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Original article

Field of Total Suspended Matter Concentration of Anthropogenic Nature at the Southern Coast of the Heraclean Peninsula (Crimea)

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Abstract
Based on the data of a series of expeditions conducted in 2008–2019, the paper analyzes features of the structure of the total suspended matter concentration field in the areas of underwater discharge outlets of urban wastewaters. The linear scale of their influence was estimated. The regularities of domestic wastewaters distribution were considered for three types of background stratification of the water column. It was revealed that the field of the analyzed value was extremely heterogeneous in the studied coastal areas. At the sea surface, against the background of low natural concentration, individual spots were observed with a concentration ten times higher than the surrounding background. The main mass of suspended matter in the outlet area was accumulating in the 0–7 m layer. In the subsurface waters, the structure of the field under consideration shows local maxima, as well as isolated lenses with low salinity. The anthropogenic suspension spread to a distance of 0.4–1.5 miles from the discharge sites. The paper confirms the known regularities of the distribution of wastewaters from deep-sea outlets. These regularities are determined by the water column stratification and are as follows: free penetration to the surface in a homogeneous environment, predominantly horizontal transport in the presence of a seasonal thermocline, and rise to the sea surface in a situation of wind upwelling against a developed seasonal thermocline.

Key words: total suspended matter, temperature, salinity, anthropogenic impact, Heraclean Peninsula, Black Sea

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Поле концентрации общего взвешенного вещества антропогенной природы у южного берега Гераклейского полуострова (Крым)

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Аннотация
На базе данных серии экспедиций, проведенных в 2008–2019 гг., проанализированы особенности структуры поля концентрации общего взвешенного вещества на участках подводных выпусков городских стоков. Оценен линейный масштаб их влияния. Рассмотрены закономерности распространения сточных хозяйственно-бытовых вод при трех типах фоновой стратификации водной толщи. Выявлено, что на исследуемых прибрежных участках поле анализируемой величины крайне неоднородно. На поверхности моря на фоне низкой природной концентрации наблюдались отдельные пятна с концентрацией в десятки раз выше окружающего фона. Основная масса взвеси в районе выпусков накапливалась в слое 0–7 м. В подповерхностных водах в структуре рассматриваемого поля отмечены локальные максимумы, а также обособленные линзы с пониженной соленостью. Антропогенная взвесь распространялась на расстояние 0.4–1.5 мили от мест выпуска. Подтверждены известные закономерности распространения сточных вод из глубоководных выпусков, определяемые стратификацией водной толщи: свободное проникновение к поверхности в условиях однородной среды, преимущественно горизонтальный перенос при наличии сезонного термоклина и выход на поверхность моря в ситуации ветрового апвеллинга на фоне развитого сезонного термоклина.

Ключевые слова: общее взвешенное вещество, температура, соленость, антропогенное воздействие, Гераклейский полуостров, Черное море

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Introduction

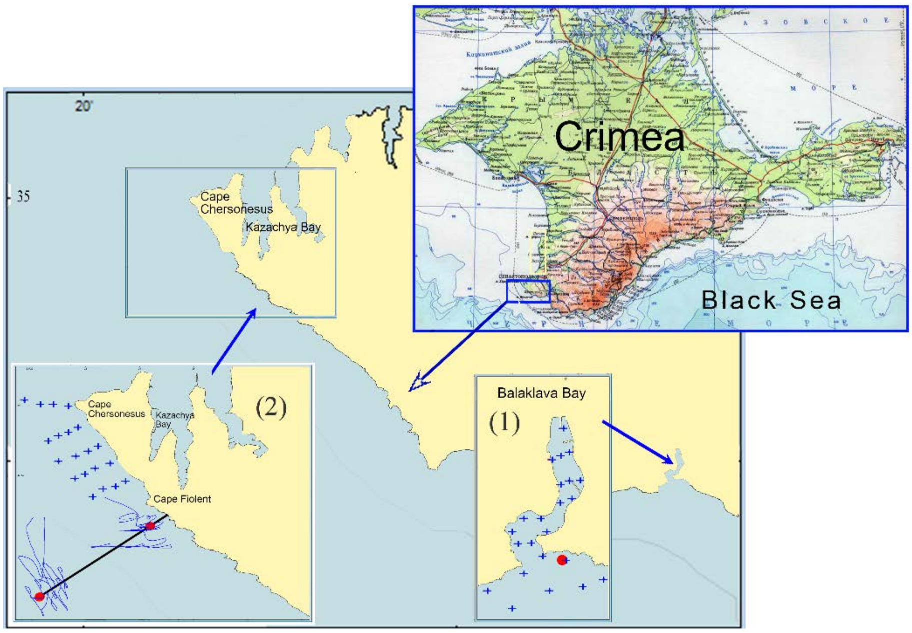
Since 2016, hydrological and hydrochemical monitoring of the state of sea waters has been carried out in the Sevastopol region, near sources of pollution in bays and open coastal area, including the studies of hydrodynamic factors that determine the transfer and accumulation of suspended matter and pollutants.

