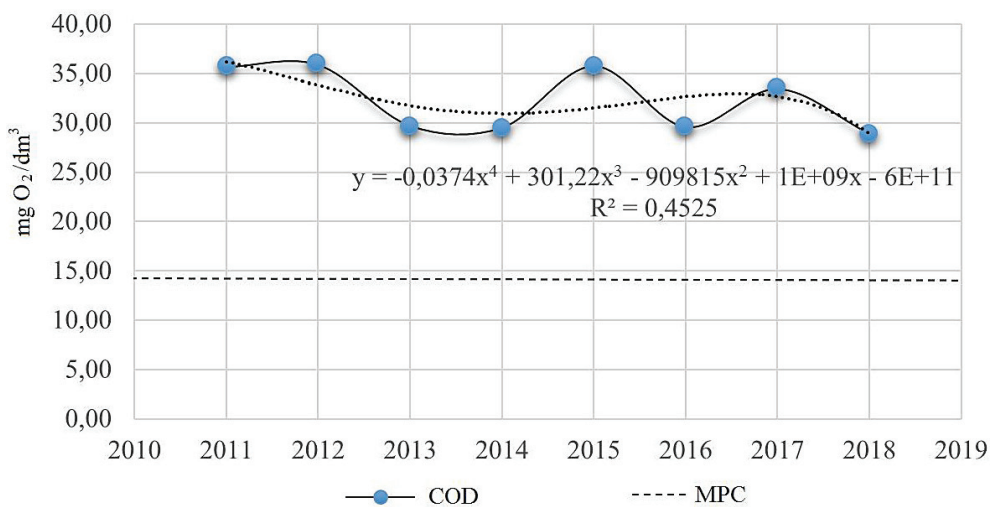$$y = -0,0374x^4 + 301,22x^3 - 909815x^2 + 1E+09x - 6E+11$$
$$R^2 = 0,4525$$

Fig. 4. Changes in COD value on the sampling point – Inhulets irrigation system (Snigurivka)

The dynamics of water hardness index in time is presented in Figure 5. The hardness index gradually decreased until 2013. However, since 2014 the trend is growing. In 2018, the value of rigidity exceeded the MPC almost twice. Exceedance of the MPC was observed during the study period. According to the current trend, the change in the increase in the value of stiffness is expected in the future.

The dry residue index fluctuated within the maximum allowable concentration. This parameter determines the total amount of dissolved in water mineral inorganic salts of calcium, magnesium, potassium, sodium, heavy metals, as well as a large percentage of organic matter. This parameter is used primarily to determine the total mineralization of water. The trend line indicates a gradual increase in the value of the dry residue over time (Fig. 6). The concentration of magnesium at the observation point changed unevenly over time. The trend line indicates a tendency to increase the concentration of magnesium (Fig. 7).

The sodium concentration in the Inhulets irrigation system varied evenly. Since 2013, there has been a gradual increase in the concentration of Na (Fig. 8). The correlation coefficient is about 1, which indicates a direct dependence on time factors. The trend line shows a further increase in the sodium content at the observation point.

Excess sodium indicates a violation of the water-electrolyte balance in the river. Water with high mineralization during irrigation causes salinization of soils and harms fish spawning grounds. The observation points are selected (Fig. 9):
- point No. 1 – p. Iskrivka, Kirovohrad region, 373 km from the mouth;
- point No. 2 – p. Arkhangelske, Kherson region, 210 km from the mouth;
- point No. 3 – p. Inhulets irrigation system, 83 km from the mouth;
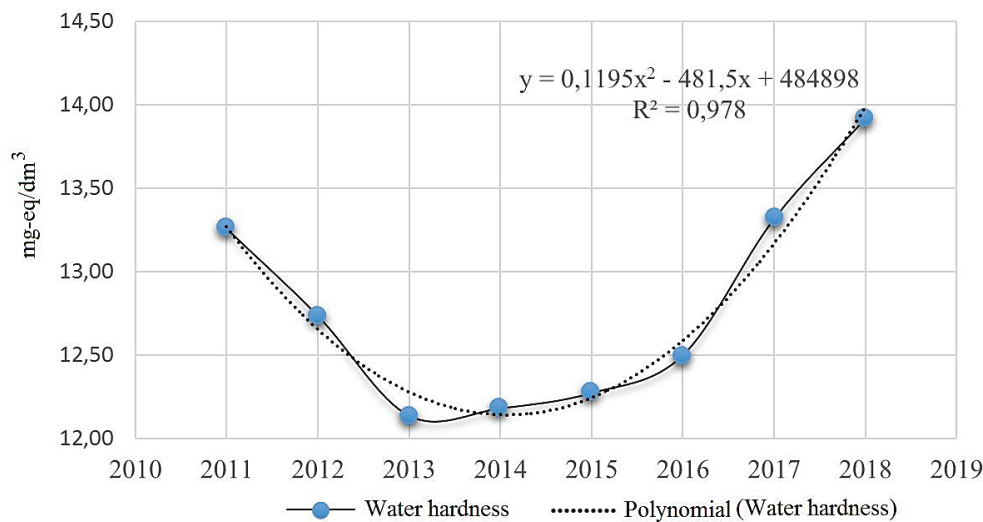- point No. 4 – p. Daryivka, Kherson region, 20 km from the mouth.

