 https://doi.org/10.1051/e3sconf/202017512010

Water regime formation of river basins in the delta zone on the example of the Azov region

Stanislav Vladimirov[1], *Igor* Prikhodko[1,*], *Tatyana* Safronova[1] and *Elena* Chebanova[1]

[1]Kuban State Agrarian University named after I. T. Trubilin, 13, Kalinina str., 350044, Krasnodar, Russia

Abstract. Ignoring the specific soil and climatic conditions of the Lower Kuban against the background of irrevocable water use and constant increase in production intensification using new, little-studied pesticides and herbicides without studying the mechanism of its environmental impact, has led to serious environmental and economic problems. In this regard, there was needed to study and analyze environmental problems, establish mechanism for its origin and develop a concept and recommendations for overcoming the environmental crisis in which the Lower Kuban, including Azov and Black Seas ecosystems. The article has processed perennial data and our own research results into dynamics of the qualitative and quantitative indicators of the Lower Kuban delta zone basin for more than 70 years. The results of the ionic composition research of estuary water and collector-drainage water were obtained and analyzed. The causal relationships of catastrophic changes in the water ecosystem of the river delta are established and specific recommendations are developed to improve the ecological environment in line with modern standards. The estuaries ichthyofauna composition is analyzed and the reasons for the reduction in fish productivity are identified, ways to solve this are proposed.

1 Introduction

Change in the water regime of the river Kuban basin, which formed in a historically short period of time and stabilized at the turn of the 90s of the last century [1, 2, 3], significantly affected the hydrological regime of delta estuaries as final link in the basin hydrographic network (table 1).

Table 1. The influx of river water into the Kuban delta estuaries at different periods.

Estuary system	Years		
	During the natural water regime of river water inflow. mln. m^3 per year	Reduction in inflows. mln. m^3 per year	Inflow reduction. %
1	2	3	4
Akhtarsko-Grivensky	800	578	27.75

[*]Corresponding author: prihodkoigor2012@yandex.ru

Central	1000	612	38.80
Akhtanizovskaya	3500	284	91.89
Total	5300	1474	72.19

During the natural water regime, the river water influx into the estuaries averaged 5,3 km^3 per year. As can be seen from the data in table 1, the river water influx into the estuaries decreased from 27,75% to 91,89%. The most significant reduction in river flow occurred in the Akhtanizovskaya estuary system [4, 5].

At the same time, the return water discharge from rice systems to the Kuban estuaries increased. Return water flows to Akhtarsko-Grivensky estuaries through the Dzherelievsky main collector, to the Central, mainly through the southern and northern trunk discharges.

In years of average water content, the return water flow to delta estuaries is 1,63 km^3 per year, at average water content (75% set up) – 1,19 km^3 per year, which exceeds the river water inflow volume for years with the corresponding water content. At the same time, the main part (more than 70% of the annual volume) of return waters with a high content of biogenic elements arrives in May-August, causing eutrophication and intensive macrophyte overgrowing of estuary shallow areas [6, 7].

In the first half of the year, when the influx of river water is especially necessary for reproduction of *Sander*, *Rutilus heckelii*, *Abramis brama*, its total volume in estuaries is only 0,67 km^3, which is 2.5 times lower than environmentally necessary [8].

Realization of the tasks set by the state is a catalyst for intensification of agribusiness entire, which often leads to serious anthropogenic impacts, the results of which do not always have a beneficial effect, which, in particular, include the negative dynamics of the main hydrological characteristics, which affect the decrease in the population in the estuaries of semi-passage fish of the Sea of Azov, such as *Sander*, *Rutilus heckelii*, *Abramis brama* [9, 10].

Against the background of the above-described negative processes, we found that there is a steady tendency of decreasing fresh water flow along with decreasing fresh water by an average of 43-51% from January to April (Figure 1).