In [1], the first results of these studies with a comprehensive estimate of the flow of sources and the level of pollution of the marine environment, analysis of hydrophysical processes and hydrochemical parameters have been published. In particular, they concern two main most polluted open sites of the Sevastopol coastal area: 1 – at the entrance to Balaklava Bay, 2 – near the southwestern section of the coast of the Heraclean Peninsula (area of Cape Fiolent), where the Balaklava and Sevastopol domestic wastewater sewers are located (Fig. 1).

The article examines the structure of the total suspended matter (TSM) content field in these areas.

The selected parameter is considered one of the most informative indicators of water pollution in coastal waters, and the structure of the concentration field of this matter contains information about the sources of anthropogenic load, degree of their influence on the aquatic environment, trajectories of the spread of pollutants, places of their accumulation and dispersion [2].

Active oceanological studies of the field of TSM content in the oceans, seas and freshwater bodies began about 30 years ago. Then, sounding complexes based on the optical principle were invented in a number of foreign countries (Midas CTD+Valeport Ltd, the UK; EXO2 Multiparameter Sonde, YSI Incorporated, the USA; CTD90M – Probe Sea & Sun Technology GmbH, Germany; Metrec•XL AML Oceanographic, Canada). They determine quickly the TSM concentration *in situ* with good spatial resolution. The accuracy of measuring the content of this matter has increased by an order of magnitude compared to the previously used method of evaporation and subsequent dry residue weighing in selected water samples.



F i g . 1 . The studied areas on the map of the southern coast of the Heraclean Peninsula. The red dots are for municipal wastewater sewers

Since the beginning of this century, a similar probe has been used in the practical coastal expeditionary research of Marine Hydrophysical Institute, in particular in the study of the distribution of wastewaters from underwater discharge outlets in the Sevastopol region.

The article aims at:

– identification of signs of anthropogenic impact on the aquatic environment in the structure of the TSM concentration field and the thermohaline field in two sites of the Sevastopol coastal area, where underwater discharges of Balaklava and Sevastopol domestic wastewaters are located;

– estimate of the horizontal and vertical scales of the anthropogenic impact of each source on the environment;

– consideration of the influence of background stratification on the nature of the spread of wastewaters from the bottom layer to the sea surface;

– comparison of the result with known patterns of distribution of sewage runoffs from deep-sea outlets, previously obtained by other methods, depending on the stratification of the water column.

Initial data and methods of study

Materials from seven complex expeditions conducted by Marine Hydrophysical Institute (MHI) and Institute of Biology of the Southern Seas (IBSS) in 2008–2019 were analyzed.

The Table shows the distribution of initial information by region and over time. The text of the article shows details and features of specific surveys.

Data from expeditions with recording the total suspended matter content in the analyzed Sevastopol coastal areas

Area	Organization	Date of survey, site of water area
1	IBSS	9 May 2008, Balakalava Bay + coastal area 14 April 2010, Balakalava Bay + coastal area
	MHI	29 May 2012, Balakalava Bay + coastal area 6 June 2012, Balakalava Bay + coastal area
2	MHI	27–28 May 2016, coastal area * 12–13 September 2016, coastal area * 23 August 2019, coastal area

* The ship was underway.

All analyzed information was obtained by two instruments. Submersible autonomous hydrobiophysical multiparametric optical probe "Kondor" [1)] Scientific Production Enterprise "Akvastandart," TU 431230-006-00241904-2015; EAEU code 9027 50 000 0; EAEU Declaration of Conformity N RU D-RU.EM03.A.00096/19) was used during standard field oceanographic surveys. During the surveys while the ship was underway, a turbidity meter was used as part of the flow-through complex of MHI associated studies (Table).

During each sounding, the TSM concentration, temperature, and salinity were recorded synchronously (in situ) with a depth discreteness of 0.1 m. The accuracy of determining the indicated values is ±0.2 mg/L, ±0.01 °C, ±0.05 PSU, respectively.

In 1970–1980s, researchers of Institute of Biology of the Southern Seas of the National Academy of Sciences of Ukraine headed by the famous oceanologist Professor V.I. Zats conducted comprehensive experimental and theoretical studies of the processes of self-purification and distribution of wastewaters from sewer discharge outlets in the Black Sea. Monographs [3, 4] show the summarized results of these studies. According to these sources, deep-sea outlet sewers should be placed below the pycnocline (thermocline). This layer prevents the diluted sewage from rising to the sea surface and ensures its predominantly horizontal distribution.

