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SEASONAL DYNAMICS OF ENVIRONMENTAL VARIABLES AND ZOOPLANKTON STRUCTURE IN WASTEWATER RESERVOIRS OF THE RIGHT-BANK SORBULAK CANAL SYSTEM

The annual increase in wastewater volumes necessitates comprehensive studies of water bodies subsidized by anthropogenic activities. An example of such reservoirs is Sorbulak and a system of shallow ponds into which pre-treated wastewater from Almaty and its environs is discharged. The published works provide fragmentary data on the hydrochemical and hydrobiological regimes of Sorbulak and ponds. There is no information on the seasonal dynamics of these variables. Our paper, aimed at studying the seasonal dynamics of pollutants and the zooplankton structure, partially fills this gap. Environmental and biological samples were taken in Sorbulak and two ponds by standard methods once a month, from April to September of 2021. The content of nutrients was high, and the heavy metals concentrations, except for copper, were low. The seasonal dynamics of pollutants in reservoirs were determined mainly by their entry from wastewater, with a more negligible contribution of natural factors. Zooplankton was represented by 80 species with an average abundance of 177.3-834.4 thousand ind./m^3 and average biomass of 9.6-10.4 g/m^3. The values of the Shannon index were 1.98-2.12 bit/ind and 0.88-1.76 bit/mg, the average mass of an individual was 0.0140-0.0853 mg. The seasonal dynamics of zooplankton in the surveyed water bodies were different. The obtained results and comparison with the data of previous studies testified to the instability of the species composition of zooplankton communities both during one year and in individual years. Contradictions between the structure of zooplankton communities and the chemical variables of the studied reservoirs were identified. The results obtained to make a theoretical and practical contribution to understanding the formation of water quality in reservoirs with mixed pollution emphasize the need for further comprehensive studies of reservoirs of this type, and show specific differences between anthropogenic and natural successions of aquatic ecosystems.

Key words: waste water reservoirs, pollution, seasonal dynamics, zooplankton.

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Сарқынды су жинақтауыш сорбұлақ каналы оң жағалауы жетектерінің гидрохимиялық көрсеткіштерімен зоопланктон құрылымының маусымдық динамикасы

Сарқынды сулар көлемінің жыл сайынғы ұлғаюы антропогендік қызмет есебінен субсидияланатын су қоймаларды жан-жақты зерттеу қажеттілігін негіздейді. Мұндай су қоймалардың бірі – Алматы қаласы мен оның маңайынан алдын ала тазартылған сарқынды сулар келіп түсетін Сорбұлақ сарқынды суқоймалар жүйесі. Бұл су қоймалар уақыт өте келе өзгеретін, ластанудың аралас түрімен сипатталады. Осыған дейінгі жарияланған жұмыстарда Сорбұлақ пен сарқынды су жинақтауыш тоғандар жүйесінің гидрохимиялық және гидробиологиялық режимі туралы үзінді деректер келтіріледі, бірақ бұл көрсеткіштердің маусымдық динамикасы туралы мәліметтер жоқ. Ластаушы заттардың маусымдық динамикасын және зоопланктондық қауымдастықтардың құрылымын зерттеуге бағытталған бұл жұмыс жоғарыда аталған олқылықтың орнын толтырады. Сорбұлақ пен сарқынды су жинақтауыш екі тоғанның кешенді зерттеулері 2021 жылы жүргізілді, оның химиялық құрамын, қоректік заттар мен ластаушы заттардың құрамын зерттеу үшін су үлгілері, сондай-ақ зоопланктон сынамалары стандартты әдістермен айына бір рет, сәуірден қыркүйекке дейін іріктелді. Талдаудың әрбір түріне барлығы 84 сынама іріктелді. 2021 жылғы зерттеулер нәтижесі қоректік және органикалық заттардың мөлшері жоғары екендігін, ал мыстан басқа ауыр металдардың мөлшері төмен екендігін көрсетті. Зерттелген сарқынды суларды жинақтауыш суқоймаларда ластаушы заттардың маусымдық динамикасы негізінен олардың табиғи факторлардың үлесі аз болған кезде ағынды сулармен келіп түсуімен анықталды. Зоопланктон 80 түрмен сипатталды, олардың орташа саны 177,3-834,4 мың экз/м^3 және орташа биомассасы 9,6-10,4 г/м^3. Шеннонның алуантүрлілік индексінің мәні 1,98-2,12 бит/экз және 0,88-1,76 бит/мг, дараның орташа салмағы 0,0140 – 0,0853 мг болды. Зерттелген су қоймалардың әрқайсысында зоопланктонның сандық және құрылымдық көрсеткіштерінің маусымдық динамикасы әртүрлі болды. Алынған нәтижелер мен алдыңғы зерттеулердің деректерімен салыстыру зоопланктон қауымдастықтарының түрлер құрамының бір жыл ішінде де, жекелеген жылдары да тұрақсыздығын көрсетті. Зоопланктондық қауымдастықтардың құрылымы мен зерттелген су объектілерінің химиялық көрсеткіштері арасындағы қайшылықтар анықталды. Алынған нәтижелер аралас ластануы бар су қоймалардағы су сапасының қалыптасуын түсінуге теориялық және практикалық үлес қосады, осы типтегі су объектілерін одан әрі кешенді зерттеу қажеттілігін атап көрсетеді, сондай-ақ су экожүйелерінің антропогендік және табиғи сукцессия арасындағы белгілі бір айырмашылықтарды көрсетеді.