$$y = 0,1195x^2 - 481,5x + 484898$$
$$R^2 = 0,978$$

Fig. 5. Changes in water hardness index on the sampling point - Inhulets irrigation system (Snigurivka)

$$y = 18,539x^2 - 74686x + 8E+07$$
$$R^2 = 0,6526$$
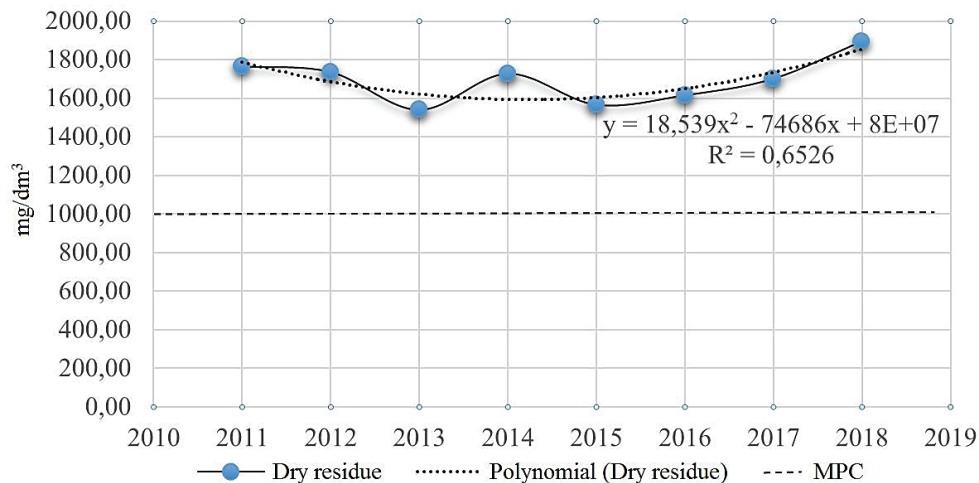
Fig. 6. Changes in dry residue index on the sampling point - Inhulets irrigation system (Snigurivka)

$$y = 0{,}1367x^5 - 1376{,}7x^4 + 6E{+}06x^3 - 1E{+}10x^2 + 1E{+}13x - 5E{+}15$$
$$R^2 = 0{,}5492$$
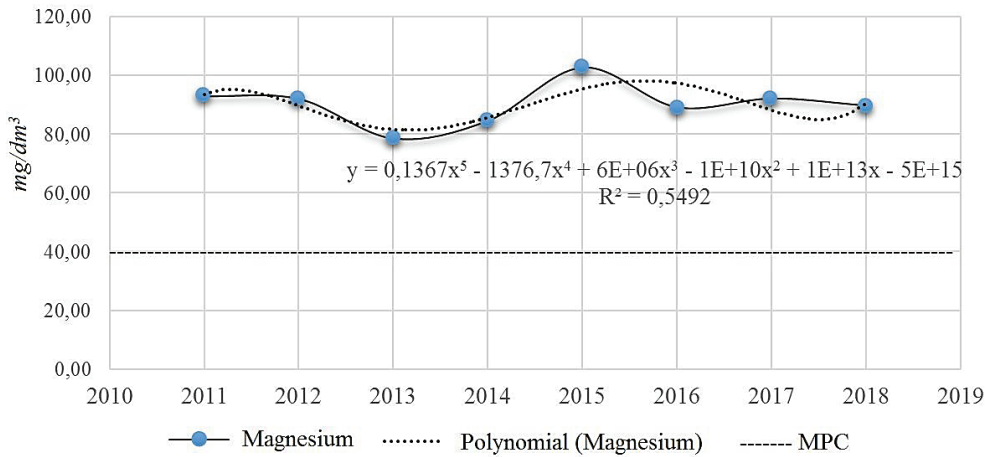
Fig. 7. Changes in Magnesium index on the sampling point – Inhulets irrigation system (Snigurivka)

$$y = 8{,}5312x^2 - 34367x + 3E{+}07$$
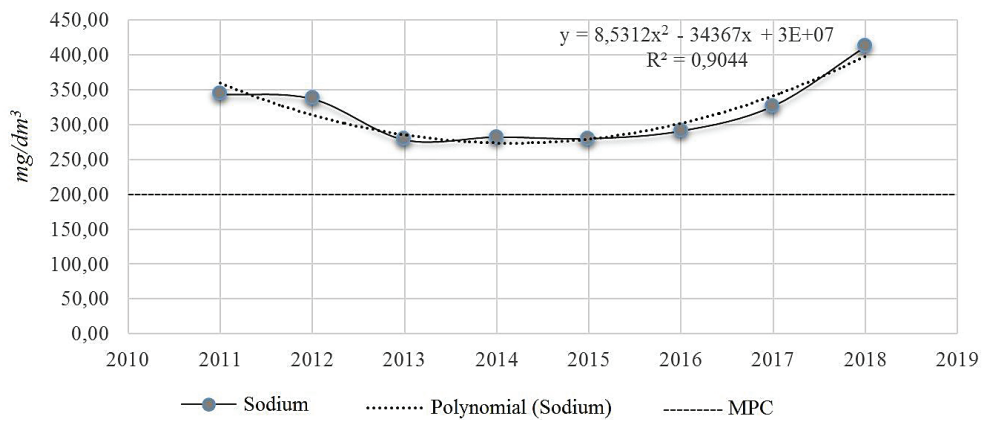$$R^2 = 0{,}9044$$