In [4], it is shown that a similar scheme works well off the coast of Crimea in the warm months of the year when water column is sharply stratified. In the cold half of the year, when there is no vertical stratification, wastewater plumes rise freely to the sea surface. The situations of upwelling in the warm season of the year, which weaken the vertical stratification of the water column and in which wastewater plumes penetrate to the surface from a depth of 50–75 m through the seasonal thermocline, are considered separately.

This result was obtained by tracking the movement and transformation of rhodamine (used to color wastewaters) spots on the sea surface. The distribution of pollutants in the water column from a point sewer is considered based on numerical modeling methods.

To solve this problem, we used another method based on an analysis of the structure of the TSM concentration field and information about the background stratification of the thermohaline field.

High accuracy and vertical discreteness of the empirical data at our disposal made it possible to trace the distribution of sewage runoff from the considered deep-sea outlets in each of the situations noted above: in the absence of a thermocline, in the presence of a developed thermocline and under conditions of wind upwelling against the background of a developed thermocline.

To date, the TSM content maximum permissible concentration has not been stated as a numerical indicator of pollution of the aquatic environment. Therefore, to estimate the significance of the anthropogenic component in the concentration field of this matter, its actual content was compared with the concentration

[1)] HYDROoptics Ltd. *Complex Hydrobiophysical Multiparametric Submersible Autonomous "CONDOR"*. 2023. [online] Available at: http://ecodevice.com.ru/ecodevice-catalogue/multiturbidimeter-kondor [Accessed: 04 March 2024].

characteristic of the natural environment – waters with the TSM insignificant anthropogenic component.

Based on the results of the analysis of materials from numerous expeditions, we established that the content of TSM varies in a wide range of 0.2–19 mg/L in the waters of the Sevastopol region in the 0–30 m layer, and the structure of the actual field of this matter in bays and open coastal areas is characterized by spottiness due to the presence of local maxima of anthropogenic nature. After the filtration of corresponding concentration extremes from the actual fields, we came to the conclusion that a concentration of 0.8 mg/L corresponds to the environment with the TSM minimal anthropogenic component [5–7].

This value, accepted conditionally as the natural norm for the content of this matter in the waters of the Sevastopol region, was used as a criterion to determine the sites with no anthropogenic impact.

The presence of anthropogenic (from sewage runoff) suspended matter is confirmed by the heterogeneity in the field of TSM concentration in the form of spots (on a plane) or lenses (in space) with a TSM concentration of more than 0.8 mg/L. Sometimes these waters appeared in the salinity field in the form of local minima.

Based on the location of heterogeneities with TSM concentrations of more than 0.8 mg/L and their special haline characteristics, the sites of the water area subject to anthropogenic load were identified, and the linear scale of the influence of the wastewater discharges under consideration was estimated.

To analyze the atmospheric synoptic situation and weather conditions that accompanied the expeditionary research, synoptic maps of the *Wetterzentrale* Hydrometeorological Center website were used (http://old.wetterzentrale.de/topkarten/fsreaeur.html). Weather data are available at: http://rp5.am/Погода_на_Херсонесском_маяке.

Results and discussion

Let us consider the structure of the TSM concentration field under conditions of different background stratification in the coastal areas of the Balaklava and Sevastopol wastewater sewers (Fig. 1).

Area 1 – Balaklava Bay and the adjacent coastal area

The main source of pollution in this area is the Balaklava wastewater sewer located on the approaches to the bay near the southeastern coast at a distance of 55 m from the edge of water at a depth of 9 m [1] (Fig. 1).