Түйін сөздер: сарқынды су жинақтауыштар, ластану, маусымдық динамика, зоопланктон.

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Сезонная динамика количественных и структурных показателей зоопланктона в сточных водах системы правобережного Сорбулакского канала

Ежегодное увеличение объемов сточных вод обусловливает необходимость всесторонних исследований водоемов, субсидируемых за счет антропогенной деятельности. Примером таких водоемов являются Сорбулак и система мелководных прудов, в которые сбрасываются предварительно очищенные сточные воды г. Алматы и его окрестностей. Водоемы характеризуются смешанным характером загрязнения, которое изменяется во времени. В опубликованных работах приводятся отрывочные данные о гидрохимическом и гидробиологическом режиме Сорбулака и прудов, но сведения о сезонной динамике этих показателей отсутствуют. Данная работа, направленная на исследование сезонной динамики загрязняющих веществ и структуры зоопланктонных сообществ, частично восполняет этот пробел. Комплексные исследования Сорбулака и двух прудов были проведены в 2021 г. Образцы воды для исследования ее химического состава, содержания питательных и загрязняющих веществ, а также пробы зоопланктона отбирали стандартными методами один раз в месяц, с апреля по сентябрь. Всего на каждый вид анализа было отобрано по 84 пробы. Было показано, что в 2021 г. содержание питательных и органических веществ было высоким, а содержание тяжелых металлов, за исключением меди, находилось на низком уровне. Сезонная динамика загрязняющих веществ в водоемах сточных вод определялась в основном их поступлением со сточными водами при меньшем вкладе природных факторов. Зоопланктон был представлен 80 видами со средней численностью 177,3-834,4 тыс. экз./м^3 и средней биомассой 9,6-10,4 г/м^3. Значения индекса разнообразия Шеннона были равны 1,98-2,12 бит/инд и 0,88-1,76 бит/мг, средняя масса особи – 0,0140-0,0853 мг. Сезонная динамика количественных и структурных показателей зоопланктона в каждом из обследованных водоемов была различной. Полученные результаты и сравнение с данными предыдущих исследований свидетельствовали о нестабильности видового состава сообществ зоопланктона как в течение одного года, так и в отдельные годы. Выявлены противоречия между структурой зоопланктонных сообществ и химическими показателями исследованных водоемов. Полученные результаты вносят теоретический и практический вклад в понимание формирования качества воды в водоемах со смешанным загрязнением, подчеркивают необходимость дальнейших комплексных исследований водоемов такого типа, а также показывают определенные различия между антропогенными и естественными сукцессиями водных экосистем.

