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SPECIFIC FEATURES OF THE SPATIAL STRUCTURE OF HYDROPHYSICAL FIELDS IN THE DNIESTER ESTUARY IN THE AUTUMN 2020

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Abstract. The analysis of the features of the structure of the fields of salinity, dissolved oxygen and turbidity of water masses of the estuary was carried out according to the data of expeditionary studies using the hydrological multiparameter sonde. The negative role of the approach shipping channel for the ecosystem of the Dniester estuary is determined. It is shown that the modern regulation of the Dniester runoff leads to a deterioration in the quality of the estuary waters.

Introduction

River flow regulation by dams and channel reservoirs creation has both positive and negative consequences for river ecosystems and water economy of the region. The total river flow is redistributed and transformed over time; the water balance changes; stream velocity in the reservoir part decreases; below the dam, the runoff of suspended particles decreases (“solid runoff”); the hydrochemical regime changes. This article presents an analysis of the modern spatial distribution features of water parameters in the water area of the Dniester estuary, as well as the influence of the approach channel from the Black Sea, through the Tsaregradskoe mouth, to the seaport Belgorod-Dnestrovsky (hereinafter referred to as “SP”) on the formation of specific conditions that affect the functioning ecosystems in the estuary. The Dniester navigable approach channel (hereinafter referred to as “NAC”) was dug in 1971 and has a length of 19.7 km, a width of 60 m, and a depth of 4.5 m [11]. Salt sea water, together with marine hydrobionts, moving in the bottom layer along the NAC, got the opportunity to penetrate far into the desalinated water area of the Dniester estuary. Traffic rules in navigable channels provide that the draft of vessels must be less than the depth in the canals by at least 20 cm [12]. When ships move along the NAC, a complex circulation of water arises in it, which promotes mixing, enrichment of water masses with oxygen and weakening their stratification. The intensity of navigation along the NAC to the SP has sharply decreased in recent years; therefore, it can be assumed that specific hydrological and hydrochemical conditions have arisen in the estuary, which in a certain way affect the vital activity of ecosystems.

Materials and methods

The initial data for the analysis of the situation were obtained during complex hydrological surveys of the Dniester estuary in September - October 2020 as part of expeditionary studies under the HydroEcoNex project. For measurements, we used a multi-parameter hydroprobe “EXO1” from XYLEM (USA) with specialized calibrated sensors from the same company.

Brief technical characteristics of EXO1 hydroprobe sensors [13]. Soundings were carried out from a motor boat. A GPS navigator was used for positioning.

The following water parameters were obtained, practically for the entire water area of the Dniester estuary, from the surface to the bottom: temperature, salinity, dissolved oxygen, mineralization and turbidity. Sampling discreteness, in time, was 500 milliseconds. On the survey verticals, where complex hydrological conditions were noted, the sampling discreteness by layers did not exceed one centimeter (the resolution of the pressure sensor was 4 mm). The declared density of data collection, up to this point, has not yet been involved in the Dniester estuary, thus the obtained data made it possible to describe in more detail the features of the structure and reveal new features of hydrophysical fields in comparison with previous studies [2,3,6,9,11].

Results and discussions

It should be noted that the survey of the Dniester estuary water area was carried out for two days (October 23 and 24, 2020), so we observed and describe the three-dimensional structure of the estuary waters. Wind speeds more than 8 m/s were not recorded during October 2020. Southwestern wind from 1 to 5 m/s was constantly acting for more than three days from October 21. Thus, the survey was carried out practically at a stationary (in modulus) wind field and a steady spatial structure of the estuary waters, typical for the autumn season.

The spatial distribution of the water salinity of the Dniester estuary in the surface and bottom layers is shown in Fig. 1. The surface structure of the salinity field is determined by: the interaction of the waters of the estuary itself with the freshwater runoff of the Dniester; water exchange with sea waters (through the Tsaregradskoe mouth); and wind action. The salinity of the northern part of the estuary (less than 0.6 PSU, Fig. 1a) is almost completely determined by the Dniester runoff. The salinity of the river waters of the lower Dniester fluctuates in the range of 0.19 - 0.37 PSU). In the northern part of the estuary, there is a water mass that is practically homogeneous in terms of thermohaline parameters, filling this entire part of the water area and formed by the hydrometeorological conditions described above. The southern part of the estuary is occupied by estuary waters with a salinity of 1 - 5 PSU, which have already been transformed when interacting with sea water. The intermediate-frontal gradient zone, peculiar in salinity, is located in the middle and narrow part of the estuary and separates the fresh waters of the northern water area and the actual estuary water mass in the southern part. A feature of this zone is the presence of areas of high salinity gradients in the SP area, which gradually erode in the northeastern direction. This is due to the configuration of the banks and hydrodynamic processes of interaction between river and estuary waters.