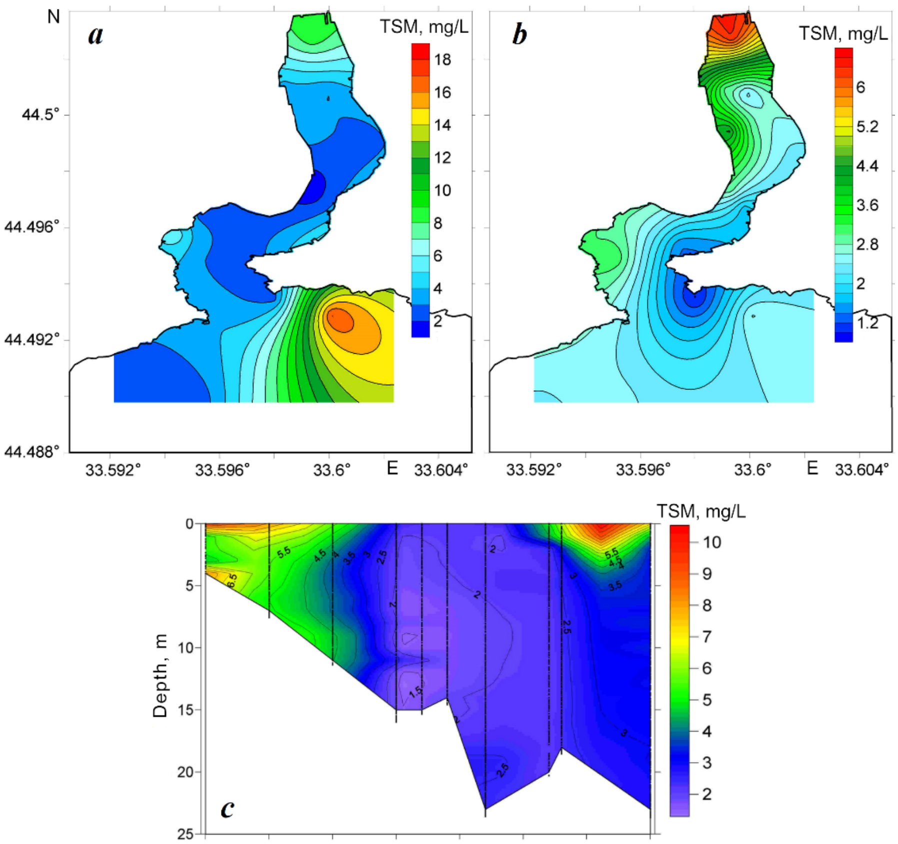
The upper boundary of the seasonal pycnocline (thermocline) in this area of the sea is on average located at a depth of about 15 m [8], which creates favorable conditions for the free rise of polluted waters from the bottom horizons and their release to the surface throughout the year.

This effect is confirmed by the results of five oceanographic surveys of Balaklava Bay and the adjacent sea area carried out by the IBSS researchers in 2000–2006 during monitoring studies of this bay and the adjacent Megalo-Yalo Bay [8].

Analysis of expedition materials showed no qualitative changes in the structure of the TSM concentration field characteristic properties from survey to survey.

In the area of discharge outlet, a local maximum in the content of this matter was observed, which varied in the range of 7.1–18.6 mg/L. At the same time, the bottom maximum was less significant and approximately 1.5–3 times higher than the natural norm. The entire water column contained anthropogenic suspended matter mainly concentrated in the upper layer 3–7 m thick. The horizontal scale of the lens of polluted water on the sea surface was 0.4–0.6 miles. According to hydrochemical studies, transformed wastewaters from the discharge area penetrated into the apex of the bay with the wind from the southern quarter.

Fig. 2 shows the situation of maximum contamination of the site under consideration, observed in August 2006. In the surface layer of the sea, the TSM concentration reached 18.6 mg/L, near the bottom it was 2.8 mg/L, and the horizontal scale of the polluted water lens was approximately 0.6 miles. The main amount of the matter under study was concentrated in the 0–5 m layer.

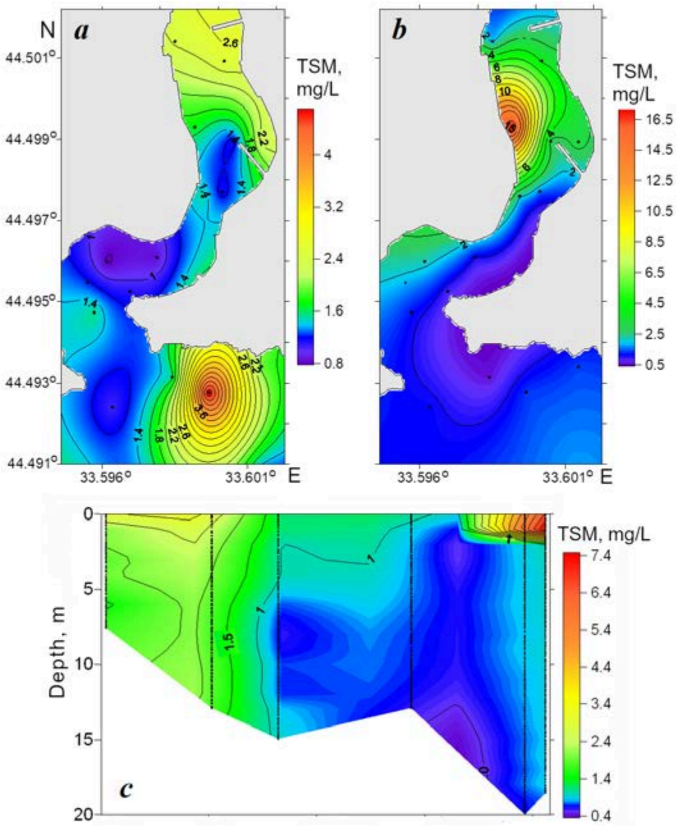


F i g . 2 . TSM concentration in the area of Balaklava Bay in August 2006: *a* – in the surface layer; *b* – near the bottom; *c* – at the longitudinal transect of the bay [8]

Analysis of data from subsequent expeditions conducted in 2008–2012 (Table) showed the same basic properties of the field structure of the content of the matter under study identified earlier, as well as its significant concentration an order of magnitude higher than the natural norm (Fig. 3). This indicates significant consumption and stability of the parameters of the source of pollution under consideration and the degree of its impact on the aquatic environment.

