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ANALYSIS OF WATER QUALITY OF RIVERS AND RESERVOIRS IN CHELYABINSK REGION, SOUTH URAL

*Anastasiya Kostryukova[1], Irina Mashkova[1], Elena Shchelkanova[2], Viktor Trofimenko[3] and Anastasiya Kornilova[1]

[1]Institute of Natural Sciences and Mathematics, South Ural State University, Russia; [2]Institute of Linguistics and International Communications, South Ural State University, Russia; [3]South Ural State Humanitarian Pedagogical University, Chelyabinsk, Russia

*Corresponding Author, Received: 10 June 2019, Revised: 17 Oct. 2019, Accepted: 01 Jan. 2020

ABSTRACT: Overland water resources of the Chelyabinsk region are presented by the basins of the Tobol, Ural, Volga (Kama) rivers. The total number of rivers exceeds 3.5 thousand, many of them are headwaters. This work assesses a ten-year change of water quality in 3 rivers and 3 reservoirs of the Tobol basin that are as well the source of drinking water for the residential area of the Chelyabinsk region. There are many ferrous, non-ferrous, power and machine-building industry facilities in the region. As a result, most of the rivers in South Ural are affected by industrial and household wastewaters. Any significant improvement of the water quality in the studied rivers has not been monitored for 10 years. The water can be characterized as "polluted" - "very polluted". The Miass river has the heaviest anthropogenic impact in the Chelyabinsk region. It used to be "extremely polluted". The given work aims to reveal interrelations between the water quality and the state of the studied water-bodies by means of principal component analysis. Principal component analysis allowed us to distinguish 2-3 periods that are characterized by similar pollution. The environment of rivers under a human-made impact changes adversely and transforms into another ecological state for a couple of years.

Keywords: Rivers, Reservoirs, Pollution, Principal Component Analysis

1. INTRODUCTION

The pollution of natural waters, both sea and fresh, is a crucial issue all over the world [1-3]. Countries have various regulations that are aimed at assessing the environment of water-bodies and designing improvement strategies. The EU Water Framework Directive aims at improving the environment of all underground and overland waters in Europe [4, 5]. The Clean Water Act governs water pollution in the USA [6]. The Water Code of the Russian Federation addresses the issue in Russia [7-9].

Russia, as well as other countries, pays special attention to freshwater rivers and artificial reservoirs. The function of the national observation network in Russia is to control the pollution of overland waters, to monitor their environment and to analyze the overland water quality [10]. All the regions of the country including the Chelyabinsk region (South Ural) monitor the chemical pollution of water-bodies [11]. According to the National report on environmental protection of 2017 [10] the Chelyabinsk region leads in the amount of wastewater discharge (691.3 million / m^3) in the Ural Federal District.

More than 3.6 thousand rivers with a total length of about 18 thousand km run on the territory of the Chelyabinsk region. They belong to the basins of such large rivers of Russia as the Kama, the Tobol, the Ural. Most of the rivers are under an intensive man-made impact [11, 12].

Annual comprehensive reports on the environment in the Chelyabinsk region present information about the chemical pollution of the large rivers and reservoirs of South Ural [11, 12]. It also refers to the rivers of the Tobol basin. Besides, separate studies of their environment and biota are being conducted [13, 14]. But these studies are scattered and do not usually consider one exact water-body and do not provide the long-term dynamics of water pollution.

The aim of the paper is to assess the change of water quality in the rivers of the Tobol basin as a source of drinking water in 2007-2016.

2. METHODOLOGY

2.1 Study Area

Three large rivers of more than 200 km, the Uy, the Uvelka, the Miass (Table 1), many smaller rivers such as the Syntashpy, the Ayat, the Kartaly-Ayat, the Kidysh, the Toguzak, the Sak-Alga, the Atkus, the Sinara, and three reservoirs Troitskoye, Argazinskoye, Shershnevskoye belong to the Tobol basin [15]. The head-rivers of the basin are the mountain rivers (the Uy, the Miass), as they start in the Urals and then flow into the plain. The Tobol basin is 55 thousand km^2 [15].