Fig. 8. Changes in sodium index on the sampling point – Inhulets irrigation system

For example, indicators with exceeding MPC in the points, such as BOC_5, sulfate ions and chloride ions are shown in Figs. 10–12. The BOD_5 indicator, which reflects water pollution by organic matter, was analyzed based on the results of hydrochemical monitoring at four observation points (Fig. 10). Natural clean waters have low BOD_5 values (usually their BOC_5 does not exceed 0.5–3 mg/dm^3) in contrast to the man-made polluted waters.

BOD_5 exceeded MPC twice in the observation point No. 2 along the river – (p. Arkhangelske, 30 km from Kryvyi Rih). The highest concentration was recorded in 2005 and 2013. Since 2016, the value of BOC_5 has been decreasing. The dynamics of the sulfates values in the observation points are shown in Figure 11.

During the study period, the concentration of sulfates in the point No. 2 (v. Arkhangelske) exceeded MPC. The concentration of sulfates varies depending on seasonal fluctuations, as well as the content of substances is influenced by geological, biological processes and anthropogenic factors.
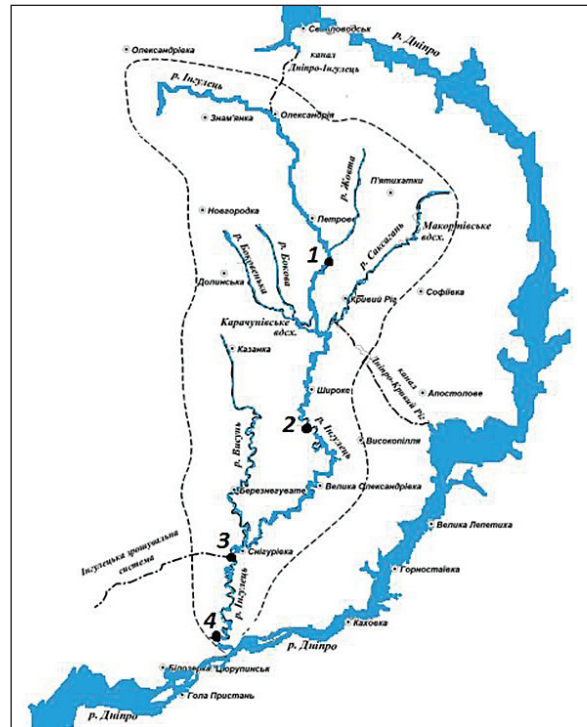

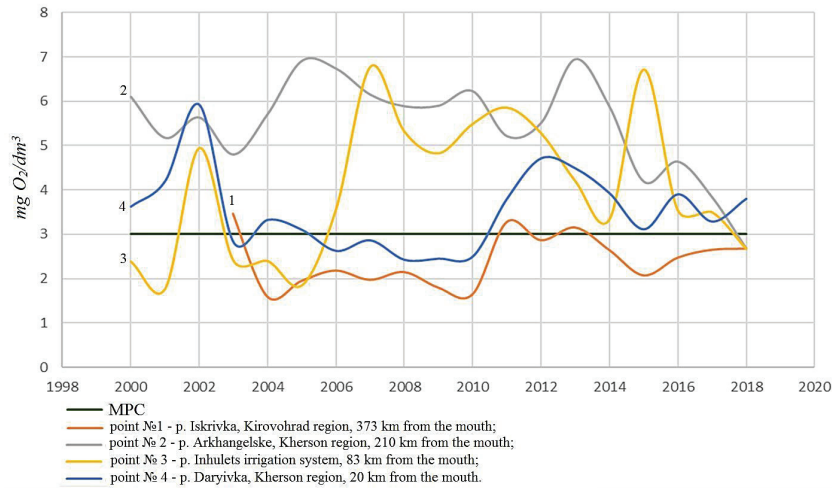**Fig. 9.** Scheme of the Inhulets river basin and points of observations

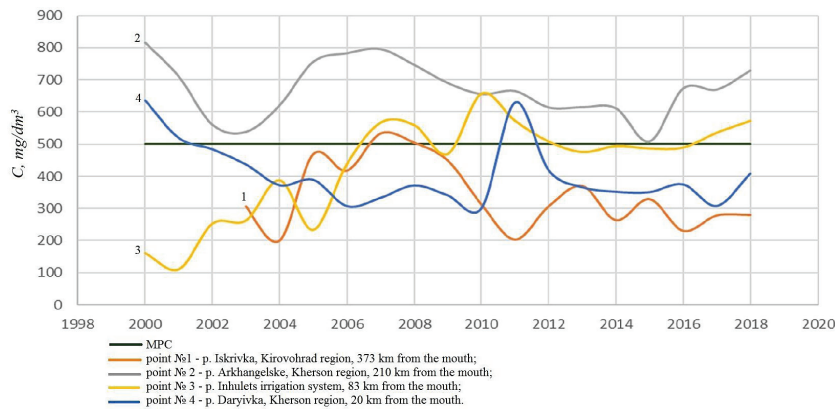**Fig. 10.** Changes in the BOD$_5$ index on the sampling points

