System approach to the water quality and bioproductivity of the Azov Sea basin

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Abstract

The environmental state of the Azov Sea is determined by a number of factors among which the influence of river basins plays the leading part. The most prominent anthropogenic impacts are concentrated within the limits of lower Don system including the huge Tsymlyansk reservoir, the group of salinized Manych lakes and ecologically vulnerable Don delta. The environmental management of this area must be based on the integrated approach to marine and freshwater objects. This paper presents preliminary results of the ecological researches carried out in marine and land parts of the Azov basin and recommendations on the development of monitoring systems as well as some practical steps for the improvement of water quality and bioproductivity.
Keywords: Azov Sea, Don River, catchment area, monitoring, quality management.

1 Introduction

The Sea of Azov with its fluvial drainage systems is a unique in many aspects part of the World Ocean. It includes only insignificant part of both: area and water amount in the chain of the internal seas, consisting of the Mediterranean, the Marmora Sea, the Black Sea and the Sea of Azov (Table 1). But it receives large amounts of fluvial run-off from the drainage system, extending from the central Russia regions till the northern slope of Great Caucasus. As it follows from the data in Table 1, annual inflow of fresh water into the Sea of Azov is more than 10% of its water amount whereas in other seas this index is in the range from 0.3% in the Marmora Sea to 0.01% in the Mediterranean. This fact conditions important peculiarities of the Sea of Azov oceanological regime that is: low salinity, its significant temporal-spatial variability; intensive water

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exchange through the Kerch strait, and a high rate of water masses renewal; abundant input of mineral and organic substances of different origin and as a consequence, a very high bioproductivity per the unit of sea area.

Table 1: Physical-geographical characteristics of the seas belonging to the Mediterranean basin [1, 2].

Sea	Area, thousand km^2	Water amount, thousand km^3	Fluvial run-off , km^3/year
Mediterranean	2505	3839	430
Marmora	12	3.0	About 10
Black Sea	422	537	355
Sea of Azov	39	0.3	40

Biomass of fishes in the Sea of Azov exceeds 80 kg / ha. During the XIX and the first half of the XX century catches of commercial fish species were in the range 150-300 thousand t annually, it should be noted that valuable species as sturgeons, sanders, breams, roaches, vimbas etc. prevailed in their composition. During subsequent decades catches declined by more than an order and during the 1990-ies they were in the range 5-30 thousand t annually. This is explained by the cumulative action of the set of factors among which according to our estimations commercial withdrawal, anthropogenic lowering of the fluvial run-off, long-term anomalies of salinity, contamination of sea and fluvial waters played the leading role [9, 10, 12]. The first among these factors is subjected to administrative regulation, the rest are the result of unintentional anthropogenic impacts combined with the natural climatic variability. They are to be accounted and corrected in the system of the complex management of nature exploitation which should include sea areas, coastal zones and drainage system.

2 General characteristics of the drainage system

Basin of the Sea of Azov covers several nature zones and is distinguished by the extreme asymmetry. Practically the whole fluvial run-off is provided by two river basins in the eastern part of the sea, which coincides with its Russian sector, Fig. 1.

According to the average long-term data [2] the River Don run-off is 27.8 km^3/year, that of the Kuban River – 11.1 km^3/year. Other rivers provide with approximately 1 km^3/year, including the Mius River, entering the Taganrog Bay which gives about 0.5 km^3/year. By the recent data for the decade 1991-2000 the run-off of the Don River diminished to the 23 km^3/year and the Kuban River run-off increased to 13 km^3 /year [7]. Nevertheless the River Don run-off is the major regulator of salinity and bioproductivity of the Sea of Azov. In the zone of its impact in the Taganrog bay a spatial gradient of salinity in the range 0 - 10‰ constantly exists at the distance of approximately 100 km, whereas the influence of the Kuban River run-off is not distributed farther then the mouth area.

Figure 1: Catchment area of the Sea of Azov basin (a) and water system Taganrog bay Lower- Don (b).