Table 1 General characteristics of the rivers

River	Total length, m	Maximum depth, m	Basin, km^2
Uy	462	15	34 400
Uvelka	234	4	5 820
Miass	658	7	21 800

The water in the Uy river in its chemical composition belongs to the hydrocarbonate class of the calcium group. Four towns, including Troitsk, are located in the Uy basin, as well as some villages where the river is the main water source. Troitskoye reservoir with a volume of 45.1 million m^3 is built on the river, which flows mainly on farmland being polluted by effluents from cattle farms and fertilizers. The river is heavily affected by human activity within the limits of Troitsk where industrial and sewage facilities discharge effluents [12]. Much of the pollution is then found in Troitskoye reservoir. The reservoir water in its chemical composition belongs to the hydrocarbonate class of the calcium group. Residential sewage comes into the river from all the catchment area [15].

The Uvelka is a left tributary, the largest one. Its water in its chemical composition belongs to the hydrocarbonate class of the calcium group. Like the Uy river, the Uvelka is polluted by farms, villages and industrial facilities of Yuzhnouralsk (a town in the Chelyabinsk region) [15].

The Miass river starts at the eastern slopes of the Urals [10]. It crosses all the forest-steppe zone of the Chelyabinsk region and then joins the Iset river. The water in the Miass river is widely used as a water supply for some cities including Chelyabinsk. Two reservoirs are built on the river: Argazinskoye and Shershnevskoye. Argazinskoye reservoir, the largest one, with a volume of 980 million m^3 [15], is the main source of water for the Chelyabinsk industrial hub. Shershnevskoye reservoir, with a volume of 176 million m^3 [15], is used as a water supply for Chelyabinsk [14]. The river water in its ion composition belongs to the hydrocarbonate class of the calcium group.

Effluents are discharged into the Miass river along its whole length. The river headwaters are the cleanest. Industrial and household effluents of Miass city come into the river and then go into the Argazinskoye reservoir. Along the way from Argazinskoye reservoir to Chelyabinsk sewage from farming and household activities of some villages are put into the Miass River. The river water then goes into the Shershnevskoye reservoir where it is slightly cleaned. But the city industrial facilities and treatment plants of Chelyabinsk also discharge their effluents into the Miass river [15].

2.2 Data of Monitoring Chemical Pollution of the Studied Rivers and Reservoirs

To analyze the dynamic pattern of water quality in the Uy, Uvelka and Miass rivers, Troitskoye. Argazinskoye and Shershnevskoye reservoirs, the data of monitoring chemical pollution of water-bodies in the Chelyabinsk region given in comprehensive reports on the environment of the Chelyabinsk region were taken. The reports are at open access on the site of the Ministry of Ecology in the Chelyabinsk region [11], [12]. The monitoring sections are represented in Fig. 1.

a) b)

Fig.1 Quick map of rivers and reservoirs of the Tobol basin (Chelyabinsk region)

2.3 Specific Combinatorial Water Pollution Index (SCWPI)

The specific combinatorial water pollution index (SCWPI) is used to assess water quality in Russia. RD 52.24.643-2002 [16] gives the methods of calculating the index. It is calculated in 2 stages: first, each separate ingredient and pollution index is measured, and then all the pollutants are considered in complex, and the final assessment is given (Table 2). A maximum permissible concentration (MPC) of a hazardous substance for fishery waters is taken for the standard.

Table 2 Effluent quality classification according to SCWPI [11]

Class	Category	Water pollution characteristics
1	–	conditionally clean
2	–	slightly polluted
3	a	polluted
	b	very polluted
4	a	dirty
	b	dirty
	c	very dirty
	d	very dirty
5	–	extremely dirty

2.4 Survey of Water Life in the Uy, Miass Rivers and Argazinskoye and Shershnevskoye Reservoirs

Natural water-bodies of the Chelyabinsk region are under scrutiny. Their chemical pollution, as well as their flora and fauna (phytoplankton and zooplankton of macrophytes, mollusks, and fish), are studied [17-19]. This is a comprehensive study giving an actual survey of the regional lakes. Unfortunately, the studied rivers and reservoirs, except Argazinskoye and Shershnevskoye, are not thoroughly analyzed and researched with the obtained data being very scattered.

