QUANTITATIVE ASSESSMENT OF WATER RESOURCES AND EVALUATION OF WATER QUALITY (ON THE EXAMPLE OF SUMY REGION)

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ABSTRACT

The study is devoted to the development and testing of the methodology for assessing water resources, which involves a combination of their quantitative assessment, determination of water quality and taking into account the basin principle, which is a modern approach to water resources management. A step-by-step algorithm for estimating water resources of Sumy region in the context of the basins of the main rivers of the region is created. The first step is to estimate the quantitative indicators of water resources (water supply of total runoff, local runoff and underground predicted resources per capita, as well as drainage into surface water bodies, volumes of discharged polluted return waters in the main river basins of the region). The second step is to assess the quality of water resources (stability of surface waters, water pollution index, anthropogenic pressure on river basins). This methodology was tested in the assessment of water resources of Sumy region in terms of basins of the main rivers of the region. It is established that water resources of the Desna river basin within Sumy region are characterized by a level "above average", which is associated with high water supply of total and local runoff, predicted groundwater resources and maximum surface water stability in the region. Water resources of the Vorskla, Seim and Sula river basins are characterized by an average integrated value. The water resources of the Psel river basin have a low value due to low water supply, which can be explained by such factors as densely populated area of the basin, high drainage rates, high water pollution and significant levels of anthropogenic pressure on natural complexes of the river basin.

Keywords: water resources, water supply, water use, stability of surface waters, water pollution index, anthropogenic pressure.

INTRODUCTION

Water resources (suitable for the use Earth's water) are an important part of the national wealth, and preservation of their volume and quality is the most important problem today. Water is the basis of human life, because a sufficient number of quality water resources determines the standard of living and health of the population [17, 19]. Water supply in the world and in Ukraine is quite uneven. In Sumy region it is 1-2 thousand m^3 per capita per year, which is higher than the average in Ukraine, but it is more than 2 times less than in Europe and 4 times less than the world average. Therefore, the problem of assessing water resources, their quantity and quality is extremely important, and its solution is necessary for the conservation and rational use of water resources.

METHODS AND EXPERIMENTAL PROCEDURES

In today's world, the use of water resources is increasing, which in turn requires their adequate assessment. To assess the country's water supply per capita per year in the world practice is used the Falkenmark water stress indicator [8]. The level of water scarcity in a given country was determined on the basis of threshold values. If the amount of renewable water resources (river runoff) in the country per capita is less than 1700 m^3/year – the country experiences water stress; less than 1000 m^3/year – there is water shortage in the country; less than 500 m^3/year – the country has an absolute shortage of water. Ukraine's water resources (river runoff) per capita are about 1800 m^3/year, which is one of the lowest in Europe and, according to the Falkenmark indicator, the country is on the verge of water stress. However, it should be borne in mind that not only the quantity of water resources is important, but also their quality. Today in the world an acute problem is reduction of water resources due to the loss of their quality, which is a greater threat than their quantitative depletion.

In addition to the assessment of specific indicators of water supply per capita, there is a methodology of assessing natural waters by determining their suitability for practical purposes, which is based on state standards and regulations.

Analysis of the methodologies for assessing water resources suggests that they are all reduced to two areas: economic (taking into account the quantitative indicators of runoff) and ecological (taking into account indicators of water quality). Economic assessment of water resources, in addition to the assessment of "physically available" water resources (surface, groundwater), specific indicators of water supply per capita, Ye. V. Obukhov [15] provides a cost estimate of water resources, determines the total cost of the resource with the calculation in the economic plane, which is discussed in the works of M. A. Hvesyk [13], L. V. Levkovska, A. M. Sunduk [11], M. M. Tsependa [18] and others.

Ecological assessment of surface water quality carries information about the state of water bodies and reflects its changes under the influence of natural and anthropogenic factors. One of the simplest methodologies for assessing the quality of water resources is assessment of the water pollution index (WPI), described in the works of V. K. Khilchevsky [16], S. I. Snizhka [17]. Other widely used methodologies are assessment of surface water quality by hydrochemical parameters [19] and ecological assessment of surface water quality by relevant categories [14].

Our own vision of the region's water resource assessment algorithm combines quantitative resource assessment and water quality evaluation, taking into account the basin principle – a modern approach to water resources management, where the main subject of management is the river basin. Implementation of the assessment of water resources of the region in the context of the basins of the main rivers is carried out by successive realization of two stages of the study: 1) assessment of quantitative indicators of water resources; 2) assessment of water quality indicators (Fig. 1).

Assessment of quantitative indicators of water resources. At the first stage of the assessment, the water supply was analyzed. The analysis was conducted by calculating the specific indicators of water supply (surface water: total runoff, local runoff, as well as predicted groundwater resources) per capita in terms of basins of the main rivers of the region. Since statistical information (population, groundwater reserves) is usually presented by administrative-territorial units, and their boundaries do not coincide with the boundaries of river basins, we have listed these indicators for the basins of the main rivers of the region, taking into account the share of administrative districts within river basins. Also, at this stage, there was conducted an analysis of water use, including drainage into surface water bodies, its volume and the amount of polluted return water discharged into water bodies in the region.