The structure of the bottom salinity field, Fig. 1b, has specific features that were first identified for the Dniester estuary water area. In the southern part of the estuary, the salinity of bottom waters (1-5 PSU) is due to the interaction of sea and estuary waters. The main feature of the salinity field is the presence of a seawater wedge (with salinity up to 14.4 PSU), which penetrates through the 4.5 m deep NAC (with an average estuary depth in this part of less than 2 m [11]). As a general feature of the salinity field structure, we note that a weak wind from the

south and southwest contributed to the “shift” of the estuary water upper layer throughout the entire water area in the northeast direction, and its place was filled with less saline water due to currents of the surface layers directed towards the southern, lower part of the estuary; therefore, the salinity near the western coast is less than that of the eastern one, Fig. 1a. Thus, four water masses of the Dniester estuary should be distinguished: fresh waters of the northern water area (salinity less than 0.6 PSU); intermediate frontal waters in the central and narrow area (0.6 - 2.0 PSU); directly estuary waters in the southern part (2.0 - 5.0 PSU); and sea waters in the NAC (more than 10 PSU). The water temperature field during the expedition was practically uniform (14.5-15.5 °C), except for the temperature of the water mass in the NAC zone, the vertical structure of which will be described below. Thus, it can be noted that all water masses of the estuary have practically the same water temperature in the autumn period, which is generally predetermined by the weather conditions of the season. The spatial structure of the surface and bottom waters mineralization generally agrees with the hydrological and hydrobiological processes taking place in the estuary. As already noted, the northern part of the estuary is under the influence of the Dniester runoff, therefore, here salinity has values of 400-600 mg/l typical for fresh waters. The commissioning of the Dniester HPP led to a noticeable smoothing of the seasonal hydrograph of the Dniester runoff and reduced the intensity of runoff through the estuary. As a result, the accumulation of mineral and organic compounds of nitrogen and phosphorus has increased in the estuary, water bloom has become a common phenomenon, as well as the appearance of hypoxia zones. On the other hand, the NAC contributed to an increase in the inflow of seawater into the estuary water area and, accordingly, to a mineralization increase. The mineralization of water masses in the southern part of the estuary increases towards the sea from 1000 to 5000 mg/l. The zone of the NAC stands out especially, the mineralization here is more than 15 g/l, which significantly exceeds the background value.

Figure 1. Spatial distribution of the Dniester estuary water salinity according to the results of a complex hydrophysical survey on October 23-24, 2020: a) the surface layer, b) the bottom layer. (The geographic diagram of the boundaries and bottom bathymetry of the Dniester estuary is taken from [11])

The estuary waters in the central and southern parts, with the exception of a thin bottom layer of 5 - 20 cm, contain at least 95% of dissolved oxygen, and in some zones, values of more than 140% were recorded, what is typical for polytrophic and hypertrophic waters and indi-

cates their significant pollution [5,8]. The zones in which the oxygen content at the bottom is less than 100% (and in the rest of the water area in the entire volume of water the saturation is more than 100%) are shown in Fig. 2. Two isolated zones with oxygen saturation less than 50% were clearly determined in the bottom layer of the northern and central regions of the Dniester estuary. These zones were also noted during the expeditionary work on **September 14, 2020, Fig. 2b**. The expedition in September 2020 carried out observations in the middle sector of the estuary, from the mouth of the Glubokiyy Turunchuk river, down to the narrow part of the estuary, between Belgorod-Dnestrovsky city and Roksolany village, Fig. 2b. The higher water temperature (about 22°C) during the survey on September 14, 2020 led to an expansion of the hypoxic zone compared to that recorded during the survey at the end of October. The metabolic activity of aquatic organisms, which is caused by an increase in the amount of dissolved and suspended forms of nitrogen in river and estuary waters in warm seasons, became especially active after the regulation of the river flow [1]. Destructive processes intensified in autumn, during the low-water period, and caused a deficiency of dissolved oxygen in the bottom layers, in places with low water exchange, especially in the northwestern part of the estuary and at the Sukholuzhie area [10].