As for the area the Don River basin exceeds that of the Kuban River by more than 7 times: 422 and 58 thousand km^2, correspondingly. Qualitative differences between them are not less important. The River Don Basin is located inside the boundaries of the forest–steppe and steppe zones of the Eastern- European plain, changes of the run-off module over the basin area are relatively insignificant. The Kuban River basin is located in the northern slope of the Great Caucasus where the major part of this river run-off is being formed and on the piedmont steppe territories with insignificant river run-off module. For the mountain areas a high variability of meteorological conditions leading to the instability of water regime is typical. On the contrary, the Don River basin in natural state is distinguished by the predictability of hydrological conditions. Variability of run-off is conditioned by mainly seasonal components: vernal flood and summer low water which in the southern part of the basin leads to the complete dry of small rivers.

These basins differ significantly also by the degree of the run-off regulation. Water reservoirs in the Kuban River basin are relatively small. In the middle current of the Don River there is exploited for more than half a century one of the largest in Europe water reservoirs - Tsymlyanskoe with area 2700 km^2 and

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water amount 23.7 km^3, which is comparable to the annual run-off of this river. This reservoir is used for a number of tasks: hydro-energy production, irrigation, navigation, water supply. The lower part of Don Basin is also regulated by smaller reservoirs. This gives ground to consider the Don River run-off to be manageable in principal though the tasks of water users cannot always be agreed.

Problems of water quality are especially sharp in the down-stream and in the delta of the Don River and in the steppe areas with unstable fluvial run-off. At the small rivers of the Sea of Azov basin increased natural mineralization is accompanied with contamination due to the application of mineral fertilizers, industrial-municipal sewerage in the settlements, atmosphere fall-out. As for the scale of the industrial discards the Seversky Donets River basin is distinguished. In its limits either fully or mainly three industrially well developed Ukraine regions are located, these are the Kharkov, the Donetsk and the Lugansk regions. From the Russia side the industrial “knots” of the Stary Oskol, Belgorod in the up-stream of the basin and the industrial part of the Eastern Donbass in the Rostov-on-Don Region contribute significantly into summary contamination.

The Don River delta is the closing valve for the Seversky Donets basin and for the industrial and domestic sewerage of agglomeration, including the Rostov-on-Don, Novocherkassk and Azov. Directly on the Taganrog bay coast industrial enterprises and municipal sewerage from Taganrog and Mariupol and sea transport serve the sources of contamination. Navigation activity in the Taganrog bay increased sharply since the start of the 1990-ies, when the major external cargo flows from the Russia south were concentrated there.

Thus, from the estimation and forecast of the marine ecosystem state and in perspective for the management of the ecosystem processes in the Sea of Azov basin there is required the system analysis of factors determining both: water quality and biological productivity in the sea and fluvial parts of the basin. The most important object for such analysis to our opinion must be aquatic system including down stream of the Don River with the Tsymlyansk water reservoir and water basins of the West Manych, the Don River delta and the Taganrog bay of the Sea of Azov, Fig. 1.

3 Aquatic system Lower Don – Taganrog bay

To reveal this aquatic system as the unique objects for investigations there exist the following grounds available: 1) close connection between hydrological conditions and bioproductivity and fluvial run-off and input of organic matters; 2) the greatest in the basin limits concentration of the anthropogenic loadings; 3) cumulative impact of both: local and external sources of contamination on the sea environment; 4) actuality of the water quality problem for the municipal agglomeration and for the marine and fresh-water fishery.

It should be stated that analogous approaches are being developed for other systems uniting sea, fluvial and lacustrine water basins. The example might serve ecological investigations of the system: the Ladoga Lake – Neva – Gulf of Finland [16]. For this aquatic system the water quality control in the basin with natural hydrological regime and a high level of the anthropogenic contamination is the priority task. In our paper the task is much wider: estimation of the possibilities of fluvial run-off management and optimization of the fishery ecosystem in both: estuary and delta of the Don River.

The aquatic system under discussion consists of the sea, delta, fluvial and lacustrine parts (the Tsymlyansk water reservoir is referred to the number of the latter). Sea area coincides with the Taganrog bay in its physical-geographical boundaries. The bay area is about 8% of the Sea of Azov area, volume is about 5%. Processes of mixing of sea and fluvial waters, formation of geochemical barriers, transformation of pollutants occur here the most intensively. Thus more than half of the technogenous material entering the Sea of Azov from all the sources is buried in the bottom sediments of the Taganrog bay [3].