Fig. 11. Changes in the sulfates index on the sampling points
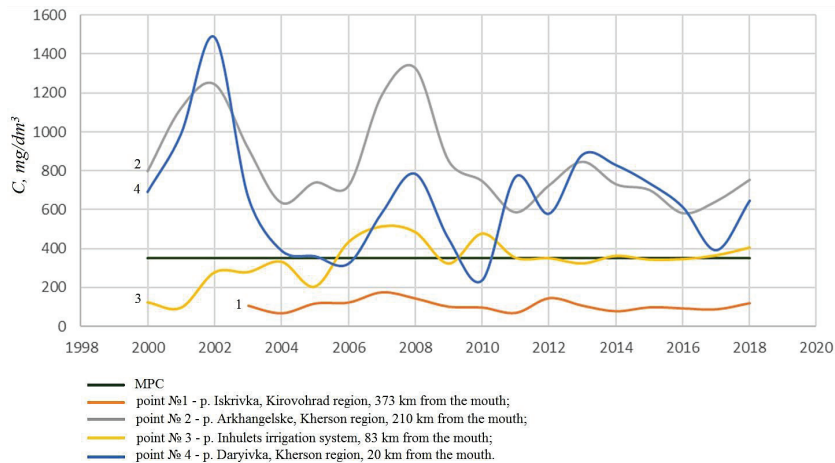

Fig. 12. Changes in chlorides index on the sampling points

The dynamics of chlorides values in the control points are shown in Figure 12.

During the study period at the point of observation of the upper reaches of the river, the concentration of chlorides varied within acceptable limits. In 2002 and 2008, the number of chlorides exceeded MPC 3 times. Since 2010, in the areas below the city of Kryvyi Rih, the excess of the MPC is due to an increase in the wastewater discharges by industrial enterprises. Clear seasonality in the distribution of concentrations is observed depending on the period: summer-autumn lows, spring floods, winter lows. For example, the maximum runoff is formed in spring floods.

DISCUSSION

Using long-term observation data, the trends in water quality in the upper, middle, and lower reaches of the Inhulets River were revealed. The generalized results of the studies are presented in Tables 4–7.

The group of chemicals detected includes various inorganic compounds of nitrogen (NH_4^+) and phosphorus (PO_4^{3-}), which are termed «biogenic» or «nutritive», along with other organic matter. These groups are closely connected with natural phenomena and can affect river dwellers either positively or negatively. This problem is relevant for this section of the river. The chemicals, as a rule, are able to stimulate high productivity in some cases. That is why, the problem of eutrophication (nutrient over-enrichment) is especially urgent for this area connected to river estuaries. The agricultural run-off comprised of highly concentrated nitrogen and phosphorus cause algal blooms, which lead to fish kills when all the oxygen dissolved in water is spent on the oxidation of organic matter. For this reason, most hydrobionts, especially those that are unable to physically flee, will perish under these conditions.

If the excessively concentrated biogenic substances infiltrate into the river frequently, the entire ecosystem of a sea changes. Large perennial plants and animals – indicators of Good Environmental Status (GES), disappear. They are replaced by small, rapidly reproducing species, which form large homogeneous accumulations, but rendering the sea itself less attractive to other sea dwellers and the humans who depend on

them. Underwater kelp forests represented by perennial brown algae (Cystoseira barbata) were replaced by cotton-like accumulations of finely branched green algae. Valuable fish species almost completely disappeared and were replaced by smaller and less valuable species.

Chlorides and sulfates are present in water in the form of salts of calcium, magnesium, potassium and sodium. The natural causes of the presence of chlorides in water are the leaching of soil layers by groundwater. In our case, the main source of chloride and sulfates are anthropogenic activity, namely the wastewater from the chemical industry (Tables 6–7).

The generalized water quality class on average indicators along the Ingulets River is shown in Figure 13. According to the water pollution index, the Inhulets River belongs to the III (third) class. The waters of the corresponding class are under significant anthropogenic influence, the level of which is close to the limit of ecosystem resilience.

The pollution coefficient was also calculated, which characterizes the level of pollution summarized by water quality indicators that were repeatedly measured in four observation points of the Inguhets River basin. Because, according to the available monitoring data in the studied points, the number of indicators exceeding the MPC is less than 10, so in the formula the values for the other indicators were taken equal to one. The results of the calculation of the surface water pollution coefficient (PC) are given in Table 8.