Ключевые слова: накопители сточных вод, загрязнение, сезонная динамика, зоопланктон.

Introduction

The growth of the earth's population causes an annual increase in the volume of wastewater containing a complex set of organic and toxic compounds [1-4]. A significant part of wastewater is discharged into natural water bodies [5-6], causing considerable damage to biological resources and human health [7-8]. The growing practice of reusing wastewater in agriculture and drinking water [9-10] increases environmental and human health risks.

Pollutants entering aquatic ecosystems with wastewater undergo transformation. These processes are determined by a complex of natural and climatic factors [11], chemical and physical interactions [13-15], morphometric characteristics of water bodies [16], as well as accumulation in living organisms [17-20]. The impact of wastewater on aquatic ecosystems depends both on its origin [industrial, agricultural, livestock, domestic wastewater] and on the composition of biological communities [21-25]. Depending on the concentration, pollutants can stimulate or inhibit living organisms [26-28].

Anthropogenic activities almost entirely subsidize artificial reservoirs created to store wastewater (wastewater reservoirs). The continuous influx of organic and toxic compounds with wastewater causes differences between wastewater reservoirs and natural water bodies, characterized by a seasonal supply of nutrients and pollutants [29-30]. In emergency discharges, the content of contaminants in wastewater can increase many times over a short period, which is also not typical for natural water bodies.

The natural processes of eutrophication of water bodies associated with the accumulation of organic matter are distorted by toxic compounds in wastewater. By suppressing the reproduction of primary producers [31], toxicants disrupt the transformation of nutrients and directly or indirectly affect the entire trophic pyramid. As a result, traditional bioindication methods based on the relationship of species to organic pollution [32-33] become ineffective under conditions of toxic or mixed pollution of water bodies. It should also be taken into account that the diverse nature of chemical interactions between pollutants [34] does not allow one to assess water quality based on chemical methods alone.

Hydrobiological studies of wastewater reservoirs expand our knowledge about the formation features of biological communities' structures under conditions of organics together with toxic pollution. According to the feedback principle, the results obtained can be used to assess the ecological state of artificial and natural water bodies with mixed pollution. Considering the annual growth of wastewater volumes [1,4], there are more and more such water bodies [5-6].

Sorbulak is one of the largest wastewater reservoirs in Kazakhstan and the world [35]. Sorbulak and ponds store pre-treated wastewater from the city of Almaty and its environs, with a total population of about 2 million people. Even after preliminary treatment, wastewater contains organic, biogenic, suspended solids, surfactants, metals, phenols, fats, dyes, oil products, cyanides, formaldehyde, and heavy metals [35-38].

Zooplankton studies in the Sorbulak reservoir were carried out in 1998, 2000, 2001, and 2017 [36, 39-41]. The cited papers provide information on the species composition, quantitative and structural variables of zooplankton communities in the Sorbulak reservoir and ponds. The interannual dynamics of zooplankton in ponds are analyzed in connection with external factors [37]. Still, there is no information on the seasonal dynamics of pollutants and the structure of zooplankton communities. This work partially fills this gap. Its purpose is to analyze the seasonal variability of environmental and biological variables in conditions of mixed pollution of wastewater reservoirs of the Right-Bank Sorbulak Canal system.

Materials and Methods

Description of Study area. Sorbulak is located 50 km northwest of Almaty. It was formed in 1973 by filling the natural lowering of the relief with untreated sewage. Sorbulak has the shape of an irregular triangle. The island (former peninsula) divides the reservoir into two parts (Figure 1). The water area is about 58 km^2. Depths range from 19.0-25.0 m in the northern part to 1.5-5.0 m in the southern and southeastern parts. The wastewater canal flows into the southeast of the reservoir. From the western bay of Sorbulak, water is periodically taken through the canal for irrigation of industrial crops.