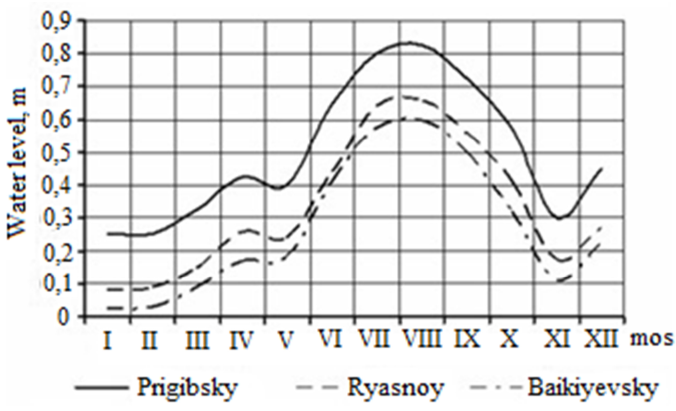

Fig. 1. Water level monitoring data in Akhtarsko-Grivensky estuaries.

The dynamics of decreasing water level in the estuaries, observed in the most unfavorable period for spawning and development of alevins and caviar, leads to an increase in temperature, resulting in overgrowing of estuaries.

As it is known, for good adaptation to marine conditions of juvenile fish rolling down from estuaries, fresh runoff attracting it and extensive desalinated zones are required. However, on the basis of the research and processing of monitoring data on river waters influx, the disappointing conclusion can be made, that there is a rapid decrease in fresh runoff, as a result of which the much-needed areas of desalinated zones at the seaside are reduced and, as a result, a catastrophic (up to 10 times) decrease in entry into estuaries from the sea fish producers to spawn [11, 12].

2 Purpose and objectives of research

The problem solution of water regime formation of river basins in the delta zone is a priority and has long gone beyond the national framework. Based on the research results, ways to solve the problem will be formed on the example of the Kuban basin rivers. The purpose is:

1. To reduce water consumption by developing water-saving technologies.
2. To reduce damage from negative impact of water on residential and agricultural territories of Russian Federation constituent entities at least two to three times.
3. To raise the quality indicators in the lower flows to the natural or ecologically acceptable state for the separately considered natural and ecological zones.
4. To minimize low water consumption in accordance with current environmental standards.
5. To improve the monitoring quality of water objects by increasing the hydrometeorological network density to existing standards.
6. Phased solution of problems through the implementation of controlled measures to achieve the required quantitative indicators of river basins.

To achieve the goals in the field of environmental safety, environmental management, environmental protection and, as well as to obtain mechanisms for its implementation that are available for use, it is necessary to solve the following tasks, which are included in the priority areas of state authorities' activity:

1. To reduce environmental pollution by herbicides, pesticides and other agrochemicals by improving the crops cultivation technology and access to ecologically adaptive integrated farming.
2. To reduce environmental pollution by reducing production waste due to the transition to non-waste production.
3. To reduce the volume and concentration of harmful substances from urban and industrial wastewater due to the full-scale reconstruction of existing and construction of new facilities for the treatment of all types of wastewater, intensification of anhydrous and low-water technologies implementation.
4. To reduce the number of emergencies by observing the requirements of technical, technological and environmental safety at potentially hazardous facilities in accordance with regional target programs aimed at reducing damage from the negative effects of water.

3 Materials and methods

In connection with the changes in watering conditions and progressive overgrowing observed in recent years, there has been a reduction in the area of the open water surface of estuaries [13]. Studies conducted in the Kuban River Delta showed that the total coverage of estuaries with macrophytes reaches 75-95%, and the productivity of thickets 30-60 t/ha. As a result of this, the total area of the open water mirror has now decreased by 25% from its long-term average of 644 km².

Rate dynamics of decrease in the area of open water surface is shown in the figure 2.