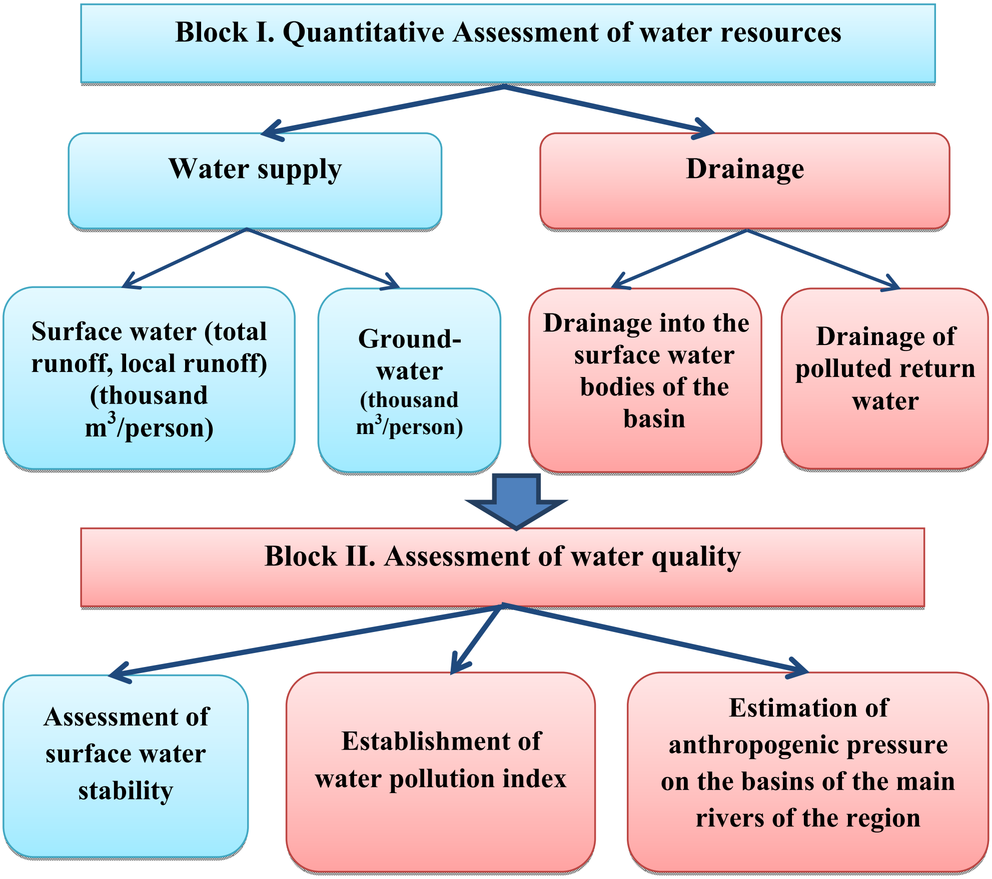


Fig. 1. Algorithm for assessing water resources of the region in terms of main river basins

Assessment of water quality indicators. When assessing the quality of water resources, the resistance of water (natural self-purification potential) to anthropogenic pressure is taken into account, because the aquatic environment can easily change its quality in different ways at low or high stability indicators. Methodological aspects of determining the stability of the natural environment were developed by V. A. Baranovskyi, M. A. Hlazovska and others [1, 9], but there are no universal methodologies for assessing the resistance of geosystems to anthropogenic pressure. Regarding the assessment of surface water stability, M. A. Hlazovska identifies the processes necessary to neutralize pollutants in various ways, namely mechanical, chemical and biological [9]. They include transparency and chemical composition of water, flow rate, temperature, biodiversity, etc. Aquatic stability is a complex process of biochemical and biological self-purification of water. It is influenced by different groups of factors: temperature and color of water, hydrological characteristics of water flow. In this paper, the stability is calculated as the product of the biotic potential of water self-purification (which, in turn, depends on the temperature and color index of water) and the coefficient of water flow (the ratio of water consumption indicator of a water meter to its average value) [12] (formula 1).

$$W = B \times h = \left(\frac{a}{365}\right) \times j \times h, \quad (1)$$

where W – stability of surface waters, B – biotic potential of water self-purification, h – coefficient of water consumption, a – number of days during the year with water temperature above 16ºC, j – index of water chromaticity (makes 1 – at chromaticity to 30º; 0,9 – at chromaticity of 30-60º; 0,8 – 60-90º, 0.7 – 90-120º and 0.6 – at chromaticity above 120º).

