Method of the Assessment of the Eutrophication of the Waters of the Gulf of Taganrog of the Sea of Azov Subject to the External Load on the Water Area

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Abstract. Eutrophication of waters is a complex problem that is widespread all over the world. These processes especially intensified during the last century because of the human activity which lead to the anthropogenic transformation of water reservoirs. The object of the study – the Gulf of Taganrog of the Sea of Azov – also subject to the processes of waters eutrophication. So the research evaluates the Gulf ecosystem from the standpoint of eutrophication. The method of such assessment was developed. It includes the regression analysis and mathematical modelling. The study showed the change in the type of eutrophication of a water body from the mehotrophic type to the eutrophic one; the estimation of the inflow of the concentrations of ammonium ion, nitrate and phosphate into the waters of the Gulf showed the sources that influence this income mostly; the natural load influences the ecosystem most.

1. Introduction

The eutrophication of shallow water bodies is a rather dangerous manifestation of the anthropogenic transformation of water reservoirs with a slowed down water exchange. The fact is that at the early stages of the development of this process, the consumer quality of water remains at an acceptable level, and an increase in fish productivity is perceived as an extremely positive change. Decades pass before the emergence of biological hindrances to water supply, fish death, and a decrease in the recreational potential remind of the accumulation of biogenic matter in the ecosystem and their involvement in the biotic cycle.

Waters eutrophication is a peculiar phenomenon of the ecosystem, which is achieved by enrichment with nutrients, which, as a rule, stimulates the growth and flowering of algae, and this, in turn, leads to a deterioration in the quality and condition of natural waters. In recent years, this has become a global environmental problem. Therefore, to develop measures to reduce eutrophication of the water area, first, it is necessary to understand how its processes.

Many authors investigate the problems of eutrophication [1-7], the eutrophic index determination is actual to many water bodies worldwide. It is important to notice that usually when determining the eutrophication index the chlorophyll “a” concentration is used [8-11].

It is significant that in the recent decades the rate of the eutrophication processes has increased due to the activities of humanity. In this regard, the concept of the anthropogenic eutrophication appeared, that is, the eutrophication happening due to the human economic activity. In order to maintain the...
balance of the aquatic ecosystems, it is important to understand what quantitative load is exerted by the sewage and other drain on the process under study.

The object of this study is the Gulf of Taganrog of the Sea of Azov (the inner sea of the Atlantic Ocean). The Gulf is the largest and most isolated part of the water area. Its length is about 140 km and the width at the entrance is about 31 km. So the square of the area is about 5600 km² [13]. It is important to notice that, despite the fact that the Gulf of Taganrog is a part of the sea; the problems of eutrophication are reasonably important. This is explained by the natural features of the water area:
- the water reservoir is shallow (the average depth is 4.9 meters);
- the reservoir is classified as slightly salted;
- the flow of water masses is practically absent;
- in the warm season, the entire water mass is heated;
- the average temperature during the vegetation period is quite high (15.6-17.1 °C).

One more important feature of the water area is that the Gulf is a natural extension of the River Don delta. Such a large river plays an important role in the hydrological regime of the water ecosystem, not only causing freshening, but also bringing in the Gulf a large amount of biogenic matter.

Simultaneously, a large amount of nitrogen and phosphorus-containing substances is supplied with household and wastewaters.

In the environmental monitoring practice, various integral indicators of the water bodies’ eutrophic state, which should reflect the outcome of the multidirectional processes of the organic substances synthesis and destruction in the water over a measured period, are used. Our study uses the statistical model [13] to calculate the water eutrophic index and a mathematical model for calculating the external load on the water area, taking into account the ways of the biogenic matter inflowing to the Gulf.

Consequently, the aim of the study is a spatial and temporal assessment of the ecological situation in the Gulf of Taganrog of the Sea of Azov from the standpoint of eutrophication.

The main tasks of the research include:
- the determination of the current state of the Gulf water area from the standpoint of eutrophication based on the previously constructed by the authors [14] mathematical model for determining the water eutrophic index;
- the assessment of the external biogenic load on the water area;
- the analysis of the influence of the natural and anthropogenic factors on the eutrophic index of the waters of the studied area.

2. Materials and methods
In this way, for the first time the waters eutrophic index was calculated to the Gulf of Taganrog of the Sea of Azov [14-17]. The sampling was carried out from the beginning of April to the end of October in the Gulf of Taganrog according to the government-approved methods. The data includes fourteen-year period for the following indexes: salinity, temperature and the concentrations of the nitrate, ammonium, nitrite and phosphate.

The statistical model [14] describing the eutrophication processes in the Gulf included all the typical stages (analysis, parameters determination, the model verification, etc.). Therefore, the regression equation for the eutrophic index of the Gulf of Taganrog is:

\[ T_{stat} = k_0 + k_1 (S) + k_2 (t) + k_3 (NH_4) + k_4 (NO_3) + k_5 (PO_4), \]

where \( T_{stat} \) – the waters eutrophic index;
\( (S) \) – salinity, ‰;
\( (t) \) – water temperature, °C;
\( (NH_4) \) – ammonium concentration, mg/dm³;
\( (NO_3) \) – nitrate concentration, mg/dm³;
\( (PO_4) \) – phosphate concentration, mg/dm³;
k – empirical coefficients.
However, the regression analysis with these factors revealed that the nitrite concentration, as well as the water current speed in the gulf, are statistically insignificant components of the regression model. Thus, the number of independent variables is five.