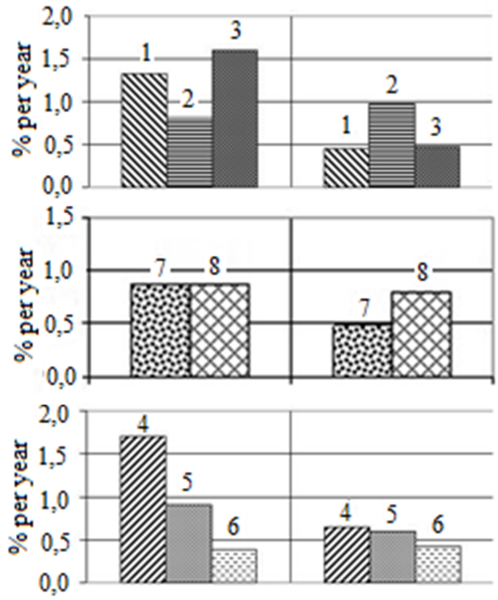

Fig. 2. Dynamics of decreasing Kuban estuaries open water surface area during the natural water regime of the river waters influx (left), now (right). Where: 1 – Central Akhtarsko-Grivensky estuaries; 2 – Western Akhtarsko-Grivensky estuaries; 3 – East Akhtarsk fish farm; 4 – Gorky estuaries; 5 – Hester estuaries; 6 – Sladkovsky estuaries; 7 – Kulikovo-Kurchansky estuaries; 8 – Akhtanizovsky estuary.

The estuaries area, which receives waste water from rice systems, was reduced to the greatest extent. So, the area of Voyskovoy estuary, which get waters of the Northern Trunk Dump, has decreased by 2 times over the past 23 years (table 2). The area of river-fed estuaries, as well as coastal reservoirs with intensive exchange with the sea, decreased significantly less [14].

Table 2. Changes in the area of the open water surface of individual estuaries.

Estuary	Area. km^2		Decrease in area. %
	During the natural water regime of river water inflow	Currently	
Return water receivers			
Voyskovoy	21.3	10.6	50
Mixed-fed estuaries			
Balyaniyevsky	4.0	3.2	20
Zamaraykov	7.3	6.1	20
Karpievsky	72.3	63.1	13
River-fed estuaries			
Dolgiy	17.6	15.7	11
Glubokiy	8.9	7.5	16
Estuaries with intensive water exchange with the sea			
Kurgansky	62.9	53.6	15
Akhtanizovsky	94.0	93.0	1

Since more than 70% of the annual volume of return water flows into estuaries through summer, maximum water levels are observed during growing season (Figure 1). The increase in this flooded area with intensive coastal vegetation (reed, cattail) notably (more than 0,3 km^3 per year) increased water losses due to evaporation and transpiration in the delta.

During the natural water regime, the mineralization of Kuban river (in the alignment of Krasnodar) averaged 239 mg/l [16] and till now it has increased to 530 mg/l.

As the studies showed, due to an increase in alkali metal ions by almost 7 times and the concentration of chlorides by 5.8 times, and sulfates by 2.6 times, there was an increase in the mineralization of river water (table 3).

Table 3. Mineralization and ionic composition of water Kuban river in different periods.

Years	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Mineralization
During the natural water regime of river water inflow							
mg/l	139.0	60.0	12.0	48.0	10.0	16.0	285
% eq.	29.0	16.2	4.4	30.8	10.6	8.6	–
Currently							
mg/l	148.0	155.0	69.0	56.0	17.0	85.0	530
% eq.	16.0	21.3	12.7	18.5	9.0	22.5	–

Further studies showed that due to sedimentation of suspended solids and consumption of phosphates in the Krasnodar reservoir, the content of mineral phosphorus in river water significantly decreased. If in natural conditions its content was 500 mg/m^3, with the predominance of weighted, then at present it does not exceed 100 mg/m^3. Ammonium nitrogen intake in estuaries has increased from 100 tons in natural conditions to 200 tons at present. The annual influx of mineral phosphorus into the Kuban estuaries decreased from 16.1 (the river water influx was 1,61 km^3) to 7,4 tons per year (average annual inflow to estuaries – 1,17 mg/m^3).

The ionic composition of river water is significantly transformed when passing through rice irrigation systems. Return water is characterized by increased salinity and high content of sulfate and chloride ions (table 4).

Table 4. Ionic composition and mineralization of collector-drainage waters of the Southern Trunk Dump on average over the past five years, mg/l.

HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Mineralization
$\frac{153-292}{201}$	$\frac{46-320}{106}$	$\frac{140-369}{232}$	$\frac{70-131}{88}$	$\frac{14-43}{30}$	$\frac{17-281}{110}$	$\frac{510-1149}{766}$

Note: in numerator –minimum and maximum values, in denominator – average for growing season.