By the end of the 80s of the last century, the filling of Sorbulak reached a critical level, and there was a threat of the dam breaking. In 1995, the emergency Right-Bank Sorbulak Canal (RSC) was built. Through this canal, part of the wastewater, bypassing Sorbulak, can be discharged into a system of 8 shallow ponds (RSC ponds). Ponds have an indented coastline (Figure 1). The largest of them is the penultimate one (No. 7) and the last one (No. 8), with an area of 3.5 and 0.4 km^2, respectively. The maximum depths do not exceed 7-8 m, with average depths of 2.7-6.0 m. Water transparency is often low. The water level in wastewater reservoirs mainly depends on the volume of incoming wastewater. During the observation period of 2021, the water level in all wastewater reservoirs has dropped significantly.

Figure 1 – The layout of sampling stations in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

Field studies. Hydrochemical and biological sampling was carried out once a month from April to September 2021 using a grid of 15 stations (Figure 1). The coordinates, depth, temperature, pH value, and water transparency at each station were determined. The pH value and water temperature were measured using a portable waterproof instrument AMTAST. Water transparency was determined using a Secchi disk. Water samples were taken to assess total dissolved solids (TDS), the content of nitrites, nitrates, phosphates, ammonium, total iron, silicon, manganese, phosphorus, oxygen, easily oxidized organic substances (PI), heavy metals (Cd, Pb, Zn, Cu, Cr, Co). At depths less than 3 m, hydrochemical samples were taken from the surface and at greater depths, layer by layer, using a bathometer. Samples for determination of TDS were taken in plastic containers with a volume of 1 l, heavy metals – 0.5 l, nutrients – in glass containers with a volume of 0.5 l, permanganate index (PI) – 0.25 l, oxygen – in oxygen bottles with a ground stopper with a volume of 0.25 l. Zooplankton samples were taken using a Judy net by pulling it from the bottom to the surface [42]. All zooplankton samples were fixed with 4% formaldehyde solution. A total of 84 samples were taken for each type of analysis.

Laboratory analysis. Chemical analysis of water was carried out according to guidelines [43,44]. Nitrogen compounds, phosphates, silicon, manganese, and iron were determined photometrically using Griess, Nessler, metallic cadmium, ammonium molybdate in combination with ascorbic and sulfosalicylic acids. The content of easily oxidizable organic substances was determined under acidic conditions by the Kubel method. The total hardness of water was determined by the volumetric complexometric method with the black eriochrome indicator. The determination of heavy metals in water was carried out by inductively coupled plasma mass spectrometry on an ELAN-9000 quadrupole mass spectrometer USA (ST RK ISO 17294-1-2011) in the low-background measurement laboratory of the Institute of Nuclear Physics (Almaty).

Identification of planktonic invertebrates species was carried out according to keys [45-48]. According to [49], the abundance of organisms was calculated. The sample was concentrated to a certain volume, depending on the abundance of organisms. After thorough mixing, three subsamples were taken from the sample using a 1 ml pipette. In this subsample, all encountered individuals and age stages of individual species (the most numerous) were counted. Next, the sample was concentrated to a smaller volume of 125-150 ml. Three subsamples were again taken from it; less abundant age stages or species were counted. In the end, the sample, with its volume of 20-25 ml, was examined to count large and rare species of planktonic invertebrates. The results obtained were recalculated per 1 m^3. We used an individual mass of individuals/species determined by the formulas to calculate the biomass [50]. The average number of species per sample, the Shannon index (Shannon Ab, bit/ind and Shannon Bi, bit/mg), and the average mass of an individual (mg) were determined to characterize the structure of zooplankton. The Shannon index was calculated in the Primer Software based on a logarithm with base two. Graphs of the seasonal dynamics of variables were plotted in the R program [51-52].

Statistical analysis. The calculation of the similarity of the species composition of plankton communities was performed as a network analysis in JASP 0.9.0.0 (Jeffrey's Amazing Statistics Program, University of Amsterdam, Amsterdam, The Netherlands) in the botnet package in R-Statistica (R Core Team, Vienna, Austria) at a similarity level of 50% at $p<0.05$ [53]. Blue lines mean positive correlation, red lines mean negative correlation. The thicker the line, the stronger the connection strength. Descriptive statistics were performed in Excel. The frequency of species occurrence was found by dividing the number of samples in which the species was encountered by the total number of samples.