The Balaklava wastewater discharge area is distinguished by the maximum concentration of TSM of anthropogenic nature compared to other open areas of the coast and bays of the Sevastopol region.

The response of the aquatic environment to local anthropogenic impact on the approaches to Balaklava Bay is also noted in the salinity field. In the area of discharge outlet, a noticeable desalination of the surface layer of water was observed in the form of a local minimum of salinity in the center of the lens with the maximum TSM concentration. Salinity at the point of this extreme was 0.2–0.5 PSU below the surrounding background.



F i g . 3 . TSM concentration in the area of Balaklava Bay in April 2010: *a* – in the surface layer; *b* – near the bottom; *c* – at the longitudinal transect of the bay

For comparison, the desalination effect in the area of the natural Georgievsky source of submarine discharge located off the southwestern coast of Balaklava Bay is tens of times less (a similar extremum is not more than 0.02 PSU) [8], which indicates the importance of the wastewater discharge from Balaklava as a water pollution factor.

Area 2 – water area off the southwestern coast of the Heraclean Peninsula where sewage facilities Yuzhnye are located

Let us note the peculiarity of the structure of this water area – here, a constant (main) pycnocline corresponding to the main Black Sea halocline is observed at depths from 50 to 100 m. A known source of pollution in this coastal area is wastewater from sewage facilities *Yuzhnye*, City of Sevastopol [1]. The pipeline head of these structures is located at a distance of ~3 km from the coast at a depth of 88 m. In 2014, a leak developed in the underwater pipeline at a distance of ~ 700 m from the coast at a depth of 34–37 m, which turned into a significant source of anthropogenic suspended matter [1].

The spread of wastewater of high turbidity from the leak is clearly observed on satellite images in the visible range (Fig. 4).

In May and September 2016, two expeditions were conducted in the area of sewage facilities *Yuzhnye* in order to record the content of TSM while the ship was underway (Table). TSM concentration measurements were carried out in a flow-through complex installed onboard the vessel, where a turbidity meter was placed. In the area of the pipe, the ship moved on irregular tacks. The distance between adjacent tacks was reduced in the most polluted areas which were visible on the sea surface as spots of increased turbidity.

In May 2016, areas in the vicinity of both discharge outlets were studied (Fig. 1; Fig. 5, *a*). In September of that year, only the site of the discharge outlet closest to the coast was studied, namely from the beach area to half the length of the wastewater pipeline (Fig. 5, *b*).

In May 2016, the work was performed in hot low-wind weather determined by an anticyclonic low-gradient field of surface atmospheric pressure. The survey was carried out at the beginning of the warm season, when the Black Sea thermocline (pycnocline) had not formed yet and the vertical exchange was not limited to this stratification element.

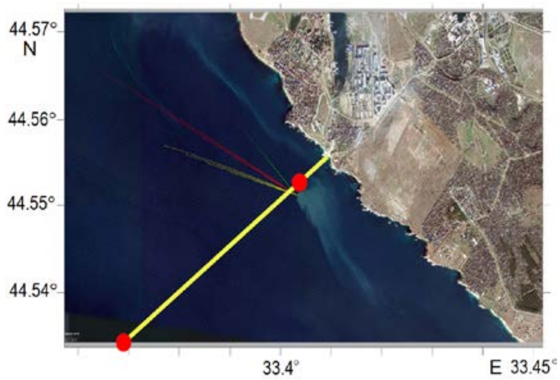
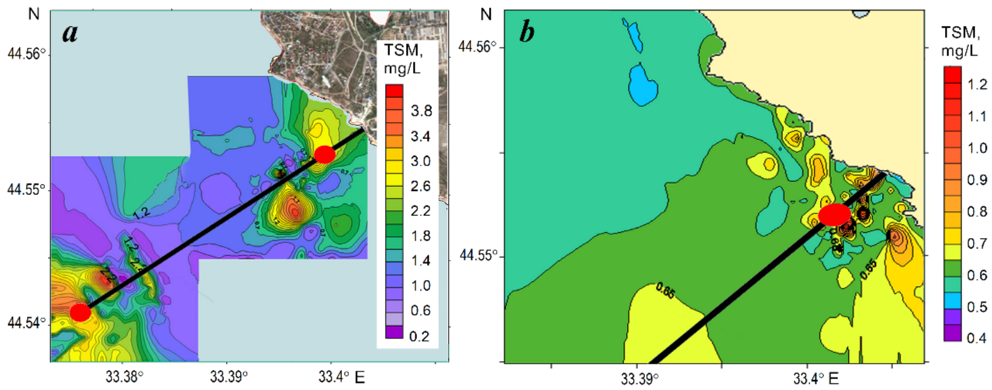