The biota of the Uy river is underexplored. Makarova and Karsakov [20] studied heavy metals content (HMs), in particular, Cu, Fe, Zn, Co, Mn, Ni, Cd, Pb in muscles, gills, fins of catfish and bream. Uneven distribution of HMs in fish is discovered. The content of all the studied HMs, except Fe, did not exceed the standards. Galatova [21, 22] analyzed the accumulation and distribution of Cu, Zn, Fe, Mn, Co, Pb and Cd in organs and tissues of *Percidae*, *Cyprinidae*, *Esocidae* and *Siluridae* fish families. The researcher discovered an uneven distribution of HMs stating that it is mainly due to the interspecies differences. The fact that HMs accumulation with its further distribution is primarily dependent on a fish species is marked by many studies [23, 24]. They show the highest absolute content of HMs in fish bones and gonads and the lowest in muscles and scales. Ali [25], Sunjog [26] also identified a lower HMs content in muscles. Some samples revealed HMs content exceeding sanitary standards for food products [21, 22]. Galatova [27] monitored HMs accumulation and distribution in blue-green alga and pointed to the following regularity: Cd < Cu < Pb < Co <Ni < Zn < Fe < Cr < Mn.

The water life of the Miass River is scarcely explored. The researchers mark its poor species diversity: 16 species of *Cyanophyta* division, 12 species of *Euglenophyta* division [28]. Davydova [29] study HMs accumulation in bream, roach and perch tissue. Most of the metals are accumulated in bones. Unlike other fish species, bream, being a benthic water organism, accumulates a higher HMs content [30, 31]. That is a tendency for carnivorous and omnivorous species [32].

The research of phytoplankton and zooplankton of Argazinskoye reservoir revealed 256 phytoplankton species [33] and 49 zooplankton species [13]. Microalga is mainly represented by the following divisions: *Bacillariophyta*, *Chlorophyta*, *Chrysophyta*, *Cyanophyta*, *Dinophyt*a, with the highest coenotic value of *Bacillariophyt*a. Zooplankton was stated to comprise 32 rotifer species, 7 copepod species, and 10 *Cladocera* species. A rotifer is a leading group in number and biomass. There is a research of HMs accumulation in perch and crucian tissue [34]. In winter perch tissue is marked by a higher concentration of Zn against sanitary standards.

The biota of the Shershnevskoye reservoir is the subject of a more serious study as it is the source of drinking water for Chelyabinsk. The comparison of HMs accumulation in bones and muscles of fish in Argazinskoye and Shershnevskoye reservoirs [35] showed that in fish tissues of the Argazinskoye reservoir, which is under the exposure of copper production, Fe and Zn contents are higher. Retrospective analysis of the phytoplankton community for 50 years [36] showed a decrease in species diversity with the structure of main divisions being preserved. The change of dominant species was noted. The study of the species composition of the macrophyte community [11] revealed 29 species of macrophytes. The state of the reservoir is closer to the eutrophic status [11, 36].

3. RESULTS AND DISCUSSION

3.1 Monitoring the Studied Water-bodies and Rivers Chemical Pollution

According to the Comprehensive reports on the environment in the Chelyabinsk region in 2007, 2008, 2012-2016 [11], average annual maximum permissible concentrations are exceeded for the following substances (Tables 3, 4).

Tables 3 and 4 show that such metals as Cu, Zn, Mn pollute the studied rivers and water-bodies constantly. Higher standard values for COD and petroleum products are registered in all the sampling sites. Phenols, Ni, sulfates, and fluorides are rare, but that kind of pollution can’t be called an isolated discharge, as the standard values for phenols, Ni, sulfates, and fluorides are exceeded throughout the year.