Results and Discussion

Hydrophysical and hydrochemical characteristics. All wastewater reservoirs are thermal. The ponds, as a rule, warmed up more strongly compared to Sorbulak. The water is alkaline, with maximum pH values in ponds. The water in the ponds is slightly mineralized (Table 1). In Sorbulak, the value of the variable is more than twice as high. According to its chemical composition, the water belonged to the chloride class, the sodium group of the second type. Only in April, sulfates prevailed in Sorbulak. The oxygen content in the surface was at a high level.

Table 1 – Physical-chemical variables of wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021 (average values with standard error)

Variable	Sorbulak	RSC 7	RSC 8
temperature, °	21.7±0.6	25.7±0.01	22.7±0.7
pH	9.41±0.03	9.51±0.05	10.00±0.07
oxygen, mg/dm^3	11.95±0.70	11.50±1.61	12.20±1.00
TDS, mg/dm^3	1340.0±20.3	546.2±26.9	464.5±16.0
hardness, mg-eq/dm^3	6.20±0.03	3.70±0.12	2.64±0.09
PI, mgO/dm^3	19.07±0.54	17.36±1.04	16.22±1.03
N-NO_2, mg/dm^3	0.05±0.01	0.13±0.05	0.03±0.01
N-NO_3, mg/dm^3	0.68±0.07	3.00±1.31	1.28±0.57
N-NH_4, mg/dm^3	0.30±0.04	0.37±0.12	0.53±0.13
PO_4, mg/dm^3	0.26±0.01	0.39±0.05	0.14±0.02
Si, mg/dm^3	3.69±0.15	8.26±0.57	7.03±0.38
Mn, mg/dm^3	0.03±0.003	0.05±0.01	0.07±0.01
Fe, mg/dm^3	0.34±0.02	0.37±0.03	0.38±0.03
Cd, mg/dm^3	0.0001±0.000002	0.0001±0.000002	0.0001±0.000002
Co, mg/dm^3	0.0002±0.00001	0.0003±0.00004	0.0002±0.00001
Cr, mg/dm^3	0.0070±0.0003	0.0060±0.0009	0.0050±0.0005
Cu, mg/dm^3	0.0115±0.0011	0.0255±0.0090	0.0359±0.0041
Pb, mg/dm^3	0.0010±0.0032	0.0008±0.0003	0.0007±0.0002
Zn, mg/dm^3	0.0053±0.0004	0.0110±0.0027	0.0085±0.0014

The average content of nitrates, ammonium, phosphates, silicon, and manganese in the ponds was higher, and easily oxidized organic substances were lower than in Sorbulak. The contents of Cd, Co, Cr, and Pb were low or very low. A somewhat increased amount of Zn was recorded in RSC 7. The Cu content was universally high, with maximum values in RSC 8.

The following features characterized the seasonal dynamics of hydrochemical variables. The surface water temperature gradually increased from April to August and decreased in September (Figure 2). In Sorbulak, water transparency increased from 0.4-0.5 m in spring to 1.9 m in autumn. In RSC 8, the average value of the variable fluctuated within 0.1-0.4 m. In RSC 7, the maximum water transparency was noted in April, the minimum – in July.