Fig. 4. Satellite image (http://dvs.net.ru/SWCrimea/stoki_ru.shtml) of the studied water area with a scheme of a pipeline of sewage facilities *Yuzhnye*. The red dots are for discharge outlets



F i g . 5 . TSM Concentration in the 0–1 m layer in Area *2* in May (*a*) and September (*b*) 2016. The black line is for the pipeline with discharge outlets (red dots)

Analysis of experimental data showed the presence of a significant amount of anthropogenic suspended matter in the upper layer of water. Against the background of low (0.2–0.4 mg/L) TSM concentration typical for the open part of the Black Sea, anthropogenic suspended matter from two discharge outlets, the concentration of which was several times and an order of magnitude higher than the background values, was observed in the predominant part of the water area. Local maximum concentration of the studied matter of 4.0–4.2 mg/L was found above both discharge outlets. The anthropogenic suspended matter in the form of spots with a diameter of about 100 m spread into shallow water from the discharge outlet closest to the coast. In the area of the seaward discharge outlet, extensive spots with a diameter of up to ~ 200 m were observed with a TSM concentration 3–5 times higher than the natural norm.

The survey on 12–13 September 2016 was carried out in clear low-wind (variable wind speeds of 2–3 m/s) weather determined by a low-gradient field of surface atmospheric pressure. The September survey was carried out under conditions of developed vertical stratification of the density field typical for the Black Sea at the end of the summer season. This survey confirmed the significant screening role of the seasonal thermocline preventing the spread of the wastewater plume from the bottom horizons to the upper layer of the sea.

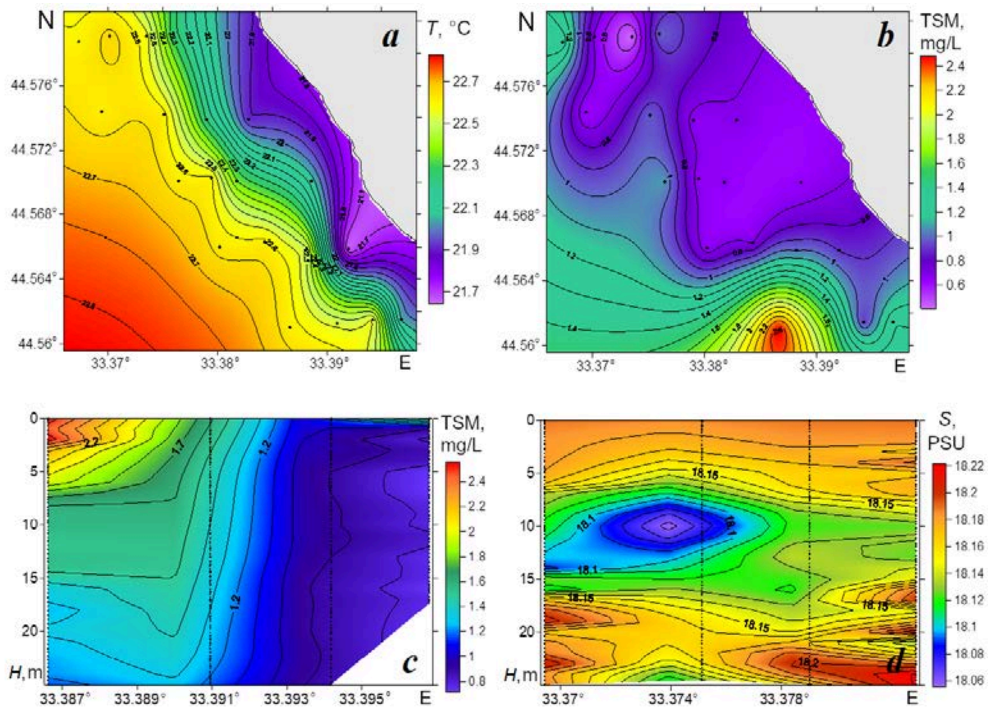
In the predominant part of the studied water area, the TSM content (0.4–0.8 mg/L) corresponded to the natural norm. Only in the coastal zone, in the area of the closest wastewater discharge outlet, separate small spots with a diameter of 10–50 m were detected with a TSM concentration of 1.0–1.2 mg/L, which is approximately four times lower than the concentration confirmed by the May survey (Fig. 5, *b*).