Given that the values for the remaining 7 indicators were taken equal to one:

Table 4. Evaluation of surface water quality by indicators (p. Iskrivka, Kirovohrad region, 373 km from the mouth)

Indicator	Water quality class	Water quality category	Environmental state of waters	The degree of water purity
Sulfates index	II	2	good	slightly polluted
Chlorides index	II	3	good	slightly polluted
Ammonium ions	III	4	satisfactory	moderately polluted
Phosphate ions	V	7	**very bad**	**very dirty**
Dry residue	I	1	very good	unpolluted
BOD_5	III	4	satisfactory	moderately polluted

Table 5. Evaluation of surface water quality by indicators (p. Arkhangelske, Kherson region, 210 km from the mouth)

Indicator	Water quality class	Water quality category	Environmental state of waters	The degree of water purity
Sulfates index	II	3	good	slightly polluted
Chlorides index	V	7	**very bad**	**very dirty**
Ammonium ions	II	3	good	slightly polluted
Phosphate ions	III	4	satisfactory	moderately polluted
Dry residue	III	5	satisfactory	moderately polluted
BOD_5	III	5	satisfactory	moderately polluted

Table 6. Evaluation of surface water quality by indicators (p. Inhulets irrigation system, 83 km from the mouth)

Indicator	Water quality class	Water quality category	Environmental state of waters	The degree of water purity
Sulfates index	IV	6	**bad**	**dirty**
Chlorides index	III	4	satisfactory	moderately polluted
Ammonium ions	II	3	good	slightly polluted
Phosphate ions	II	3	good	slightly polluted
Dry residue	III	4	satisfactory	moderately polluted
BOD$_5$	III	5	satisfactory	moderately polluted

Table 7. Evaluation of surface water quality by indicators (p. Daryivka, Kherson region, 20 km from the mouth)

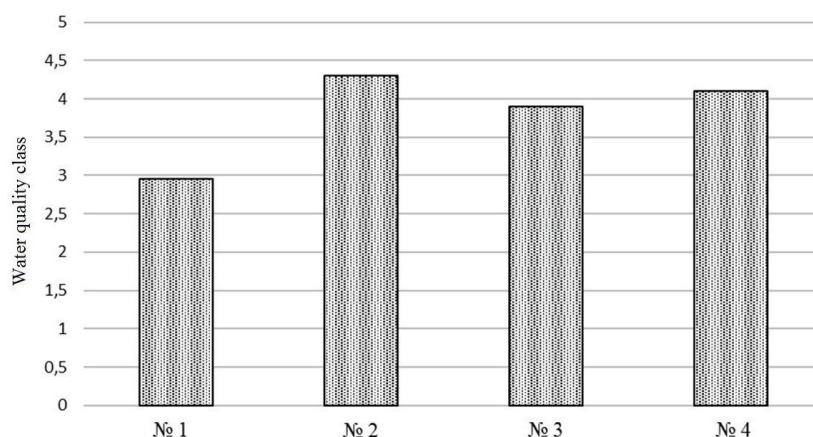| Indicator	Water quality class	Water quality category	Environmental state of waters	The degree of water purity
Sulfates index	III	5	satisfactory	moderately polluted
Chlorides index	IV	6	**bad**	**dirty**
Ammonium ions	II	3	good	slightly polluted
Phosphate ions	III	4	satisfactory	moderately polluted
Dry residue	II	3	good	slightly polluted
BOD$_5$	III	4	satisfactory	slightly polluted

Fig. 13. Generalized water quality class on average indicators

$$PC = 1.11 + 1.58 + 1.36 + (1 \times 7) = 1.10.$$

The value of the short circuit characterizes the multiplicity of exceeding the standards in the shares of the MPC. The calculated short circuit = 1.10 means that the normalized indicators of the Inhulets water quality on average 1.10 times (or 10%) higher than the MPC. In other words, in general, the water quality of the Inhulets River during the study period is 1.10 times worse than the norm.

The analysis of the results of the study suggests that the ecological condition is satisfactory; the degree of purity of water is «moderately polluted». The environmental status of the waters indicates the need for the introduction of effective technologies for cleaning the riverbed and improving the quality of the composition.

One of the known ways of utilization of mine waters is their demineralization, and the other is the injection of mine waters into unproductive deep aquifers with subsequent migration of pollutants in the underground hydrosphere.

Mine water treatment with removal of 60 to 80% of harmful impurities is provided by the use of coagulant reagents – also a possible option. At present, high-basic aluminum coagulants – aluminum hydrochlorides – a are increasingly often used in the world (https://www.iwapublishing.com/news/coagulation-and-flocculation-water-and-wastewater-treatment, Prakash et al. 2014**,** Bratby 2006).

In many countries, phytotechnologies – bioengineering facilities – are intensively used to treat mine water before discharge into the hydrographic network. Higher aquatic plants, in combination or without a sand-gravel filter made of natural materials, are the main elements of the treatment system. Higher aquatic plants form a biocenosis, which includes various groups of microorganisms, algae, fungi and other organisms due to which water is

Table 8. The value of the short circuit in the observation points

The observation point	Sulfates	Chlorides	BOC$_5$
No. 1	16.08	16.00	16.29
No. 2	21.34	36.23	29.87
No. 3	8.42	8.25	11.74
No. 4	16.26	27.84	18.50
∑	62.10	88.32	76.39
Number of observations	56	56	56
Number of observations above the MPC	23	35	26
PC	1.11	1.58	1.36

Note: Calculation of the multiplicity of exceeding the MPC.

purified (Mitryasova et al. 2016, Vlasov and Hryshchankava 2014, Birk et al. 2012, Aguiar et al. 2016, Bakker et al., 2016, Ishchenko et al. 2016, Kvaternyuk et al. 2017, O'Hare et al. 2018).