Beyond the limits of gradient zone in the bay in the off-sea area homogenous field salinity close to the average long-term values are observed. Salinity regime in the off-sea area is regulated by the joint action of the fluvial run-off, water-exchange with the Black Sea and the Sivash bay and with the balance of fall-out and evaporation. In current conditions only the first of these factors is to a determined degree a manageable which confirms significance of the Lower Don aquatic system for the support of the ecosystem stability in the Sea of Azov.

The Don River delta located compactly at the area of about 300 km^2 represents a unique natural complex, enduring impact of the fluvial run-off natural variability, entering of large amounts of suspended and dissolved matter of natural origin, and from numerous sources of anthropogenic contamination. In the major watercourse of the Don River the regime of sea channel with constant depths is supported, run-off of other branches is not regulated. In the delta boundaries approximately 70 species of waterfowl and near water birds inhabit and reproduce. Some valuable fish species spawn there.

The Tsymlyansk water reservoir is the major factor of artificial regulation of the Don River run-off for more than half a century; this caused to the significant ecosystem consequences. Filling of water reservoir after the finish of integrated hydro-scheme construction in the year 1951 led to the significant lowering of run-off, which was observed till the middle of the 1970s at the preservation of a high inter-annual variability, Fig. 2a. At that as it is clearly shown on Fig. 2b-2d, a leveling of run-off in the seasonal aspect occurred. Maximal shortening of run-off is registered in the vernal period. Average values of summer run-off changed little, but its inter-annual variability declined noticeably. Autumnal and winter run-off increased in relative expression but by absolute values this addition has not compensated lowering of the flood maximums.

In the current conditions the Tsymlyansk water reservoir acquired the features of a natural lacustrine water basin with a stable hydrological and hydrochemical regime. It plays the role of a settler for the suspended matter and accumulates partially pollutants entering from the upper part of the basin. Construction of the Tsymlyansk dam broke the conditions for restoration of valuable fish species [10, 12].

One of the most important factors affecting the ecosystem processes in the Sea of Azov basin is a group of lakes and rivers with brackish waters; the general name for all of them is West Manych. It belongs to the Kumo-Manych trough

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geosystem, along which a strait connecting the Caspian Sea and Sea of Azov passed during Quaternary period. During subsequent period and up to nowadays there preserved a chain of water reservoirs with unstable hydrological regime and alteration of the drained and drainless state.

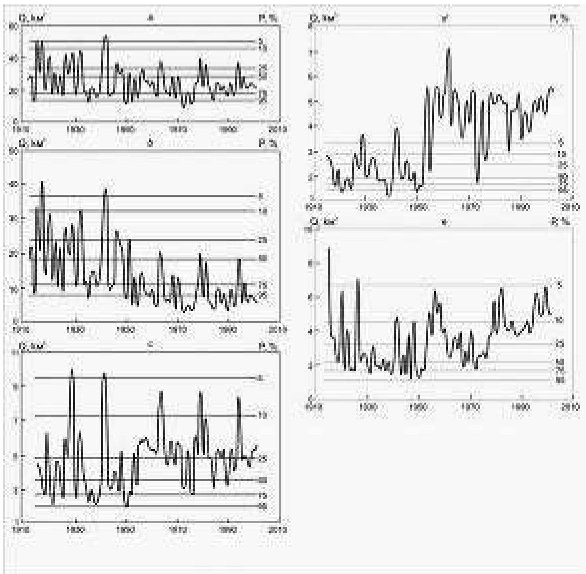

Figure 2: Long- term changes of the Don River run-off: annual (a), vernal (b), summer (c), autumnal (d), winter (e) [6].

Vegetation cover in the western part of the trough is represented by sheep's fescue- European feather –grass steppes, in the eastern – by communities of the dry desert steppe. Water reservoirs in the region serve the inhabitancy places and migration areas for a rich avifauna and promote to the high abundance and biological diversity of mammals [13]. The Veselovskoe water reservoir and the Manych Gudilo Lake are included into the national list of aquatic- moors lands protected by the Ramsar Convention.

Due to the weak smoothness of relief and natural variability of humidification this water basin endured significant fluctuations of both: level and amount of water even in the natural regime. Thus, during the years when large water amounts were observed its depth reached 3 m, whereas in the years with small amounts of water (1881, 1911) it dried completely.