In August 2019, the MHI researchers conducted a comprehensive oceanological survey at a test site located half a mile northwest of the pipeline of sewage facilities *Yuzhnye* under conditions of strong northeasterly offshore winds (Table, Fig. 1). This successful experiment made it possible to understand the features of water structure and the TSM distribution from real sources of pollution in a situation of upwelling and maximally stratified water column.

A developed seasonal thermocline was observed in the coastal area under study. Its upper boundary was located at a depth of 7–11 m and was raised near the coast. The vertical gradient in the thermocline (in absolute value) exceeded 1 °C/m.

The source of upwelling on the sea surface was clearly visible in the field of temperature and TSM concentration in the form of a minimum of these values extended along the coast: 21.6–22.1 °C and 0.4–0.8 mg/L (Fig. 6, *a*, *b*).

Despite a well-defined seasonal thermocline that prevented vertical exchange, anthropogenic suspended matter that penetrated through this screening layer in the system of ascending upwelling circulation was found in the upper layer of water almost throughout the entire test site water area. Everywhere in the area under study, with the exception of the northwestern sites most remote from the pipeline of sewage facilities *Yuzhnye*, the TSM concentration exceeded the natural norm and varied in the range of 0.8–2.6 mg/L.



F i g . 6 . Distribution of hydrophysical parameters in August 2019: temperature, °C (*a*) and TSM concentration, mg/L (*b*); TSM concentration, mg/L (*c*) and salinity, PSU (*d*) at transects normal to the coast

A fragment of a lens with a vertical scale of 3–5 m and a maximum TSM concentration of 2.4–2.6 mg/L was recorded in the southern part of the test site, in close proximity to the pipe. Anthropogenic suspended matter was observed in the upper layer of water in an area with a linear size of about 1.0–1.5 miles (Fig. 6, *b*, *c*).

The structure of the haline field reflects clearly the response to anthropogenic interference in the state of the aquatic environment in the coastal area under study. The vertical structure of the transformed wastewaters discharged to the sea surface showed signs of anthropogenic impact. They were especially clearly manifested in the stratification of the salinity field in the subsurface layer of 5–20 m in the form of heterogeneities that should not exist in an unpolluted aquatic environment.

Against the surrounding background, these formations were represented by isolated lenses with a vertical size of 3–10 m and salinity reduced by 0.05–0.2 PSU (Fig. 6, *d*).

Note that traces of wastewater discharge on the sea surface were also discovered in the Sevastopol region due to the analysis of high spatial resolution data from satellites Landsat8 and Sentinel1 [10, 11].

The results of this study concerning the features of the distribution of suspended matter from underwater discharge of Balaklava and Sevastopol domestic wastewaters with different stratification of the water column correspond to the main patterns of distribution of sewage discharge outlets from underwater runoff off the Crimean coast identified by the authors of monographs [3 , 4].

It should be noted that the above mentioned authors studied the distribution of artificial dye, while in our case we consider the TSM, a parameter of the aquatic environment actual state. These are two different substances, and each of them could be distributed differently under the same type of background stratification. The discovered similarity of the results determines the possibility of using the method discussed in this article to study the distribution of sewage runoff from deep-sea discharge outlets. It is quick and less expensive.

Thus, a comprehensive survey using probe “Kondor” with recording the TSM concentration in the areas where wastewater discharge outlets are located in Balaklava and Sevastopol takes several hours at a ship speed of 6–8 knots and a sounding depth of 100 m.

In addition, the method based on determining the TSM concentration is more informative, since it gives an idea of the three-dimensional structure of the actual suspended matter field which makes it possible to trace the distribution of this substance in the water column. Observations of the dye [3, 4] were carried out only on the sea surface through aerial photography. The distribution of suspended matter in the water column was modeled.

Conclusion

Based on the data provided by seven expeditions conducted in 2008–2019, the structure of the TSM concentration field and the thermohaline field was analyzed at the sites off the southern coast of the Heraclean Peninsula, where the Balaklava (area 1) and Sevastopol (area 2) underwater discharge outlets of domestic wastewaters are located. Signs of domestic wastewaters were identified. The scale of the anthropogenic impact of each of the considered sources on the environment was estimated. The influence of background stratification on the distribution of wastewaters from the bottom layer to the sea surface was considered.

It is shown that domestic wastewaters appear in the field of TSM concentration in the form of local maxima with a concentration several times and tens of times higher than the natural norm in each of the studied areas. Sometimes these waters were detected in the salinity field in the form of local minima.

In area 1, the location of the Balaklava wastewater sewer above the seasonal thermocline facilitates the free rise of anthropogenic suspended matter from the bottom horizon to the sea surface throughout the year.

In this area, the structure of the TSM concentration field was stable and was characterized by the following properties during 2000–2018. A local maximum of 7.1–18.6 mg/L was observed in the surface layer 3–7 m thick. The entire water column contained anthropogenic suspended matter. The impact of the sewer extended over a distance of 0.4–0.6 miles from the discharge outlet. Area 1 is distinguished by the maximum anthropogenic TSM concentration compared to other open areas and bays of the Sevastopol region.