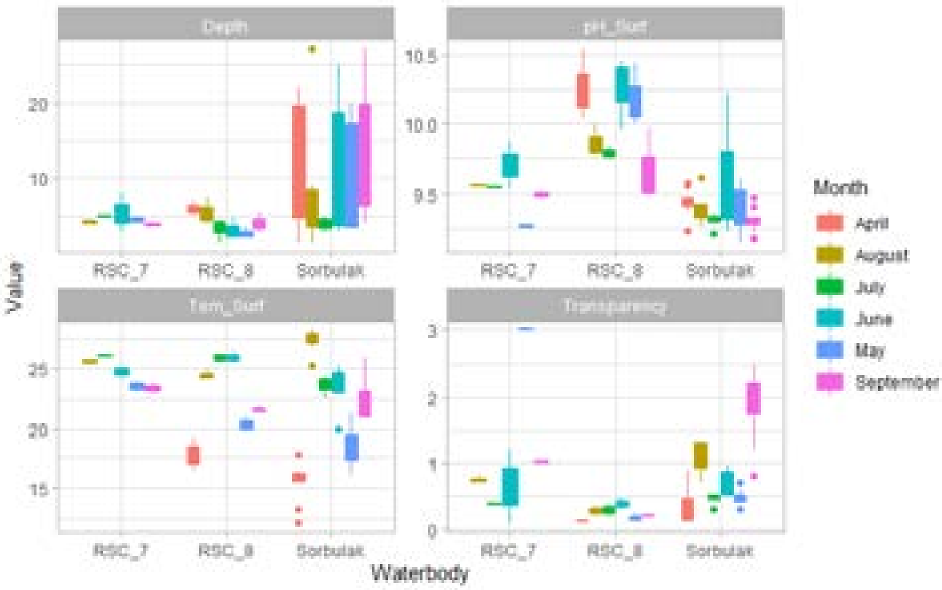


Figure 2 – Seasonal dynamics of hydrophysical variables in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

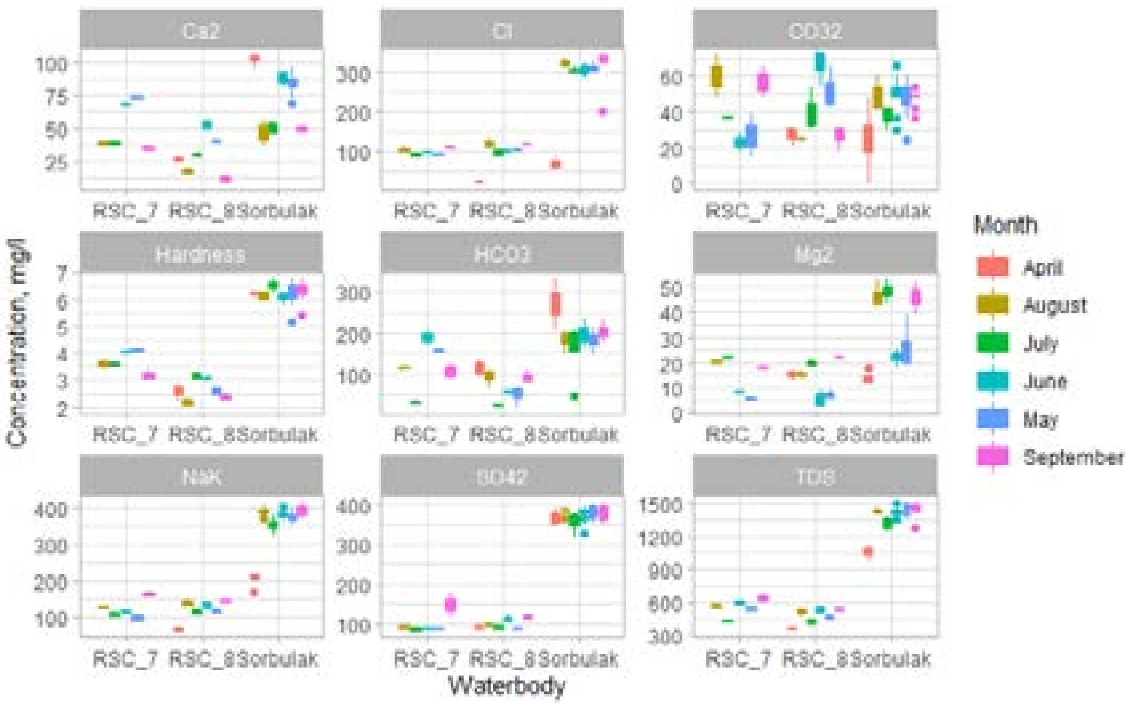


Figure 3 – Seasonal dynamics of hydrochemical variables in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

The minimum oxygen content in the surface in Sorbulak and RSC 7 was recorded in July and RSC 8 in August. The maximum TDS water in all wastewater reservoirs was recorded in September against a decrease in water level (Figure 3).