Figure 2. Spatial distribution of the content of dissolved oxygen (%) in the bottom layer of the Dniester estuary waters based on the results of complex hydrophysical surveys in September-October 2020

A certain deficit in the oxygen content in the bottom layer is observed practically throughout the entire water area of the southern part of the estuary, with the exception of the coastal zones. The NAK zone forms a water mass, which has a separate hydrological regime and characteristics that differ from the rest of the estuary. The NAK is one of the main ways of penetration of seawater in the bottom layer into the overlying sections of the estuary. The invasion of seawater into the estuary in conditions of low water, with a decrease in the river flow for natural reasons or due to the interception of the flow by reservoirs, during strong surge phenomena, can oppress not only the freshwater delta ecosystem, but also create threats in the river bed itself, in places of fresh water intake for water supply [7]. Let us consider the graphs of the vertical distribution of the hydrological and hydrochemical parameters of the waters at the station located directly

in the NAC in the area of the SP, Fig. 3. Figures 3a, 3b clearly show sharp jumps in the values of salinity and water temperature, which form a halocline and a thermocline, respectively, a pycnocline is created in the density field. The uniqueness of the hydrological situation lies in the fact that, in contrast to the negative density gradient created by an increase in temperature to the bottom, an increase in salinity is a more significant factor for creating a sharp pycnocline. The pycnocline prevents the penetration of oxygen into the underlying layers and promotes the accumulation of hydrogen sulfide at the bottom in the absence of mechanical mixing. Detritus accumulates on isopycnal surfaces in the water column in the NAC and in the port water area. Low current velocities, natural and artificial isolation of the NAC and SP waters accelerate the formation of a pycnocline in comparison with neighboring estuary sections and create noticeable differences in the hydrophysical and hydrochemical characteristics of water. In fact, a two-layer structure (homogeneous for each layer vertically) is observed, in the upper part of which there is estuary water mass, and in the lower part there is seawater with its own specific water masses characteristics. The upper layer of the estuary water with a thickness of 1.2 m has a water temperature characteristic as the entire estuary - about 15°C and salinity of about 1 PES. The lower layer - from 1.7 m to the bottom has a noticeably higher temperature of 17-20°C and salinity - 13.8 - 14.2 PSU. Sea water obtained such characteristics in September. That is, water exchange in the NAC did not occur for at least about a month. The upper and lower water masses are separated by a density jump layer, the thickness of which is only 0.5 m, but with very high values of the average gradients over the layer: for temperature - 4°C/m, salinity - up to 25 PSU/m. The indicated values of the gradients have never been before recorded in the water area of the Dniester estuary.

Figure 3. Graphs of vertical distribution: a) temperature, b) salinity, c) dissolved oxygen, d) water turbidity of the Dniester estuary on the spot at the entrance to the SP according to the results of a complex hydrophysical survey on October 23-24, 2020.

The formation of a sharp pycnocline in semi-enclosed water areas serves as a “hard cover” that prevents the penetration of oxygen into the interior and contributes to its almost complete consumption in the bottom layer. In the NAC and adjacent areas in the hot summer-autumn period, saprobiotic conditions are created, and the death of bottom fauna may occur. From the bottom layer, not only biogenic substances, but also hydrogen sulfide and other gases (methane, ammonia, mercaptans, etc.), formed during the decomposition of organic matter under anoxia and hypoxia, enter the water column and even into the surface layer [8]. This is evidenced by the graph of the vertical distribution of dissolved oxygen, Fig. 3c. If oxygen saturation in the upper layer reaches 120% or more, then below the pycnocline its content in the waters decreases from 20% under the jump layer to 6% at the bottom.

The vertical distribution of water turbidity can supplement information on the fine-structured features of the hydrological and hydrobiological characteristics of waters, Fig. 3d. The surface water of the Dniester estuary had a turbidity in the central part of 8-10 NFU, in the northern part - 13-19 NFU, in the southern - 11-17 NFU, and in the near-surface layer, from 0 to 5 cm, the turbidity values were about 2-5 units above.

Formally, the ratio between the unit of turbidity in terms of formazin and the solid particles amount in water of 1 unit FNU corresponds to the content of 0.58 mg/l of kaolin [4]. Liman water which occupies the upper layer with a thickness of 1.2 m has a value of about 7.8 FNU (excluding the upper 5 cm). The vertical variation of oxygen and turbidity in a thin about 3 cm thick layer on the 1.20 m horizon is abnormally released and indicates that it is a hypertrophic layer with a higher oxygen content - 128% (+10%) and solid suspended particles - 8.11 NFU (+0.3 FNU units) than in the higher and lower horizons (most likely, detritus and dead organic matter are concentrated in this thin layer). This layer cannot go deeper due to large gradients of water density, i.e. it is located at the interface between two dissimilar water masses.

In the jump layer, the turbidity values decrease to 4.30 units. Below the turbidity continues to decrease to 3.41 NFU, practically correlating with the change (decrease) in the amount of oxygen with depth, Fig. 3c, 3d. Obviously, with a decrease in the amount of dissolved oxygen in the seawater of the NAC, its transparency increases, since turbid estuary waters rich in suspended solids cannot penetrate into these layers. A similar phenomenon is observed on the seashore during the upwelling of deep sea waters, when very cold, but transparent and “contaminated” with hydrogen sulfide waters come to the shore under the action of the wind of the corresponding directions.