In area 2, a qualitative dependence of the anthropogenic TSM distribution on water stratification was traced. In a situation where the seasonal thermocline was not formed (May 2016), anthropogenic suspended matter was found in the surface layer with its concentration several times and an order of magnitude higher than the background values. The TSM content corresponded to the natural norm with a developed seasonal thermocline (September 2016) in the predominant part of the water area. In August 2019, anthropogenic suspended matter was observed in the surface layer of water throughout the entire water area of the test site in a situation of upwelling and a developed seasonal thermocline.

In area 2, the impact of wastewaters extends over a distance of 1–1.5 miles from the discharge outlet.

The results of this study based on an analysis of the structure of the TSM concentration field confirm the dependence of the distribution of sewage runoff on the background stratification of water for deep-sea discharge outlets in the Crimean region, previously identified using other methods. This makes it possible to apply the method we used to study the distribution of sewage runoff from deep-sea discharge outlets.

REFERENCES

1. Gruzinov, V.M., Dyakov, N.N., Mezenceva, I.V., Malcheko, Y.A., Zhohova, N.V. and Korshenko, A.N., 2019. Sources of Coastal Water Pollution near Sevastopol. *Oceanology*, 59(4), pp. 523–532. https://doi.org/10.1134/S0001437019040076
2. Eisma, D., 2011. *Suspended Matter in the Aquatic Environment*. Berlin: Springer, 315 p. https://doi.org/10.1007/978-3-642-77722-6
3. Zats, V.I., Nemirovsky, M.S., Andryushchenko, B.F., Kandybko, V.V., Stepanov, V.N., Agarkov, A.K., Shulgina, E.F., Kiseleva, M.I., Senichkina, L.G. and Fedorenko, L.V., 1973. [*Experience of Theoretical Experimental Study of the Problem of Deep-Water Sewage Discharge: the Case of the Yalta Area*]. Kiev: Naukova Dumka, 274 p. (in Russian).

4. Zats, V.I. and Goldberg, G.A., eds., 1991. *Modelling of Water Selfpurification Processes of the Shelf Zone of Sea Water*. Leningrad: Gidrometeoizdat, 230 p. (in Russian).
5. Lomakin, P.D. and Chepyzhenko, A.A., 2019. Hydrophysical Conditions and Characteristics of Water Pollution of the Kazachya Bay (Crimea Region) in September of the Year 2018. *Monitoring Systems of Environment*, (1), pp. 48–54. https://doi.org/10.33075/2220-5861-2019-1-48-54 (in Russian).
6. Lomakin, P.D., Chepyzhenko, A.I. and Grebneva, E.A., 2019. Fields of Hydrophysical and Hydrochemical Elements in South and Ship Bays (Crimea) in December 2018. *Monitoring Systems of Environment*, (3), pp. 44–50. https://doi.org/10.33075/2220-5861-2019-3-44-50 (in Russian).
7. Lomakin, P.D. and Chepyzhenko, A.I., 2022. The Structure of Fields of Oceanological Quantities in the Upwelling Zone at the Herakleian Peninsula (Crimea) in August 2019. *Ecological Safety of Coastal and Shelf Zones of Sea*, (1), pp. 31–41. https://doi.org/10.22449/2413-5577-2022-1-31-41
8. Lomakin, P.D. and Popov, M.A., 2013. *Oceanological Characteristic and Estimation of the Water Pollution in the Balaklava Bay*. Sevastopol: ECOSI-Gifrofizika, 220 p. (in Russian).
9. Bondur, V.G., Ivanov, V.A., Dulov, V.A., Goryachkin, Yu.N., Zamshin, V.V., Kondratiev, S.I., Lee, M.E., Mukhanov, V.S., Sovga, E.E. and Chukharev, A.M., 2018. Structure and Origin of the Underwater Plume near Sevastopol. *Fundamentalnaya i Prikladnaya Gidrofizika*, 11(4), pp. 42–54. https://doi.org/10.7868/S2073667318040068 (in Russian).
10. Bondur, V.G. and Grebenyuk, Yu.V., 2001. Remote Indication of Anthropogenic Influence on Marine Environment Caused by Depth Wastewater Plum: Modelling, Experiments. *Issledovanie Zemli iz Kosmosa*, (6), pp. 49–67 (in Russian).
11. Dulov, B.A., Yurovskaya, M.V. and Kozlov, I.E., 2015. Coastal Zone of Sevastopol on High Resolution Satellite Images. *Physical Oceanography*, (6), pp. 39–54. https://doi.org/10.22449/1573-160X-2015-6-39-54

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