The next step is to assess the quality of water resources in the region, which is carried out through the establishment of the average value of WPI for the basins of the main rivers of the region. For surface waters, the number of indicators taken for the calculation of the WPI should be at least 6 [16, 17]. These indicators include ammonium nitrogen, nitrite nitrogen, petroleum products, phenols, dissolved oxygen, biochemical oxygen demand (BOD_5). The sum of the values of all six indicators, expressed in terms of MAC (ammonium nitrogen, nitrite nitrogen, petroleum products, phenols) or standard (BOD_5, dissolved oxygen) is divided by the number of indicators (formula 2). In the absence of some pollutants in the water, the total value is still divisible by 6.

$$WPI = \sum \frac{C}{MAC} / n \quad (2)$$

where WPI – water pollution index, MAC – maximum allowable concentration (value) of the indicator; C – actual concentration (value) of the indicator; n – number of indicators.

The next step involves calculating the average value of anthropogenic pressure on the basins of the main rivers of the region, because according to the methodology that we have used [2], the levels of anthropogenic pressure on the basins of small rivers are calculated, which must then be averaged. This methodology involves: 1) assessment of factors of anthropogenic impact by calculating the appropriate coefficients: forest cover – Kf, bogging of the basin – Kb, plowing – Kp, settlement – Ks, soil erosion – Ks, over-regulation of the riverbed – Kover, drainage in the river basin – Kd, pollution of the basin by pesticides – Kpp, plowing of the coastal protection strip – Kpcps; 2) since the calculated coefficients have different dimensions, their normalization is carried out according to formulas (3-4), for factors that have a direct and inverse effect on the level of anthropogenic pressure, respectively;

$$Y_i = \frac{X_i - X_i^{min}}{X_i^{max} - X_i^{min}} \quad (3)$$

$$Y_i = 1 - \frac{X_i - X_i^{min}}{X_i^{max} - X_i^{min}} \quad (4)$$

where X_i – non-normalized value of the indicator *i*; X_i^{min} – minimum value of the indicator *i*; X_i^{max}– maximum value of the indicator *i*; Y_i – normalized value of the indicator *i*.

The weight of each coefficient as a result of normalization is expressed in tenths and hundredths of a unit, except for the minimum and maximum values (0 and 1.0 points, respectively).

All normalized coefficients are summed and the integrated coefficient of anthropogenic pressure (K_{an}) is determined (formula 5):

$$К_{an} = \sum_i^9 У_n \quad (5)$$

where K_{an} – integrated coefficient of anthropogenic pressure on the river basin, $У_n$ – normalized values of the corresponding coefficients.

An important stage of the study is to determine the integrated indicator of water resources assessment, which is carried out through a number of procedures. At the first stage, the normalization of quantitative indicators of water resources (water supply and water use) and indicators that determine their quality (stability of surface waters, WPI, and anthropogenic pressure). Integrated assessment of water resources of the region is calculated as the sum of normalized values of indicators according to formula 6:

$$О_{w.r.} = \sum_{i}^{8} У_{n} \quad (6)$$

integrated assessment of water resources, $У_n$ – normalized values of indicators (direct effect: $У_1$ – stability of surface waters of the basin, $У_2$ – water supply of total runoff, $У_3$ – water supply of local runoff, $У_4$ – water supply of groundwater; inverse effect: $У_5$ – drainage in the surface water objects, $У_6$ – drainage of polluted return waters, $У_7$ – index of water pollution, $У_8$ – integrated coefficient of anthropogenic pressure on the river basin.

At the final stage of the study, the levels of comprehensive assessment of water resources are established. Possible values of the integrated indicator of such an assessment according to the proposed methodology are in the range from 0 to 8. Within this range, the following assessment levels: low (<2.0), average (2.01-4.0), above average (4, 01-6.0) and high (6.01-8.0) have been determined.

THE RESEARCH RESULTS AND DISCUSSIONS

Water resources of Sumy region include surface (rivers, lakes, reservoirs, ponds, swamps) and ground waters. The main share in the structure of water resources of the region falls on rivers. As of January 1, 2020, 1,543 rivers with a total length of 8,020 km flow through the region. The only large river that is part of the hydrographic network of Sumy region is Desna. In addition, there are 6 medium rivers (Seim, Kleven, Sula, Psel, Khorol, Vorskla) and 1536 small rivers and streams. The most flooded river in Sumy region (except the Desna) is the Seim with an average long-term runoff of 3.15 km^3, an average total surface runoff in the region is 5.79 km^3. A significant number of watercourses in the region is transit. First of all, these are such rivers as the Desna, the Seim, the Kleven, the Psel and the Vorskla and a large number of small rivers. Therefore, transit runoff accounts for 60 % and only 40 % for local runoff. There are 537 lakes in the region, with a total water volume of 25 million m^3 and a water surface area of 2,042 hectares. The number of reservoirs is relatively small, there are 42, with a total area of 4,366 hectares and a total volume of 94.57 million m^3. There are 2,192 ponds, with a total area of 11,386.6 hectares and a total water volume of 121.3 million m^3. Wetlands of Sumy region are quite uneven; the total area of bogs is 46.6 thousand hectares. According to rough estimates, about 1.35 km^3 of water is concentrated in the swamps, which is 25 % of the total surface runoff of the region and can be a promising, backup source of water resources [4]. The swampiest is the northern part of the region where the share of wetlands is about 4 %, with an average swamp of the region 1.4 %.