CONCLUSIONS

The temporal patterns of changes in surface water quality were determined. Currently, the environmental condition of the Inhulets basin is unsatisfactory. Recently, the wastewater volume discharged by enterprises of the city of Kryvyi Rih into surface water bodies is 27.5%.

During the growing season, the Inhulets River is flushed by Dnieper water, which dilutes the highly mineralized discharges of Kryvbas. However, despite the reduction of concentrations of some pollutants within the Mykolaiv and Kherson regions, the water quality does not meet the current surface water standards. According to studies in time and space, on average, exceeded MPC were in the observation points, such as the concentrations of pH, COD, BOC$_5$, hardness, dry residue, sulfates, chlorides, magnesium, sodium. The Inhulets water quality indicators were on average 1.10 times higher than the MPC.

According to the frequency of exceeding the MPC at the observation points: No. 1 – Iskrivka – unstable water pollution BOC$_5$, No. 2 – Arkhangelske – typical water pollution BOC$_5$, sulfate ions, and chloride ions; No. 3 – Snihurivka – unstable water pollution BOC$_5$ and persistent pollution by sulfate ions and chloride ions; No. 4 – Daryivka is characteristic contamination of water with chloride ions.

A result of the evaluation of water quality in certain classes: in terms of ammonium ions and BOD$_5$ – III quality class, the water is slightly polluted; in phosphate content – V quality class, water is very low in the bottom; according to the content of suspended solids, phosphates and BOD$_5$ – III class of water quality, water is polluted; by concentration of chlorides – V class of quality, degree of purity – very dirty; the value of suspended solids and chlorides – III class; in terms of sulfate content – IV class. In general, the highly excessive concentration of substances in the middle course remains stable, the environmental state is poor (quality class IV).

REFERENCES

1. Bharti, N.; Katyal, D. 2011. Water quality indices used for surface water vulnerability assessment. Inter. J Environ. Sciences, 2(1), 154–173.

2. Mitryasova, O.; Pohrebennyk, V.; Kochanek, A., Stepanova, O. 2017. Environmental Footprint Enterprise as Indicator of Balance it's Activity. 17th International Multidisciplinary Scientific Geoconference SGEM 2017, Albena, Bulgaria, 29 June – 5 July 2017, 51(17), 371–378.

3. Coirolo, C.; Rahman, A. 2014. Power and Differential Climate Change Vulnerability among Extremely Poor People in Northwest Bangladesh: Lessons for Mainstreaming. J. Climate and Development, 6(4), 336–344.

4. Jepson, W.; Budds, J.; Eichelberger, L.; Harris, L.; Norman, E.; O'Reilly, K.; …Young, S. 2017. Advancing human capabilities for water security: A relational approach. J. Water Security, 1, 46−52.

5. Pohrebennyk, V.; Mitryasova, O.; Klos-Witkowska, A.; Dzhumelia, E. 2017. The Role of Monitoring the Territory of Industrial Mining and Chemical Complexes at the Stage of Liquidation. 17th International Multidisciplinary Scientific GeoConference SGEM 2017, Vienna, Austria, 27–29 November 2017, 33(17), 383– 390.

6. Staddon, C.; Sarkozi, R.; Langberg, S. 2017. Urban water governance as a function of the 'Urban Hydrosocial Transition'. In: E. Karar (Ed.), Freshwater Governance for the 21st Century. Springer, 81–102.

7. Mitryasova, O.; Pohrebennyk, V.; Kardasz, P. 2018. Hydrochemical Aspects of Surface Water Quality Assessment. 18th International Multidisciplinary Scientific Geoconference SGEM, Albena, Bulgaria. 30 June – 9 July 2018, 5.2(18), 513−520.

8. Petrov, O.; Petrichenko, S.; Yushchishina, A.; Mitryasova, O.; Pohrebennyk, V. 2020. Electrospark Method in Galvanic Wastewater Treatment for Heavy Metal Removal. Applied Sciences, Spec. Iss., 10(15), 5148.

9. Barakat, M.A. 2011. New trends in removing heavy metals from industrial wastewater, Arab. J. Chem., 4, 361–377.

10. Pohrebennyk, V.; Koshelnik, P.; Mitryasova, O.; Dzhumelia, E.; Zdeb, M. 2019. Environmental Monitoring of Soils of Post Industrial Mining Areas. Journal of Ecological Engineering, 20(9), P. 53–61.

11. Casal-Campos, A.; Butler, G. Fu, D.; Moore, A. 2015. An Integrated Environmental Assessment of Green and Grey Infrastructure Strategies for Robust Decision Making. J. Environmental Science and Technology, 49(14), 8307–8314.

12. NRDC. Climate Change and Water Resource Management, 2013, URL: https://www.nrdc.org/resources/climate-change-and-water-resource-management

13. Mitryasova, O. & Pohrebennyk, V. 2017. Integrated Environmental Assessment of the Surface Waters Pollution: Regional Aspect. International Multidisciplinary Scientific GeoConference SGEM, Vienna, Austria, 27–29 November 2017, 33(17), 235–242.