In 1930s construction of the Manych shipping-irrigation route offering connection of the Caspian and the Sea of Azov began. The Manych Gudilo Lake became a constituent part of the Proletarskoe water reservoir. A high level of natural mineralization of the lake promoted to the increase of salinity in the water reservoir, which affected negatively the possibility to use it for the water supply and irrigation.

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In the 1940s the Nevinnomyssk Channel along which the water from the Kuban River enters the Egorlyk River and subsequently into the Proletarskoe and the Veselovskoe water reservoirs in the amounts up to 75 m^3/sec was put into operation. Since that time a uniform system of the drained Manych water reservoirs with the run-off into the Don River was formed. The transfer to the manageable water regime prompted to the re-freshening of the Manych Gudilo Lake and improvement of the aquatic and terrestrial ecosystems state. The drying of water basin ceased, but significant fluctuations of water level and water-salinity balance preserved. They were caused by the dam construction within the Proletarskoe reservoir and additional water supply from the Tsymlyansk reservoir. In general, the lowering of salinity was favorable to the spawning of valuable fish species. The lake has acquired important fishery significance as 600-1000 t fish were caught there annually.

By the beginning of the 1990s new changes took place in the water salinity balance of the Manych Lakes. They were caused by the lowering of the regular supply of the Kuban River water into the western part of the Proletarskoe water basin due to its significant usage for the irrigation in the Stavropol and Krasnodar regions. Fish fauna diversity started to decrease. Reeds disappeared almost completely; other ecosystem components of the water reservoir were subjected to the significant changes.

According to the latest data obtained during the summer expeditions carried out by the Azov Branch of MMBI and Southern Scientific Center RAS in 2004 average level of salts contents was in July 36.1 g/l, in August – 42.6 g/l [14]. The lake became unsuitable for feeding and spawning of almost all valuable fish species, having lost its significance as a fishery water reservoir.

4 State of chemical and radioactive contamination

Sources of chemical contamination in the system Lower Don-Taganrog bay are discharges from the water collecting basins, industrial and domestic sewerage from the coastal towns and cities, sea transport. Atmospheric fall-out affects the ecological situation indirectly through the fluvial run-off. The most complete long- term data are available on the amounts of pollutants removal by rivers and pollutants concentrations in the mouth area of the Don River [7]. Indices of both these groups during last 20 years showed the tendency for lowering. Thus, average oil products discards into the Don River upper of the Rostov-on-Don for the period 1996-2000 became 3 times as lower in comparison to the period 1981-1985, that of heavy metals – by 3-4 times, HCHG and DDT – by 5-6 times. For the Mius River analogous index gives lowering on oil products by 8 times, by heavy metals – stable low level (5-10% from the discharges of the Don River), by HCHG and DDT – practically lack of discharges during modern period.

For the Lower Don a systematic lowering of pollutants concentrations especially sharp for heavy metals and chlorine-organic pesticides and less pronounced for oil products is established. Nevertheless water quality as far as the degree of TAC norms breakage is concerned remains low on both: separate chemical agents and total sum of toxic compounds taking into consideration their

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danger for the fishery basins [15]. A high degree of waters eutrophication is observed.

State of the radiation environmental contamination seems more favorable. As it was shown earlier [8], input of radio-nuclides into the Sea of Azov ecosystem was connected with mainly consequences of the Chernobyl accident in spring 1986 in the form of atmospheric fall-out, subsequently – as the result of migrations in the fluvial basins. Hydrological and hydrochemical conditions in the closed Sea of Azov promoted to the accumulation of radio-nuclides in water, bottom sediments and biota. In 1986 maximal concentrations of ^{137}Cs and ^{90}Sr isotopes reached 100 Bq/m^3 and more, which exceeds by one order the levels typical for instance for the Barents Sea. In conditions of the isolated marine ecosystem it created danger of nuclides accumulation in the living organisms of sea products. Subsequently, due to the processes of natural decay and bury of nuclides in bottom sediments the contents of the pointed out isotopes in the Sea of Azov waters lowered according to the exponent law with the period of concentration lowering by 2 times which is 2.6 years for cesium and 6.7 years for strontium [11].

5 Tasks of management of sea water quality and bioproductivity

As it follows from the carried out above preliminary analysis, ecological processes in the Sea of Azov basin are closely interconnected. The greatest levels of the natural and anthropogenic impacts on the marine ecosystem are registered in the Taganrog bay and in the low part of the Don River regulated by the Tsymlyansk water reservoir and water basins of the Manych cascade.