The assessment of water resources of Sumy region was carried out in the context of the basins of the main rivers of the region, namely: the Desna (without the Seim river basin), Seim, Sula, Vorskla and Psel. As the Desna river flows along the border of Sumy and Chernihiv regions for only 37 km, the indicators of the average annual perennial runoff of the Desna river were not taken into account in the calculations.

Assessment of quantitative indicators of water resources of Sumy region. Water supply. The maximum water supply indicators of the total runoff are set in the Seim basin (12.87 thousand m^3/person per year), which is quite logical, as the Seim is the deepest river in the region, the minimum – in the Psel river basin (2.4 thousand m^3/person per year), due to the significant population of the basin (Table 1). The maximum indicators of water supply by local runoff are set for the Desna river basin (3.1 thousand m^3/person per year), the minimum – for the Psel river basin (0.85 thousand m^3/person per year).

Table 1. Water supply of surface waters in terms of the basins of the main rivers of Sumy region

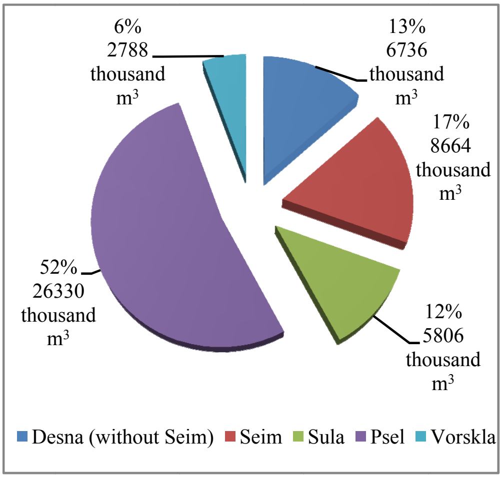
Basins of the main rivers	Volume of total long-term annual runoff (thousand m^3)	Population (as of 01.01.2020)	Water supply with total runoff (thousand m^3/person per year)	Local average annual runoff (thousand m^3)	Water supply by local runoff (thousand m^3/person per year)
Desna (without Seim)	500200	161298	3,1	500200	3,1
Seim	3267500	253741	12,87	618400	2,4
Sula	334000	125335	2,66	334000	2,66
Psel	987000	408616	2,4	347100	0,85
Vorskla	599000	117065	5,1	258600	2,2

In hydrogeological terms, the territory of the region is located within the Dnieper-Donetsk artesian basin, where almost half of all operational reserves of groundwater in Ukraine are concentrated. Indicators of drinking and technical groundwater reserves in Sumy region are considered to be one of the highest in Ukraine. The total predicted groundwater resources in the region are 1251.5 million m^3 per year, approved operational reserves – 210.8 million m^3 per year. Water supply of groundwater (artesian) per capita in the region is 0.177 thousand m^3 per year, the number of deposits – 25, the number of sites – 50, the exploration of predicted resources – 18 % [4]. Water supply of predicted groundwater resources on average per capita of the region is 1,174 thousand m^3 per year. The maximum is for the Sula river basin (2.55 thousand m^3/person per year), the minimum is for the Vorskla river basin (0.12 thousand m^3/person per year) (Table 2).

Table 2. Water supply of groundwater in terms of the basins of the main rivers of the Sumy region

Basins of the main rivers	Predicted resources thousand m^3/year	Population (as of 01.01.2020)	Groundwater water supply (thousand m^3/person per year)
Desna (without Seim)	261035	161298	1,6
Seim	218085	253741	0,85
Sula	320480	125335	2,55
Psel	319830	408616	0,78
Vorskla	132070	117065	0,12

Water use. Water consumption in the region is quite uneven. The maximum values (48.32 million m^3 per year) of water intake were recorded in the basin of the Psel river, which is explained by its flow through the regional center, where water consumption is many times higher than in other settlements due to the concentration of industrial facilities and larger population. The basins of the Seim and Sula rivers have significant indicators – 19.45 million m^3 and 10.22 million m^3, respectively. The minimum value of water intake and use is represented in the basin of the Vorskla river and is 4.441 million m^3 per year [4]. Since drainage directly depends on water consumption, both maximum and minimum data have a corresponding trend, namely the Psel river basin has the highest rates of drainage and discharge of polluted return water, and the Vorskla river basin – the lowest (Fig. 2).