Conclusions

Expeditionary studies of the spatial structure of the waters of the Dniester estuary made it possible for the first time to reveal sharp differences in the values of the hydrophysical characteristics of the waters of the estuary and the waters of the NAC.

The features of the spatial structure of the salinity field of the estuary waters made it possible to distinguish four water masses.

The relatively stationary zones of the estuary water area where the oxygen content in the

bottom waters is less than 50% have been determined. Sharp differences in the values of temperature, salinity, mineralization, turbidity, and the content of dissolved oxygen in the vertical structure of water in the NAC were revealed for the first time. These differences are due to the lack of navigation in the Channel. Significant gradients of temperature and salinity in the PC (- 4oC/m and up to 25 PSU/m, respectively) form a powerful pycnocline under certain hydro-meteorological conditions.

Under the pycnocline in the bottom and middle layers of the NAC, the content of dissolved oxygen decreases from 20% to 6%; therefore, these layers may contain hydrogen sulphide. The redox line may rise into the water column in some situations. This leads to a significant deterioration of ecological conditions in the waters of the estuary and the oppression of the biota living in it.

The flow pass through the estuary has noticeably slowed down, the accumulation of mineral and organic compounds of nitrogen and phosphorus has increased primarily because of the regulation of the Dniester runoff. Large values of the content of dissolved oxygen and mineralization in the waters of the estuary indicate unfavorable biochemical processes: in the estuary, “blooming” of waters has become a common phenomenon, as well as the appearance of hypoxia zones, which is characteristic of significantly polluted polytrophic and hypertrophic waters.

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Bibliography

1. Garkavaya G.P., Bogatova Yu.I., Berlinsky N.A., et al. Long-term variability of the nutrient runoff of the Dniester. // Water resources, 2008, volume 35, no. 6, pp. 1-8
2. Gazetov Y.I., Medinets V.I., Snigirov S.M. Hydrological research of the Dniester estuary for 2012-2017 / Lyudina and Dovkilla. Problems of neoecology, No. 1-2 (29), 2018. P. 47-56. DOI: 10/26565 / 1992-4224-2018-29-05
3. Gazetov Y.I., Medinets V.I., Snigirev S.M., Konareva O.P. Long term changes in the direction of the hydrochemical regime of the Dnistrovsky estuary in summer 2003-2013 rr. / Materials of the All-Ukrainian NPK “Limani of the Pivnichno-Zahidnogo Prychornomor’ya“ Hydroecological Camp; problems of water and environmental management; recommendations for the show ”1-3 October 2014, Ukraine, m. Odesa. TES 2014.S. 78-80
4. Guseva T.V., Molchanova Ya.P., Zaika E.A., Hydrochemical indicators of the state of the environment. Reference materials./Ecoline. Moscow. 2000. 74p.1-9.
5. Gritsenko A.V., Vasenko O.G., Vernichenko G.A., et al. Methodology for ecological assessment of surface water quality by different categories., Kharkiv. 2012.-37s.
6. Medinets V.I., Kovaleva N.V., Gazetov E.I. Novikov A.N., Snegirev S.M. The results of environmental monitoring of the waters of the Dniester estuary in the summer period 2003-2004// Bulletin of the Odessa National University. Ecology, 2005.-T.10.Vip.4 - S.266-273.
7. Onishchenko E.G. Calculation of the sea water wedge advance along the Dniester estuary and

- the Dniester river / Academician L.S. Berg - 145. International conference. Bender: Eco-TI-RAS. 2021. R.425-429
8. Prikhodko V.Yu. Characteristics of the ecological state and assessment of water quality of the lower part of the Dniester estuary // Ukrainian Hydrometeorological Journal, 2013, No. 13. S.155-161
 9. Rosengurt M.Sh. Hydrology and perspectives of reconstruction of natural resources of Odessa estuaries. - K.: Naukova Dumka, 1974.224 p.
 10. Shuisky Yu.D. Natural conditions of the Dniester river in its lower reaches // Ecological safety of the coastal and shelf zones of the sea. No. 4. 2020. S. 66-77. Doi: 10/22449 / 2413-5577-2020-4-66-77
 11. Shuiskiy Yu.D., Bereznitska N.O. Gizhko L.V., Murkalov O.B. To the question of the Dnistrovsky estuary nature at the Black Sea coast // Environmental ecology and safety of life. -2008. -No. 5, -C. 15-27.
 12. Vinogradov A.K., Yu.I. Bogatova, I.A. Sinegub. Ecology of seaports (Black Sea-Azov basin): [monograph] - Odessa. Astroprint, 2014. - 568p.
 13. <https://www.ysi.com/exo1>