Table 3 Intervals of pollutant concentration (C_i), C_i / MPC_i

Index	Uy river		Uvelka river		Troitskoye reservoir
	s. 1	s. 2	s. 3	s. 4	s. 5
Cu	2.0-4.0	1.6-3.5	1.8-4.2	2.2-4.2	1.9-4.1
Zn	2.9-12.0	2.7-9.6	2.7-3.6	3.0-3.7	2.8-13.7
Mn	11.9-45.6	5.7-9.5	4.0-7.5	12.0-26.2	6.2-13.9
Fe	2.3-4.0	-	-	1.1-1.8	-
PO_4^{3-}	-	1.1-1.5	-	1.1-3.5	-
SO_4^{2-}	1.4-2.4	1.5-2.0	1.2	1.1-6.8	1.3-2.8

Mn, Zn and Cu are registered as the main pollutants in all the sampling sites, except for 11 and 12. Zn and Cu are normalized according to their concentration in food products including fish. But, there are no data on the exceeding content of these elements in fish of the studied rivers and reservoirs [20-22, 29, 35, 36]. However, there is a study [37] showing that the risk of HMs accumulation can be higher even in spite of the HMs content in fish muscles being lower than the permissible concentration. That could be health hazardous.

Figure 2 shows the analysis of Mn content with the help of principal component analysis (PCA) for all monitoring period [38]. Most of the sampling sites are grouped in one locality and characterized by similar pollution. Sites 1, 4, 6 and 8 differ from the rest.

Fig.2 Resulting diagram Mn content of PCA

Exceeding the average annual Mn content over MPC in sampling sites 1 (the Uy river) and 8 (Argazinskoye reservoir) in some years was marked 45.6-47. Mining and ore-processing effluents come into the water of sampling site 1. Sampling site 2 is under the adverse impact of the Miass river tributary that is polluted by copper mining and processing facilities. Sewage, industrial and storm waters of Yuzhnouralsk are discharged into sampling site 4, site 6 is the head of the Miass River.

Figures 3 and 4 show the PCA of Cu and Zn content for all monitoring period. Unlike Mn, the situation with Cu and Zn is slightly different. Sampling site 8 is singled out of the rest with an average annual Zn content 2-5 and Cu 2.5-6 times higher than in the other sampling sites where these metals content in water is almost the same irrespective of the year.

Table 4 Intervals of pollutant concentration (C_i), C_i / MPC_i

Index	Miass river		Argazinskoye reservoir		Shershnevskoye reservoir	Miass river	
	s. 6	s. 7	s. 8	s. 9	s. 10	s. 11	s. 12
Cu	1.7-3.0	2.3-3.7	10.8-24.5	2.0-4.1	1.4-2.8	2.3-3.4	1.7-2.6
Zn	2.8-3.7	2.0-4.3	7.8-19.0	3.2-3.7	2.7-3.8	2.9-4.2	3.1-3.7
Mn	12.9-23.1	8.0-12.8	20.1-47.0	4.3-12.60	3.6-5.9	5.9-11.2	4.4-9.4
Fe	-	1.1-1.3	3.0-5.3	-	1.2	1.2	-
Ni	-	-	-	-	-	1.1-1.2	-
PO_4^{3-}	-	1.7-3.9	1.4-2.1	-	-	3.3-6.7	2.5-5.9
SO_4^{2-}	-	-	-	-	-	-	-
F^-	-	-	-	-	-	1.2	1.3
NO_2^-	-	3.2-6.7	1.2-2.5	-	-	3.8-12.3	2-12
NH_4^+	-	1.8-2.1	1.4	-	-	1.2-5.7	1.8-4.3
COD	2.0-2.4	2.1-2.6	1.5-2.3	1.5-1.9	1.9-2.2	2.1-3.1	2.2-2.9
BOD_5	1.2	1.1-1.7	-	-	1.2	1.8-3.0	1.6-2.5
Oil pipeline	1.2-1.5	1.4-1.9	1.3	1.2-1.3	-	3.9-10.2	2.8-6.8
Phenols	-	-	-	-	-	2	-