Within the Kuban delta, waste water mineralization (from April to September) for various reservoirs varies on average from 0.7 to 1.8 g/l.

Wastewater from rice systems is characterized by lower concentrations of oxygen dissolved in water (usually not more than 70% saturation), low pH values (7.6-7.8), and high content of organic suspension. About 70 thousand tons of suspended, mainly organic substances are supplied to Kuban estuaries annually.

The impact of wastewater from rice fields on the estuary ecosystem is especially evident of Kulikovo group. The consequences of this effect are revealed by comparing the chemical composition of the Kulikovsky estuaries water (waste water receivers) and the Zhestersky, which only receive river water. Table 5 presents data on the ionic composition and mineralization of compared estuaries systems water.

Table 5. Ionic composition of the water of Kulikovo and Zhestersky estuaries, % eq. average over the last five years.

HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	$Na^+ + K^+$	Mineralization, %
Kulikovo estuaries						
7	18	25	11	13	26	1.43
Zhestersky estuaries						
14	13	23	14	14	22	0.65

Analysis (table 5) shows that the proportion of sulfate and chloride ions, as well as sodium and kalium ions is increased in the estuaries that feed on waste water, the proportion of hydrocarbonate ions and calcium is reduced, and the overall mineralization of water has increased [158].

The necessary ecological condition for the conservation of juvenile fish reproduced in the Kuban estuaries and sliding into the sea from the Kuban river, are desalinated zones at the main branches of the river and estuary vents. It has a great adaptive importance in the transition of juvenile fish to marine habitats and play the role of “desalinated bridge” for its migration to the Taganrog Bay.

The data were obtained that the Petrushin branches, the area of desalinated water 64 km^2 and Protoka – 94 km^2 and salinity no less than 9% for the period of natural water regime of river water inflow, as a result of Kuban runoff transfer along the Nevinnomyssky Canal, after 20 years, the area of desalinated zones in June at Petrushin’s branch was about 37 km^2, and Protoka – 52 km^2 [158].

Currently, due to an increase in volume of runoff transport in Stavropol and growth of irrevocable seizures in Krasnodar region, as well as river Kuban mineralization increase, led to even greater reduction of desalinated zones (table 6).

Table 6. Change in the area of desalinated zones off the Kuban coast in June – September, km^2.

Period	Kuban	Channel	Jasen Bay	Estuary delta arms	Total
Natural	64	94	135(180)*	20	313(358)
Currently	18	14	56(101)	7	95(140)

(*) – in brackets including Akhtarsky estuary area.

Through following years, along with the continued reduction of desalinated zones near the main branches of Kuban, a relatively stable zone was formed in the Yasensky Bay, due to its shallow water and increased inflow of waste water from rice systems to the Akhtarsko-Grivensky estuaries.

4 Results

Processing of long-term monitoring data showed that the quantitative and qualitative transformation of river inflow, discharge of return water and the associated changes in the hydrological and hydrochemical regime of estuaries and its intensive overgrowing led to catastrophic changes in the river delta water ecosystem.

According to the obtained data, the annual productivity of higher aquatic vegetation thickets in estuaries on an area of 43.7 thousand ha is 1.68 million tons, including an excess of 0.87 million tons.

It has been established that as the detoxicants of pesticides and mineralizers of oil products by absorption of macrophytes, it accumulates radionuclide ions and heavy metals by absorbing it from water and soils, organic substances and biogenic elements.

Estimated calculations showed that during only one growing season, higher aquatic vegetation in Kuban estuaries assimilates about 4995 tons of nitrogen, 390 tons of phosphorus and 2666 tons of kalium (table 7).

It can be argued that uncontrolled vegetation growth without appropriate measures for its timely cleaning leads to serious environmental problems, the main one is the secondary "biological" pollution of estuaries, which is the final result of the "enleaching" of absorbed organic and mineral substances as a result of tissue destruction.

Table 7. Average biogenic elements absorption by macrophytes in Kuban estuaries for 1 year.