System of arrangements for the optimization of natural environment in the region should include:

- development of the regional technology of ecological monitoring, based on the complex assimilation of the data from the observation systems and application of the numerical modeling;
- recommendations on the fluvial run- off regulation considering its multipurpose usage;
- estimation of trans- boundary flows of pollutants and development of mechanisms for their regulation;
- management of the hydrological regimes in the lakes and water reservoirs of the Manych cascade, restoration of the freshwater flora and fauna.

Let us dwell on these tasks in more details. The system of ecological monitoring in the Sea of Azov basin was formed already in the Soviet period. Means for observations including those for the sea expedition works are upon the whole sufficient for the sea environment and biota current state assessment. But now on the Sea of Azov basin a specific problem appeared. The estimation of the trans-boundary pollutants transfers in all the environments: atmosphere, terrestrial waters and sea waters is needed. The balance of these transfers in this region is not favorable for Russia. Major contribution into the contamination of atmosphere, surface and subterranean waters of the land is made by the industry

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of Donbass (Ukraine). In the fluvial basins the most contaminated water catchment areas are located on the Ukraine area, whereas the mouth areas- in Russia. The situation with the sea trans-boundary transfers is less definite as large sources of coastal contamination exist in both the countries and contamination balance in different sea areas is impacted by the complicated complex of dynamic and biochemical processes. Such estimations must be one of the directions to apply numerical models of marine environment [3, 4].

Management of the fluvial run-off is one of the most important aspects to preserve bioproductivity of the sea and stability of ecosystems. Fluvial run- off affect the salinity indices and as a consequence Sea of Azov productivity is well studied. The fullest developments in this direction are fulfilled by Gargopa [5, 6]. He obtained the estimations of the ecologically allowable and maximally allowable excavations from the run-off of the Sea of Azov Basin Rivers, first of all the Don River. It is shown that for the support of the sea ecosystem stability it is important to support the annual run-off of the Don River at the level of 24.5-26.5 km^3 and seasonal vernal – 14.6-15.6 km^3.

The major contribution into the formation of the Don River run-off is made by the Tsymlyanskoe water reservoir of the long- term regulation and the only large tributary entering lower than the Tsymlyansk dam – the Seversky Donets, which run-off is also regulated by the water reservoirs. Management of the water regime in this region demands agreements of interests of many water users. The Tsymlyansk water reservoir represents the largest freshwater basin on the south of Russia, where its own ecosystem has been formed and, consequently, there exist local criteria to support its stability. All these requirements are necessary to take into consideration when the decisions are being taken on the run-off regulation and on the development of the forecasts of the nature state in the conditions of climatic vagueness.

Water basins of the Manych cascade contribute greatly to the mineralization of the fluvial and sea waters, balance of organic matter, inter- basin regulation of the fluvial run-off. As long-term experience showed, their artificial re-freshening promotes upon the whole to the optimization of aquatic and terrestrial ecosystems. Breakage of ecological stability in this part of the basin is connected with the irrational usage of aquatic and terrestrial resources. Up to the latest period there was no ecosystem monitoring here. Economic situation in the region has not promoted to the development of the nature protection arrangements. As the nearest practical steps it is recommended to cease non- regulated discharge of the drainage waters from the irrigation systems and to transfer to the progressive drops irrigation system [14].

6 Conclusion

The integrated approach to the marine-riverine water systems is necessary and prospective in many aspects. However, it is practically not developed for the environmental assessment and management of the Azov Sea basin.

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Analysis carried out gives ground to come to the following conclusions:

1. The Lower Don and the Taganrog bay aquatic system provide vital activity of the densely populated and economically developed Russia regions. It supports a high resources potential and ecosystem stability.
2. Management of natural processes in this system must be based on the data of national and trans-boundary monitoring, application of statistic and balance models of water dynamics, geochemical and biological processes.
3. Complex of nature protection arrangements must include priority actions, pointed out above, and long-term projects on optimization of water balance and lowering of anthropogenic loadings. Development of such projects demands complex ecological-economic analysis and must become a part of strategy of social-economic development of the Russia Southern Federal Area.

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