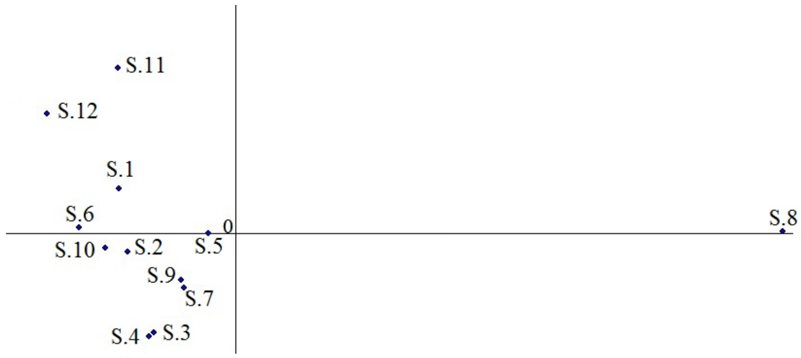

Fig.3 Resulting diagram Cu content of PCA

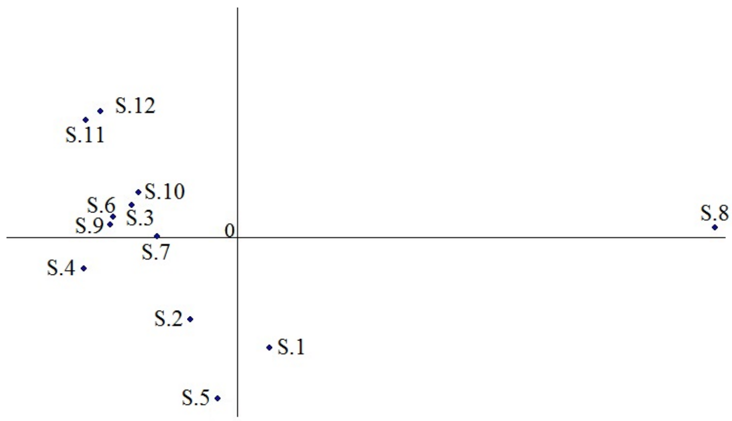

Fig.4 Resulting diagram Zn content of PCA

Sampling sites 11 and 12 can also be marked. They are the furthest down the stream of the Miass River and take effluents from the city sewage systems, ferrous, non-ferrous, power, and machine-building facilities. The list of the main pollutants varies in sites 11 and 12. Mn is still leading with nitrites identified in both sampling sites and petroleum products and phosphates being found in site 11.

3.2 Water Quality Assessment of the Studied Rivers and Water-Bodies

Pollutant content ordination with the help of PCA for the sampling points in the Uy river, Troitskoye reservoir and it's tributary (Fig. 5, a) and the Miass river and its reservoirs (Fig. 5, b) allows distinguishing 2-3 periods that are characterized by similar pollution. Thus, it can be noted that the environment of rivers under a human-made impact changes adversely and transforms into another category for a couple of years.

Figure 6 shows the water pollution class of the studied rivers and reservoirs on the basis of specific combinatorial water pollution index (SCWPI) for 2012-2016. As the figure shows the water can't be called conditionally clean or slightly polluted. As these water-bodies are used as the main source of drinking water, there is a serious problem concerning the water quality and its influence on the population. Water quality is deteriorating downstream the rivers. The worst situation is in Chelyabinsk. Although water quality in most of the sampling points is stated to become better since 2014-2015, the water is still not clean.

The situation is similar in many regions of Russia. Thus, the federal project "Clean Water" is designed in the frameworks of the national project [39]. The aim of the project is to improve drinking water quality by means of modern water supply and treatment systems with the help of innovative technologies. Its realization will provide 95.5 % of the city population with clean quality water.