Estuary system	Area, ha	Specific indicators, kg/ha				Total, t			
		thickets production (dry matter)	N	P	K	thickets production (dry matter)	N	P	K
1	2	3	4	5	6	7	8	9	10
Kulikovo	4750	6680	119	3	28	31730	565	14	133
Yeisk fish farm	5400	6840	150	21	141	36936	810	113	761
Chelbass	6300	3110	59	3	21	19593	372	19	132
Akhtarsko-Grivensky	20247	5680	112	8	52	115003	2268	162	1053
Akhtarsky fish farm	6600	4570	85	5	29	30162	561	33	191
Gorky	2800	1830	41	3	29	5124	115	8	81
Kestersky	6800	788	20	2	24	5358	136	14	163
Chernerkovsky-Sladkovsky	5430	550	12	1	13	2987	65	5	71
Kurchansky	6400	310	9	2	7	1984	58	13	45
Akhtanizovsky	8970	180	5	1	4	1615	45	9	36
TOTAL	73697					250492	4995	390	2666

In conditions of such significant environmental transformations, role of Kuban estuaries in valuable fish reproduction of Azov Sea has significantly decreased. So, under the conditions of the natural water regime, the fish productivity of Kulikovo estuaries was estimated at 1,91 dt/ha, including *Sander* and *Rutilus heckelii* – 1,5 dt/ha (in industrial return). Industrial productivity declined for semi-migratory fish to 0,28 dt/ha, and commercial fish productivity up to 0,25 dt/ha (table 8).

Table 8. Dynamics of fish productivity in Kulikovo estuaries.

Fish species	Years			
	During the natural water regime of river water inflow		Currently	
	c	%	dt	%
1	2	3	4	5
Rutilus heckelii	480	14.6	2.1	1.6
Sander	497	15.1	28	2.1
Abramis brama	208	6.3	83	6.3
Cyprinus carpio	270	8.2	290	22.0
1	2	3	4	5
Silurus glanis	35	1.1	8	0.6
Esox lucius	184	5.6	36	2.7
Carassius	108	3.1	133	10.1
Cyprinus	–	–	186	14.1
Hypophthalmichthys	–	–	74	5.6
Other	1449	44.1	455	34.5

Total	3287	100.0	131 9	100. 0
Fish productivity. dt/ha	0.41		0.26	

Processing of the obtained results showed that composition of estuaries ichthyofauna also underwent significant changes. So, juvenile of *Rutilus heckelii* and *Sander* composes 3-12%, of which up to 10% do not slide into the sea.

23% of the total fishes – *Gasterosteus aculeatus* and *Perca fluviatilis*. The presence of an insignificant amount of other fish species was estimated: *Culter alburnus*, *Blicca bjoerkna*, *Scardinius erythrophthalmus*, *Carassius*.

The biodiversity ща estuary collectors contains an overwhelming majority of coarse and low-value fish, the percentage of which reaches 64.3% in Kulikovo estuaries.

5 Conclusion

According to the study results, it becomes obvious that the priority measures to improve the ecological situation in the river basins delta zones are normalized, justified removal of plant phytomass and optimization of anthropogenic eutrophication of water objects by developing environmental-adaptive solutions based on an integrated approach to taking into account all quantitative and qualitative indicators and its relationships for single, specific ecosystem. Intensive overgrowth of estuaries by macrophytes negatively affected the productivity of phytoplankton. Comparing the currently obtained data with the data for the period of the river water inflows natural regime, it was found that the biomass decreased from 1.77 to 0.61 g/m^3, as a result, phytoplankton diversity decreased from 113 to 69.

In the composition of estuary phytoplankton, the value of pyrophytic algae, characteristic for highly eutrophic reservoirs, increased. By the presence of indicator organisms, estuaries are mainly related to mesosaprobic water objects. At the same time, organisms belonging to the polysaprobic, the most polluted type, appeared.

In the composition of estuary zooplankton, indicators of eutrophied reservoirs and overgrown biocenoses gained mass development.

The structure of biocenoses has significantly changed. In estuaries – waste water receivers the number of valuable feed item for juvenile *Sander* sharply decreased (6-7 times).

Decrease in zooplankton biomass in the estuary-receivers is observed, on average, by a factor of 2–3 per season than during the period of the natural water regime of river waters inflow.

The accumulation of organic matter in bottom sediments determined the mass development of benthos in estuaries (biomass – 10-12 g/m^2).