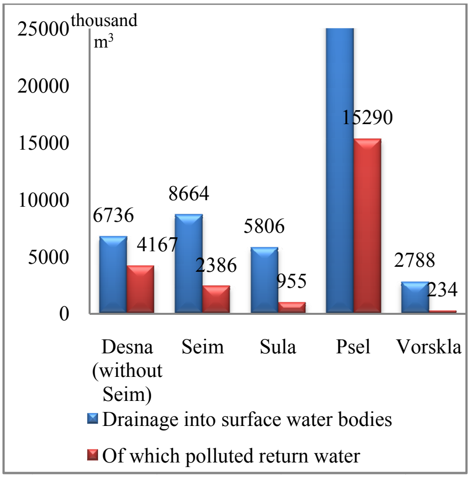


Fig. 2. Water drainage in terms of the basins of the main rivers of Sumy region

Assessment of water quality indicators of the Sumy region.

Stability of surface waters of the region. To establish the stability of the surface waters of Sumy region, 23 rivers were selected, which, in our opinion, are representative for this study. The initial information within the main river basins of the region is accepted according to the data of the Regional Office of Water Resources in Sumy Region. Having analyzed the information on the water temperature, color and average long-term water flow on selected rivers, we found that the average value of average long-term water flow for rivers in the region was 16.8 m^3/s. The stability of surface waters of the region was calculated with the help of the above methodology. The obtained results allow to distinguish the levels of surface water potential of the Sumy region (corresponding to the levels of surface water stability on the map of Ukraine [12]). The maximum values of surface water stability index were obtained for the Desna river and the Seim river – 3.342 and 2.008, respectively, which are identified as "very high level" of stability. The "high level" is typical for the Psel and Vorskla rivers – 0.582 and 0.351, respectively. The "average level" of surface water stability corresponds to the Sula river and the Kleven river – 0.199 and 0.116, respectively. The rivers Khorol, Romen, Vyr and Ivotka with the indicators – 0.055, 0.057, 0.075 and 0.061, respectively, belong to the "low level" of stability potential. Most of the studied small rivers in the region are characterized by a "very low" stability potential with an integrated value of less than 0.05. In general, large and medium-sized rivers in the region are characterized by very high, high and average levels of stability, and small rivers – by low and very low, ranging from 0.019 (for small rivers of the Psel basin) to 0.047 (for small rivers of the Sula basin).

In terms of the basins of the main rivers of the region, the situation is as follows: the maximum indicators of surface water stability are typical for the rivers of the Desna basin (0.867 average) and the Seim basin (0.45), the minimum – for the rivers of the Psel basin (0.091) [5, 6] (table 3).

Table 3. Stability of surface waters of the Sumy region

Basins of the main rivers	River	Dates of transition t of water through +16 °C	a	Chromaticity of water, deg.	J	Q, m^3/s	h	B	W
Desna (without Seim)	Desna	29.05-25.09	114	24	1	180	10,7	3,342	0,867
	Znobivka	01.06-30.08	91	51,5	0,9	2,94	0,18	0,04	
	Ivotka	01.06-30.08	91	33,6	0,9	4,6	0,27	0,061	
	Shostka	28.05-20.09	116	37,6	0,9	1,4	0,08	0,023	
Seim	Seim	27.05-22.09	119	24,4	1	103,5	6,16	2,008	0,45
	Kleven	07.06-25.08	80	28,2	1	9.8	0,53	0,116	
	Yezuch	25.05-25.09	123	34,1	0,9	2,3	0,14	0,042	
	Vyr	10.05-20.09	133	38	0,9	3,9	0,23	0,075	
	Chasha	30.05-15.09	108	35	0,9	0,44	0,03	0,008	
Sula	Sula	25.05-30.09	128	34,9	0,9	10,6	0,63	0,199	0,097
	Tern	30.05-27.09	121	33,6	0,9	2,02	0,12	0,036	
	Romen	25.05-30.09	128	32,1	0,9	3,02	0,18	0,057	
Psel	Psel	20.05-15.09	118	27,7	1	30,2	1,80	0,582	0,091
	Khorol	05.05-25.09	143	29,7	1	1,48	0,09	0,055	
	Sumka	18.05-10.09	115	40	0,9	1,16	0,07	0,02	
	Vilshanka	30.05-15.09	108	30,7	0,9	0,48	0,03	0,008	
	Syrovatka	18.05-15.09	120	48	0,9	1,8	0,11	0,033	
	Bezdryk	30.04-01.10	155	25,5	1	0,23	0,01	0,004	
	Hrun	18.05-15.09	120	27,9	1	1,67	0,10	0,033	
	Rybytsa	18.05-15.09	120	30,5	0,9	2,9	0,05	0,013	
Vorskla	Vorskla	20.05-23.09	126	34,7	0,9	19	1,13	0,351	0,144
	Vorsklytsia	25.05-20.09	118	30,5	0,9	2,9	0,17	0,049	
	Boromlia	18.05-23.09	128	49	0,9	1,7	0,10	0,032	