The eutrophication of a water body can be significantly influenced by both natural and anthropogenic factors. The total flow of the biogenic matter into the water area constitutes the total external load, which depends on many factors: the number and types of point sources, the topography of the catchment area and types of land use, geological features of the area, hydrological characteristics of water bodies and streams, human economic activity, etc. Usually, the method of calculating the load of nitrogen and phosphorus is based on calculations of the elements of the following equation [11]:

\[
L = L_{\text{wastewater}} + L_{\text{diffused source}} + L_{\text{flat drain}} + L_{\text{recreation}} + L_{\text{water transport}} + L_{\text{atmosphere}} + L_{\text{river}},
\]

where \( L \) – the overall load of nitrogen and phosphorus, tons/year; \( L_{\text{wastewater}} \), \( L_{\text{diffused source}} \), \( L_{\text{flat drain}} \), \( L_{\text{recreation}} \), \( L_{\text{water transport}} \), \( L_{\text{atmosphere}} \), \( L_{\text{river}} \) – the load of nitrogen and phosphorus, inflowing respectively with wastewater; the diffused sources; the flat drain; the recreation; the water transport exploitation; the atmospheric precipitation and the river runoff, tons/year.

Meanwhile the purpose of the study is to determine the influence of the human activity on the eutrophication, let us group these indicators:

\[
L_{\text{nature}} = L_{\text{atmosphere}} + L_{\text{river}},
\]

where \( L_{\text{nature}} \) – the load including the natural factors;

\[
L_{\text{antropogenic}} = L_{\text{wastewater}} + L_{\text{diffused source}} + L_{\text{flat drain}} + L_{\text{recreation}} + L_{\text{water transport}}
\]

where \( L_{\text{antropogenic}} \) – the load including the anthropogenic factors.

To determine the external load from the natural sources, it is necessary to calculate the load from the atmospheric precipitation and the river runoff.

The load generated by the atmospheric precipitation for phosphorus and nitrogen can be calculated using the following equation:

\[
L_{\text{atmosphere}} = K_{\text{atmosphere}} S_{\text{water}},
\]

where \( L_{\text{atmosphere}} \) – the load of nitrogen and phosphorus, generated by the atmospheric precipitation, tons/year; \( K_{\text{atmosphere}} \) – coefficient of nitrogen and phosphorus input with the atmospheric precipitation, grams/(hectare-year); \( S_{\text{water}} \) – area of a water body, hectare [18].

The load generated by the river flows takes into account all the loads of the entering rivers with wastewater and surface runoff, which are almost entirely transported to the underlying water bodies. In the process of self-purification of the rivers, the nitrogen and phosphorus compounds can largely transform into their mineral forms, i.e. into the forms accessible and well assimilated by phytoplankton, which can aggravate the eutrophication of water bodies receiving river flows [19].

The amount of nitrogen and phosphorus supplied with the river waters is calculated by the equation:

\[
L_{\text{river}} = L_{\text{w}}(1 - R_{\text{p}}),
\]

where \( L_{\text{w}} \) – the load of nitrogen and phosphorus inflowing to the i-river from all the incoming sources, tons/year; \( R_{\text{p}} \) – the retention coefficient of nitrogen and phosphorus in the system of the i-river (if the river has no lakes on its way, then \( R_{\text{p}} = 0 \)) [11].

The load of the biogenic matter inflowing with the wastewater is defined as:

\[
L_{\text{wastewater}} = Q \cdot C,
\]

where \( Q \) – the wastewater consumption from the i-th source, m³/year; \( C \) – the concentration of the biogenic matter in the treated wastewater of the i-source, g/m³ [12].

The load generated by the intake of the biogenic matter from the diffused sources of pollution is calculated as the load incoming from the residents of unsewered areas that do not have any sewage-purification facilities:

\[
L_{\text{diffused source}} = N_{\text{i}} \cdot K_{\text{i}} \cdot (1 - R_{\text{n}}),
\]

where \( L_{\text{diffused source}} \) – the load of nitrogen and phosphorus incoming from the diffused sources, gram/day; \( N_{\text{i}} \) – the number of inhabitants of the area; \( K_{\text{i}} \) – the extraction coefficient of nitrogen and phosphorus, gram/(day-person); \( R_{\text{n}} \) – the containment coefficient of nitrogen and [11].