It has been established that due to the uncontrolled accumulation of phytomass in estuaries, benthic organisms make the nutrition of fish almost inaccessible.

It was found that in the bottom layer there is a lack of oxygen, while in the surface layer there is a supersaturation of water with oxygen with average values of 200-250%, which is the result of the almost complete absence of vertical wind mixing of water masses and water stratification.

Further research showed that the mass of vegetation accumulated in water objects (more than 1.5 million tons per year) worsens the main indicators of the gas regime, in particular methane concentration (CH_4), free carbon dioxide ($C0_2$), oxygen (0_2) and hydrogen sulfide (H_2S). So the measurements showed that since May the concentration of 0_2 composes 30-40% from values regulated by environmental requirements.

It has been established that the signs of eutrophication are especially manifested in waste water estuaries, due to the expansion of oxygen deficiency and hydrogen sulfide infection zones, the accumulation of organic matter and the slowing down of water self-purification.

It was determined that the eutrophication of most Kuban estuaries proceeds according to the macrophytic type. The biomass of submerged vegetation on average over the past three years has reached the following values: Akhtarsko-Grivensky estuaries – 20-50; Chernerkovsky-Sladkovsky – 15; Kulikovsky – 70-90 t/ha.

References

1. P. Jacek Gierszewski, M. Habel, J. Szmańda, M. Luc, Science of The Total Environment **710**, 136202 (2020)
2. F. Gallart, N. Cid, J. Latron, P. Llorens, N. Bonada and others, Science of The Total Environment **607-608**, 519-540 (2017)
3. N. Yaraghi, A.-kaisa Ronkanen, H. Darabi, B. Kløve, A. Torabi Haghighi, Science of The Total Environment **675**, 429-438 (2019)
4. R. Kumar Raman, M. Naskar, S.K. Sahu, G. Chandra, B.K. Das, Regional Studies in Marine Science **34**, 101035 (2020)
5. M. Marquès, R. Fatima Bangash, V. Kumar, R. Sharp, M. Schuhmacher, Journal of Hazardous Materials **263(1)**, 224-232 (2013)
6. E. Kuznetsov, T. Safronova, I. Sokolova, A. Khadzhidi, A. Gumbarov, JEMT **81(17)**, 78-83 (2017)
7. Thi Nguyet Minh Luu, Josette Garnier, Gilles Billen, Didier Orange, Julien Némery, Thi Phuong Quynh Le, Hong Thai Tran, Lan Anh Le, Journal of Asian Earth Sciences **37(3)**, 219-228 (2010)
8. T. Safronova, O. Degtyareva, S. Vladimirov, I. Prikhodko, Research Journal of Pharmaceutical, Biological and Chemical Sciences **9(6)**, 1845-1852 (2018)
9. B. Mukhopadhyay, Journal of Hydrology **412-413**, 114-33 (2012)
10. O. Degtyareva, T. Safronova, I. Rudchenko, I. Prikhodko, IOP Conf. Series: Materials Science and Engineering **698**, 022015 (2019) doi:10.1088/1757-899X/698/2/022015
11. A. Torabi Haghighi, B. Kløve, Limnologica **51**, 118-130 (2015)
12. S. Vladimirov, I. Prikhodko, A. Verbitskiy, Journal of Agriculture and Environment **1(9)**, 15 (2019)
13. R. Logsdon Muenich, I. Chaubey, M. Pyron, Ecological Modelling **340**, 116-125 (2016)
14. C. Chirayut, S. Sangam, B. Mukand, Science of the total environment **708**, 135148 (2020) DOI: 10.1016/j.scitotenv.2019.135148
15. A. Usman, An Kwang-Guk, Ecological indicators **110**, 105813 (2020) DOI: 10.1016/j.ecolind.2019.105813
16. P. Seo-Yeon, S. Chanyang, L. Joo-Heon, K. Jong-Suk, Ecological indicators **109**, 105830 (2020) DOI: 10.1016/j.ecolind.2019.105830
17. B.R. Gillespie, P. Kay, L.E. Brown, Ecohydrology **e2174** (2020) DOI: 10.1002/eco.2174