Assessment of the quality of water resources by WPI. According to the results of the calculation of WPI for the period (1999-2015) [7], the areas of water pollution around large settlements were obtained: Sumy, Okhtyrka, Konotop, and Seredyna-Buda. These areas are characterized by the most polluted river water and belong to the IV class of water quality [2]. The rivers of the Psel basin (mainly), as well as the rivers Boromlia, Vyr, Chasha, Shostka, Ivotka, Znobivka are characterized by moderately polluted waters of the III class quality. The river waters of the Seim, Kleven, Ret and the Sula and Khorol basins within the region belong to the II class of water quality, which is characterized as “clean”. In 2018, the Regional Office of Water Resources in Sumy Region calculated the surface water resources of the region. According to it, the maximum indicators of WPI – 4.29 and 3.24 were recorded for the river Bobryk (basin of the river Desna), the waters of which belong to the V class of water quality and are characterized as “dirty” (Table 4). The waters of the Psel river (the village Stare Selo, below the city of Sumy) with an WPI of 2.73 belong to the IV class – “polluted”. All other river waters of Sumy region belong to the III class of water quality – “moderately polluted”. Comparing the data of the river water quality assessment of the region on the basis of WPI in 2018 and for the period 1999-2015, we can conclude that in general the situation in the region has deteriorated. Thus, the waters of the Sula and Khorol rivers from the II class “clean”, passed to the III “moderately polluted”, the waters of the Bobryk river from the III class “moderately polluted”, passed to the IV “polluted” and V “dirty”. Relative improvement of water quality is observed only on the river Yezuch, which from the IV class (“polluted”), passed to the III class (“moderately polluted”) [3]. In terms of the basins of the main rivers of the region, the maximum average values of WPI are typical for the basins of the Desna river – 2.4 and the Psel river – 2.2 (in the first case the impact of non-functioning sewage treatment plants in Seredyna-Buda, in the second – Communal Enterprise "Miskvodokanal" Sumy), and the minimum – in the basin of the Vorskla river – 1.55.

Table 4. Assessment of water quality of surface water bodies of Sumy region by WPI

Basins of the main rivers	River	Range	WPI	Water quality class	Average value
Desna (without Seim)	Ivotka	above the v. Yampil	1,86	3	2,4
	Ivotka	below the v. Yampil	1,74	3	
	Shostka	v. Hamaliivka	1,68	3	
	Bobryk	above the v. Seredyna-Buda	4,29	5	
	Bobryk	below the v. Seredyna-Buda	3,24	4	
	Znobivka	v. Znob-Trubchevska	1,96	3	
	Znobivka	v. Novovasylivka	2,22	3	
Seim	Seim	v. Pisky	1,48	3	1,85
	Seim	v. Chumakovo	1,5	3	
	Seim	v. Melnia	2,20	3	
	Kleven	v. Zrutsne	1,70	3	
	Yezuch	v. Viazove	2,12	3	
	Yezuch	v. Sarnavshchyna	2,13	3	
Sula	Sula	t. Romny	2,02	3	1,96
	Sula	v. Cheberiaky	1,90	3	
Psel	Psel	v. Myropillia	1,95	3	2,2
	Psel	v. Velyka Chernechchyna	1,94	3	
	Psel	v. Stare Selo	2,73	4	
	Psel	v. Byshkin	2,14	3	
	Psel	v. Kamiane	2,04	3	
	Khorol	v. Panasivka	2,36	3	
	Khorol	v. Luchky	1,91	3	
Vorskla	Vorskla	v. Velyka Pysarivka	1,45	3	1,55
	Vorskla	v. Klymentove	1,67	3	
	Vorsklytsia	v. Pozhnia	1,53	3	

Assessment of anthropogenic pressure on the basins of main rivers of the region. According to our previous study, to assess the anthropogenic pressure on the basins of small rivers of the region [2], it was found that moderate anthropogenic pressure was experienced by 8 river basins, Kan is from 1.19 to 1.99, so their condition can be defined as relatively natural, it is 16.7 % of the area of the region within the Znob-Shostka-Ivotka landscape-hydrological district of Novhorod-Siverske Polissia [10]. Almost 3/4 of territory of the region (72.5 %) is under medium (Kan 2.17-2.99) (27 basins) and high (Kan 3.06-3.96) (26 basins) anthropogenic pressure and form the area with anthropogenic and anthropogenic-altered state of the basins. 5 basins (10.8 %) are characterized by a very high level of anthropogenic pressure (Kan 4.18-4.5), which corresponds to the crisis-anthropogenic state of the basins.