14. Wang, X.; Daigger, G.; Lee, D.-J.; Liu, J.; Ren, N.; Qu, J.; Liu, G.; Butler, D. 2018. Evolving Wastewater Infrastructure Paradigm to Enhance Harmony with Nature. Sci. Adv. 4, 1–10.

15. De Haan, F.J.; Rogers, B.C.; Frantzeskaki, N.; Brown, R.R. 2015. Transitions through a Lens of Urban Water. J. Environmental Innovation and Societal Transitions, 15, 1–10.

16. Butler, D.; Ward, S.; Sweetapple, C.; Astaraie-Imani, M.; Diao, K.; Farmani, R. and Fu, G. 2016. Reliable, Resilient and Sustainable Water Management: The Safe and SuRe Approach. J. Global Challenges, 1 (1), 63–77.

17. Ishchenko, V.; Pohrebennyk, V.; Kochan, R.; Mitryasova, O.; Zawislak S. 2019. Assessment of Hazardous Household Waste Generation in Eastern Europe. International Multidisciplinary Scientific Geoconference SGEM, Albena, Bulgaria. 30 June – 6 July 2019, 6.1, 19, 559−566.

18. Charis, M.; Galanakis, E.A. 2010. Sustainable Water and Wastewater Processing. Elsevier: Amsterdam, The Netherlands, 393 p.

19. Mitryasova, O.; Koszelnik, P.; Gruca-Rokosz, R.; Smirnov, V.; Smirnova, S.; Bezsonov, Ye.; Zdeb, M.; Ziembowicz, S. 2020. Features of heavy metals accumulation in bottom sediments of the Southern Bug hydroecosystem, Journal of Ecological Engineering, 21(3), 51–60.

20. Bezsonov, Ye.; Mitryasova, O.; Smyrnov, V.; Smyrnova, S. 2017. Influence of the South-Ukraine electric power producing complex on the ecological condition of the Southern Bug River. Eastern-European Journal of Enterprise Technologies, 4/10 (88), 20–28.

21. Banjaw, D.T.; Megersa, H.G.; Lemma, D.T. 2017. Effect of water quality and deficit irrigation on tomatoes yield and quality: a review. Advanced Crop Science and Technology, 5(4), 295.

22. Abbasi, T.; Abbasi, S.A. 2012. Water quality indices. Amsterdam: Elsevier Science Ltd. 384.

23. Byrne, D.M.; Lohman, H.A. C.S.; Cook, M.; Peters, G.M. & Guest, J.S. 2017. Life Cycle Assessment (LCA) of Urban Water Infrastructure: Emerging Approaches to Balance Objectives and Inform Comprehensive Decision-Making. J. Environmental Science: Water Research and Technology, 3(6), 1002–1014.

24. Gersonius, B.; Ashley, R.; Pathirana, A.; Zevenbergen, C. 2013. Climate change uncertainty: Building flexibility into water and flood risk infrastructure. Clim. Change, 116(2), 411– 423.

25. Mitryasova, O.; Pohrebennyk, V.; Kochanek, A. 2019. Comparative analysis of the surface water environmental status. International Multidisciplinary Scientific Geoconference SGEM, Albena, Bulgaria. 30 June – 6 July 2019, 6.1, 19, 101−108.

26. Farrelly, M. & Brown, R. 2011. Rethinking Urban Water Management: Experimentation as a Way Forward? J. Global Environmental Change, 21(2), 721–732.

27. Ward, S., Borden, D.S., Kabo-Bah, A., Fatawu, A.N., & Mwinkom, X.F. 2019. Water resources data, models and decisions: International expert opinion on knowledge management for an uncertain but resilient future. Journal of Hydroinformatics, 21(1), 32-44.

28. Fernandez, N.; Ramirez, A.; Solano, F. 2012. Revista Busta Physico-chemical Water Quality Indices. A Comparative Review, URL: http://www.academia.edu/193200/physico-chemical_water_quality_indices

29. Meyer, A.M., Klein, C., Fünfrocken, E., Kautenburger, R., Beck, H.P. 2019. Real-time Monitoring of Water Quality to Identify Pollution

Pathways in Small and Middle Scale Rivers, Science of the Total Environment, 651, 2323-2333.

30. Mitryasova, O., Pohrebennyk, V. 2017. The Status of the Small River as an Indicator of the Water Security of Natural Surface Water, 17th International Multidisciplinary Scientific GeoConference, SGEM, Vienna, Austria, Hydrology and Water Resources, 17(33), 391–398.

31. Schickele, A., Leroy, B., Beaugrand, G., Francour, P., Raybaud, V. 2020. Modelling European Small Pelagic Fish Distribution: Methodological insights, Ecological Modelling, 416, 108902.

32. Karpinski, M., Pohrebennyk, V., Bernatska, N., Ganczarchyk, J., Shevchenko, O., 2018. Simulation of Artificial Neural Networks for Assessing the Ecological State of Surface Water, 18th International Multidisciplinary Scientific GeoConference SGEM, Albena, Bulgaria, 693–700.