The load generated by the recreation area is calculated mainly as the inflow of nitrogen and phosphorus from the number of swimmers in the tourist season:
\[ L_{\text{recreation}} = N_2 \cdot K_2 \cdot d_2, \]

where \( L_{\text{recreation}} \) – the load of nitrogen and phosphorus incoming from the recreation, gram/year; \( N_2 \) – number of swimmers, person/year (it can be assumed that the number of swimmers is equal to the number of the beds during the tourist season); \( K_2 \) – the extraction coefficient of nitrogen and phosphorus, gram/(day-person); \( d_2 \) – duration of the tourist season, days. \( K_2 \) for the Gulf of Taganrog for nitrogen is 1 and for phosphorus is 0.05 (determined experimentally).

3. Results

Based on the database of the long-term averages during the vegetation period of in the Gulf of Taganrog northeastern part, the regression equation was obtained:

\[ T_{\text{stat}} = 6.294 + 0.104(S) + 0.114(t) - 1.06(NH_4) + 0.021(NO_3) - 0.929(PO_4). \]

As a result, during the study the statistic identification showed the factors that influence the processes of the eutrophication of the Gulf of Taganrog mostly. The most important factors are the concentrations of the biogens (namely, nitrate, ammonium and phosphate), the salinity of water and the temperature of water. The model was verified using the experimental data of fourteen years with a satisfactory degree of adequacy (82%).

Based on the studied characteristics and the constructed regression model, a statistical indicator of the eutrophication of the waters of the Gulf of the Taganrog was calculated. Analyzing the obtained values of the eutrophic index, it can be concluded that in different areas of the Gulf of the Taganrog, the processes of the eutrophication of waters are intensified and, often, the ecosystem turn to the eutrophic type from the mesotrophic one.

Consequently, for example, the maximum eutrophic index (more than 9.5) was observed in 2011. Remarkable that such a high values were typical not only for one sample point, but several. This indicates a wide scope of diligence of eutrophication processes in the water area. With this, the minimum eutrophic index (7.24) was observed in 2003. Therefore, the spatio-temporal analyses shows that the eutrophication of waters of the Gulf intensifies from year to year.

The natural and anthropogenic loads on the Gulf were calculated to determine the external sources affecting the eutrophication processes of the water area:

\[ L_{\text{nature}}(PO_4) = 14007.117 \text{ t/year}; \]
\[ L_{\text{nature}}(NH_4) = 21234.112 \text{ t/year}; \]
\[ L_{\text{nature}}(NO_3) = 38570.625 \text{ t/year}; \]
\[ L_{\text{anthropogenic}}(PO_4) = 42.541 \text{ t/year}; \]
\[ L_{\text{anthropogenic}}(NH_4) = 22.015 \text{ t/year}; \]
\[ L_{\text{anthropogenic}}(NO_3) = 1441.384 \text{ t/year}; \]

The total external load of nitrate is 40012.009 tons/year, the total external load of ammonium is 21256.127 tons/year and the total external load of phosphorus is 14049.658 tons/year.

As a result, the anthropogenic load for phosphates is 0.3% of the total external load, for ammonium ion - 0.1%, and for nitrates - 5.56%.

Based on the obtained results, it is obvious that the nitrate sources have a significant effect on the ecosystem balance from the point of view of the eutrophication.

Experimental studies of the comparative role of nitrogen and phosphorus in the eutrophication of the Gulf of Taganrog carried out by the authors [20] also showed that the dominant role of nitrogen in eutrophication is currently characteristic of the water area.

Thus, the amount of nitrates coming from the anthropogenic sources into the water area of the Gulf is significant for the acceleration of the eutrophication processes.

4. Conclusion

In the study, a specific assessment of the eutrophication of the waters of the Gulf of Taganrog of the Azov Sea was carried out taking into account the external load on the water area, which showed that:
1. The change in the type of eutrophication of a water body from the mesotrophic type to the eutrophic one is often observed in the Gulf of Taganrog. This indicates the increase in these phenomena in the water area.

2. A specific estimation (in %) of the inflow of the concentrations of ammonium ion, nitrate and phosphate into the waters of the Gulf showed the sources that influence this income mostly. The nitrate sources have a significant effect on the ecosystem balance from the point of view of the eutrophication.

3. The main source of the biogenic matter entering the water area of the Gulf of Taganrog is the River Don. At the same time, the amount of nitrate supplied from the anthropogenic sources to the water area of the Gulf is significant for the speeding up of the eutrophication processes.

The foregoing allows authors to conclude that in the aquatic (as well as in the terrestrial) ecosystems, the main factor limiting the productivity of the primary phytoplankton production under the natural conditions is the low concentration of the biogenic nitrogen in the water. With its anthropogenic input into the water bodies, the rapid growth of algae begins. Hence, it follows that the main measure aimed at preventing the anthropogenic eutrophication should be the regulation of the input of the limiting biogen into water bodies, i.e. nitrogen, to the ecological minimum of its concentration in the water body, since the eutrophication process is controlled, like other natural phenomena, by the law of minimum.

The work does not take into account the anthropogenic load on the Don River; therefore, a comprehensive analysis of the ecosystem data (the Gulf and River) may show a more intense anthropogenic load. This direction is the further research of the authors.

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