The Desna river basin within the region is characterized mainly by low indicators of the Kan of small river basins – from 1.19 (Znobivka river) to 1.99 (Svyha river). Only the Shostka river basin is under a high level of anthropogenic pressure, which is 3.67 due to high rates of settlement coefficients, plowing of the coastal protection zone and low forest cover of the basin. For the Seim river basin, ambiguous Kan values from 1.53 (Seim river) to 4.5 (Kukolka river) have been recorded, but the vast majority of small river basins are subject to moderate and medium anthropogenic pressure. In the Psel river basin, most small river basins are under medium anthropogenic pressure (Kan ranges from 2.17 to 2.99), and the basins of right-bank tributaries such as Oleshnia, Hrun, Khorol (within the region) are under high anthropogenic pressure (Kan – 3.14-4.27), and the basin of the Sumka river – very high (Kan – 4.27) due to the high level of almost all studied indicators. The basins of the Sula and Vorskla rivers do not differ in contrast to the Kan of the basins of small rivers within them. Most of them are subject to high anthropogenic pressure due to high rates of plowing of the basins, soil erosion, plowing of the coastal protection zone and low rates of forest cover of the basin. When generalizing the results obtained in terms of basins of the main rivers of the region, it was found that the basins of the Vorskla and Sula rivers were characterized by a high level of anthropogenic pressure with Kan 3.29 and 3.26, respectively, basins of the Desna, Seim and Psel rivers – by an average level with Kan 2.8, 3.01, 3.05, respectively.

Integrated assessment of water resources in terms of the basins of the main rivers of the region. As it has been already mentioned, the integrated assessment of water resources in the region is calculated by formula (6) as the sum of normalized values of quantitative indicators of water resources and indicators that determine their quality. The obtained indicator $O_{w.r.}$ ranges from 1.27 to 4.17 (Table 5).

Table 5. Assessment of water resources of Sumy region in terms of basins of the main rivers

Basins of the main rivers of Sumy region	W	y_1	Total water supply runoff, thousand m^3/person per year	y_2	Local water supply runoff, thousand m^3/person per year	y_3	Groundwater supply thousand m^3/ person per year	y_4	Drainage in the surface water bodies, thousand m^3	y_5	Drainage of polluted return waters, thousand m^3	y_6	WPI	y_7	Kan	y_8	$O_{w.r.}$
Desna (without Seim)	0,867	1	3,1	0,07	3,1	1	1,6	0,6	6736	0,2	4167	0,3	2,4	0	2,08	1	4,17
Seim	0,450	0,46	12,87	1	2,4	0,7	0,85	0,3	8664	0,3	2386	0,1	1,85	0,4	3,01	0,23	3,49
Sula	0,097	0,007	2,66	0,02	2,66	0,8	2,55	1	5806	0,1	955	0,05	1,96	0,5	3,26	0,03	2,57
Psel	0,091	0	2,4	0	0,85	0	0,78	0,27	26330	0	15290	0	2,2	0,8	3,05	0,2	1,27
Vorskla	0,144	0,068	5,1	0,3	2,2	0,6	0,12	0	2788	1	234	1	1,55	1	3,29	0	3,99

The maximum indicator of integrated assessment of water resources 4.17 (above average) is typical for the Desna river basin, which is primarily due to their high quantitative indicators within the region. This basin is characterized by high indicators of total water supply and local runoff and ranks second in the provision of predicted groundwater resources in the region. Regarding water quality, the resources of the Desna basin are characterized as one of the most polluted (Bobryk, Seredyna-Buda), which is due to non-functioning sewage treatment facilities and unsatisfactory work on water treatment of industrial and municipal enterprises within the basin (Shostka). Even the maximum value of the surface water stability coefficient in the region does not improve the situation.

The water resources of the Vorskla river basin within the region are characterized by an average value with an integrated water resources assessment index of 3.99, which is explained by high water quality indicators (insignificant value of WPI and one of the highest surface water stability indicators in the region), as well as low quantitative indicators of reverse action (minimum amount of water intake to use and meet the needs of the population and, as a consequence, insignificant drainage, with a smaller share of polluted return water). However, analyzing the quantitative indicators of water resources of the basin, it should be noted that they are not high and occupy one of the last positions in water supply within the region.

Water resources of the Seim river basin within the region are also characterized by an average value with an integrated assessment of water resources of 3.49, which is primarily due to high quantitative indicators of water resources (maximum water supply, maximum total runoff and predicted resources of groundwater). At the same time, the indicators of drainage into surface water bodies occupy the second position in the region, of which 28 % are polluted. All other data taken for calculation have average values.

Water resources of the Sula river basin within the region are characterized as “average”, according to the selected levels, with an integrated indicator of water resources of 2.57, but such values are close to low. All the calculated indicators are relatively insignificant, only in terms of water supply with predicted groundwater resources, the basin ranks first in the region.

The minimum integrated assessment of water resources with an index of 1.27 was obtained for the Psel river basin and is characterized as “low”. These values are obtained due to the minimum indicators of surface water stability, low total water supply and local runoff, due to the dense population of the basin, low water supply values, insignificant predicted groundwater resources and, conversely, maximum drainage and high values of WPI and Kan on the river basin.