33. Law of Ukraine "On approval of the National target program for the development of water management and ecological rehabilitation of the Dnieper river basin for the period up to 2021". https://zakon.rada.gov.ua/laws/show/4836 -17 (in Ukrainian).

34. Regional office of water resources in the Mykolaiv area. http://mk-vodres.davr.gov.ua/water_resources (in Ukrainian).

35. Regional report on a condition of environment in the Mykolaiv area. http://www.niklib.com/eco/dop.pdf

36. Regional report on a condition of environment in the Dnipropetrivk area. https://adm.dp.gov.ua/pro-oblast/rozvitok-regionu/ekologiya

37. Lykhovyd, P.V.; Kozlenko, Ye.V. 2018. Assessment and forecast of water quality in the River Ingulets irrigation system. Ukrainian Journal of Ecology, 8(1), 350–355.

38. Yurasov, S.M., Safranov, T.A., Chugai, A.V. 2012. Assessment of Natural Water Quality. Odessa: Ecology, 168 (in Ukrainian).

39. Shakhman, I.A.; Bystriantseva, A.N. 2017. Assessment of Ecological State and Ecological Reliability of the Lower Section of the Ingulets River. Hydrobiologica l Journal, 53(5), 103-109.

40. Mitryasova, O.; Pohrebennyk, V. 2020. Hydrochemical Indicators of Water System Analysis as Factors of the Environmental Quality State. Sustainable Production: Novel Trends in Energy, Environment and Material Systems. Studies in Systems, Decision and Control In: Królczyk G., Wzorek M., Król A., Kochan O., Su J., Kacprzyk J. (Eds), Vol. 198. Springer, Cham., 91−104.

41. Vasenko, O.G.; Rybalova, O.V.; Korobkova, G.V. 2017. Ecological Rationing of Surface Water Quality Taking into Account Regional Features. Hydrology, hydrochemistry and hydroecology, 1 (44), 21-33. (in Ukrainian).

42. Bashynska, I.L. 2018. Environmental estimation of efficiency of drinking water purification on plumbing of UC «Zhytomyrvodokanal». Naukovi Horyzonty (Scientific Horizons), 7–8(70), 50–58. (in Ukrainian).

43. Coagulation and Flocculation in Water and Wastewater Treatment. URL:: https://www.iwapublishing.com/news/coagulation-and-flocculation-water-and-wastewater-treatment

44. Prakash, N.B.; Sockan, V.; Jayakaran, P. 2014. Waste water treatment by coagulation and flocculation. International Journal of Engineering Science and Innovative Technology, 3(2), 479-484.

45. Bratby, J. Coagulants in Coagulation and Flocculation in Water and Wastewater Treatment, 2nd ed., IWA Publishing, London, UK, 50-68.

46. Mitryasova, O.; Pohrebennyk, V.; Kochanek, A., Sopilnyak, I. 2016. Correlation interaction between electrical conductivity and nitrate content in natural waters of small rivers. 16th International Multidisciplinary Scientific Geoconference, SGEM, Vienna, Austria, pp. 357-364.

47. Vlasov, B.; Hryshchankava, N. 2014. Community of higher aquatic plants. Zoology and Ecology, 24(2), https://www.tandfonline.com/doi/full/10.1080/21658005.2014.925240?scroll=top&needAccess=true

48. Birk, S.; Bonne, W.; Borja, A.; Brucet, S.; Courrat, A.; Poikane, S.; Solimini, A.; W. van de Bund, N. Zampoukas, D. Hering. 2012. Three hundred ways to assess Europe's surface waters: An almost complete overview of biological methods to implement the Water Framework Directive. Ecological Indicators, 18, 31–41

49. Aguiar, F.C.; Martins, M.J.; Silva, P.C.; Fernandes, M.R. 2016. Riverscapes downstream of hydropower dams: Effects of altered flows and historical land-use change. Landscape and Urban Planning, 153, 83–98.

50. Bakker, E.S.; K.A. Wood, J.F.; Pages, G.F.; Veen, M.J.; A. Christianen, L.; Santamaría, B.A.; Nolet & S. Hilt. 2016. Herbivory on freshwater and marine macrophytes: a review and perspective. Aquatic Botany, 135, 18–36.

51. Ishchenko, V., Pohrebennyk, V., Kozak, Y., Kochanek, A., Politylo, R. 2016. Assessment of batteries influence on living organisms by bioindication method. 16th International Multidisciplinary Scientific GeoConference Ecology, Economics, Education and Legislation, SGEM, 16(2), 85-92.

52. Kvaternyuk, S., Pohrebennyk, V., Petruk, R., Kochanek, A., Kvaternyuk, O. 2017. Multispectral television measurements of parameters of natural biological media. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 17(51), 689-696.

53. O'Hare, M.; Aguiar, F.T.; Asaeda, T.C.; Bakker, E.; Chambers, P., Clayton, J.S.; Elger, A.; Ferreira, M.T.; Gross, E.M.; Gunn, I.; Gurnell, A.; Hellsten, S.; Deborah, H.; Li, W.; Mohr, S.; Puijalon, S.; Szoszkiewicz, K.; Willby, N.J.; Wood, K.A. 2018. Plants in aquatic ecosystems: current trends and future directions. Hydrobiologia, 812(1), 1-10.