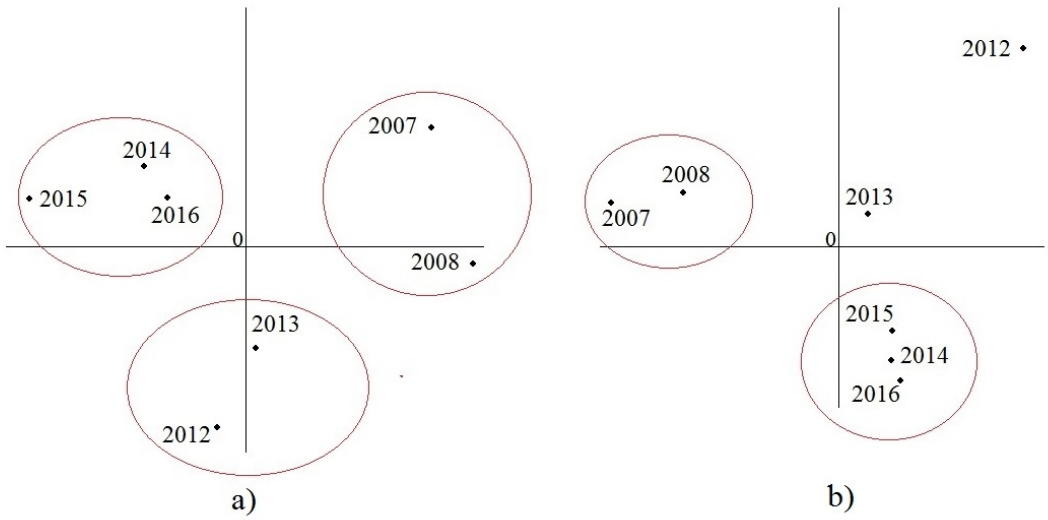

Fig.5 Resulting diagram of PCA ordination of pollutants content in the Uy, Uvelka rivers, Troitskoye reservoir, the Miass river, Argazinskoye, and Shershnevskoye reservoirs

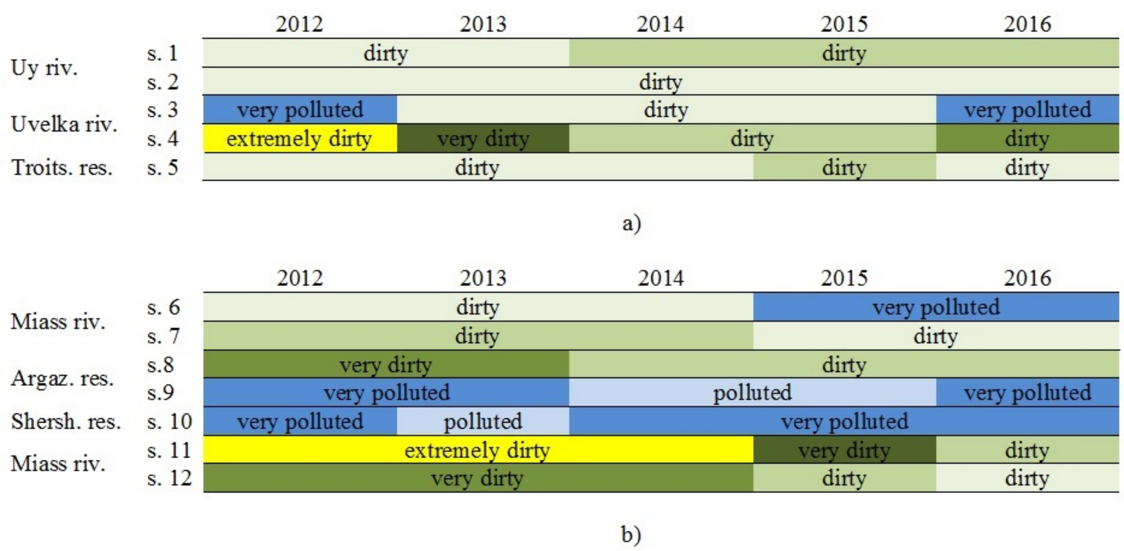

Fig.6 Water pollution class of the studied rivers and reservoirs. Class 3 is blue, 4 - green, 5 - yellow. Colour density shows the category deterioration

4. CONCLUSION

An adverse environment of drinking water sources is one of the crucial issues of the Chelyabinsk region. Rivers and reservoirs of the Tobol basin have been continuously polluted by the city sewage treatment facilities, industrial plants, agribusinesses, and spate flow. Higher concentrations of Cu, Zn, Mn, Fe, Ni, phosphates, sulfates, nitrites, ammonium ions, fluorides, COD, BOD5, petroleum products, and phenols were registered during the monitoring process. Cu, Zn, Mn, COD, and petroleum products are chronically exceeding the standard values. Unfortunately, the water of the studied water-bodies in the Chelyabinsk region can't be qualified as satisfactory. In spite of some improvement, the water is not clean enough. That is the matter of national concern, so the federal project "Clean Water" has been designed to tackle it.

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