CONCLUSION

The proposed methodology is an attempt of a comprehensive (combined) assessment of water resources on water quality indicators and quantitative characteristics of water resources based on the basin principle. The methodology is based on the study of water supply (specific indicators of the population’s water resources per capita) and water use in quantitative terms; stability of surface waters, water pollution and anthropogenic pressure on river basins – in terms of water quality. This method of water resources assessment has been tested on the example of the basins of the main rivers of Sumy region. It is established that water resources of the Desna river basin within the Sumy region are characterized by a level “above average”, and the water resources of the Psel river basin within the region are characterized by a “low” level of integrated assessment. The obtained results are explained by the uneven distribution of water resources, different population densities within the region, as well as the uneven deterioration of the quality characteristics of natural waters, which is the result of differentiated human economic activity.

REFERENCES

[1] Baranovskyi V.A., Ecological geography and ecological cartography, Ukraine, 2001, 252 p. (in Ukrainian)

[2] Danylchenko O.S., River basins of Sumy region: geoecological analysis, Ukraine, 2019, 270 p. (in Ukrainian)

[3] Danylchenko O.S., Havrysh V.V., Assessment of surface water quality of Sumy region according to 2018 / Current problems of environmental research, Ukraine, 2019, pp. 181-184. (in Ukrainian)

[4] Danylchenko O.S., Havrysh V.V., Water resources of Sumy region and their use / Scientific notes of Sumy State Pedagogical University named after A. S. Makarenko. Geographical sciences, Ukraine, Vol. 1, Issue 10, pp. pp. 47-55, 2019. (in Ukrainian). DOI: https://doi.org/10.5281/zenodo.2639636

[5] Danylchenko O.S., Havrysh V.V., Vinarchuk O.O. Stability of Surface Waters of Sumy Region / Scientific notes of Sumy State Pedagogical University named after A. S. Makarenko. Geographical sciences, Ukraine, Vol. 2, Issue 1, pp. 48-53, 2020. (in Ukrainian). DOI: https://doi.org/10.5281/zenodo.3762324

[6] Danylchenko O.S., Kornus A.O., Kornus O.H., Vynarchuk O.O. Assessment of the geo-ecological potential of the landscape districts (on the example of Sumy region, Ukraine) / Journal of Geology, Geography and Geoecology. Vol 30(1). P. 13-24, 2021. DOI: https://doi.org/10.15421/112102

[7] Danylchenko O.S., Kornus A.O., Kornus O.H., Siutkin S.I. Water-Protecting Arealing of Territory of the Sumy Region / Scientific herald of Kherson State University. Geographical sciences, Ukraine, № 11, pp. 106-113, 2019. (in Ukrainian) DOI https://doi.org/10.32999/ksu2413-7391/2019-11-14

[8] Falkenmark water stress indicator, Retrieved from https://uk.wikipedia.org/wiki/Фалькенмарк_Малін (Last accessed: 25.03.2021)

[9] Glazovskaya M.A., Geochemistry of natural and technogenic landscapes of the USSR, Russia, 1989, 328 p. (in Russian)

[10] Kornus A.O., Danylchenko O.S., The landscape-hydrological districting of territory of the Sumy region / Scientific notes of Ternopil National Pedagogical University named after V. Hnatiuk. Geography, Ukraine, No1, pp. 49-56, 2015. (in Ukrainian).

[11] Khvesyk M.A., Levkovska L.V., Sunduk A.M., The cost of water resources of Ukraine and its regions in terms of national wealth / Economy of Ukraine, Ukraine, № 10 (647), pp. 84-96, 2015 (in Ukrainian)

[12] Map of surface water stability of Ukraine, Ukraine, Retrieved from http://geomap.land.kiev.ua/ecology-10-2.html (Last accessed: 20.03.2021) (in Ukrainian)

[13] Methodical approaches to aggregated economic assessment of water resources as a component of natural wealth of Ukraine / Ed. by: M. A. Hvesik, Ukraine, 2014, 36 p. (in Ukrainian)

[14] Methods of ecological assessment of surface water quality by relevant categories / Ed. by: V.D. Romanenko, V.M. Zhukinsky, O.P. Oksiuk and others, Ukraine, 1998, 28 p. (in Ukrainian)

[15] Obukhov E.V. Indicators of water supply of the population of Ukraine in early 2019, Retrieved from https://uhe.gov.ua/sites/default/files/2019-08/10.pdf (Last accessed: 15.03.2021) (in Ukrainian)

[16] Peleshenko V.I., Khilchevsky V.K., General hydrochemistry, Ukraine, 1997, 384 p. (in Ukrainian)

[17] Snizhko S.I., Assessment and forecasting of natural water quality, Ukraine, 2001, 262 p. (in Ukrainian)

[18] Tsependa M.M., Peculiarities of component-economic-geographical assessment of water-resource potential of the territory / Scientific herald of the Volyn National University named after Lesya Ukrainka. Section II. Economic geography, Ukraine, № 8, pp. 96-100, 2009. (in Ukrainian)

[19] Yurasov S.M., Estimation of quality of natural waters, Ukraine, 2011, 164 p. (in Ukrainian)