The most considerable amount of easily oxidized organic substances (21.07-25.00 mg/dm^3) entered the wastewater reservoirs in May, with a minimum in April and September (11.67-15.00 mg/dm^3).

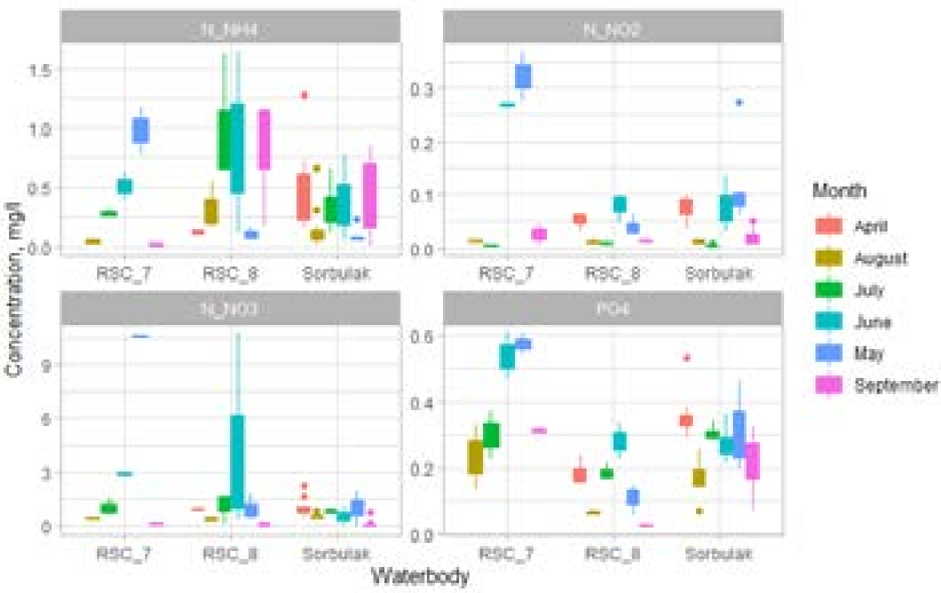


Figure 4 – Seasonal dynamics of nutrients in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

The seasonal dynamics of nitrogen and phosphorus compounds in Sorbulak did not follow clear patterns, with a weakly expressed trend of decreasing their concentrations from April to September. In RSC 7, this trend was more pronounced: the content of nitrogen compounds and phosphates decreased from spring to autumn (Figure 4). In RSC 8, the maximum concentrations of nutrients were recorded in June, and ammonium nitrogen – in July.

During the study period, the content of zinc, copper, and lead changed to a certain extent synchronously (Figure 5). The Pearson correlation coefficient values were statistically significant between Zn and Cu (r=0.657), Zn and Pb (r=0.682), Cu and Pb (r=0.432, $p<0.05$). In Sorbulak, the highest amount of copper was recorded in June, in ponds – in August. In August, a relatively high amount of chromium was detected in Sorbulak.

Zooplankton

As part of zooplankton, 80 species were recorded, including 53 rotifers, 16 cladocerans, 9 copepods, and 2 others (Table 2). The most significant number of species was found in RSC 8, and the minimum in RSC 7.

During the entire observation period, the zooplankton species composition was characterized by a relatively high similarity between Sorbulak and ponds (Figure 6). The allocation of RSC 8 to a separate cluster indicated an almost complete change in the species composition of planktonic invertebrates in August and September relative to other periods of research.

According to the average values, the quantitative variables of zooplankton communities were at a high level, with a maximum in RSC 8 and Sorbulak (Table 3). Copepods dominated. Rotifers and cladocerans subdominated. In RSC 7, the distribution of taxonomic groups by abundance was relatively uniform. The average zooplankton biomass did not differ in water bodies. Cladocerans dominated in Sorbulak and RSC 7, while copepods subdominated. In RSC 8, the ratio of groups in the total zooplankton biomass was reversed.

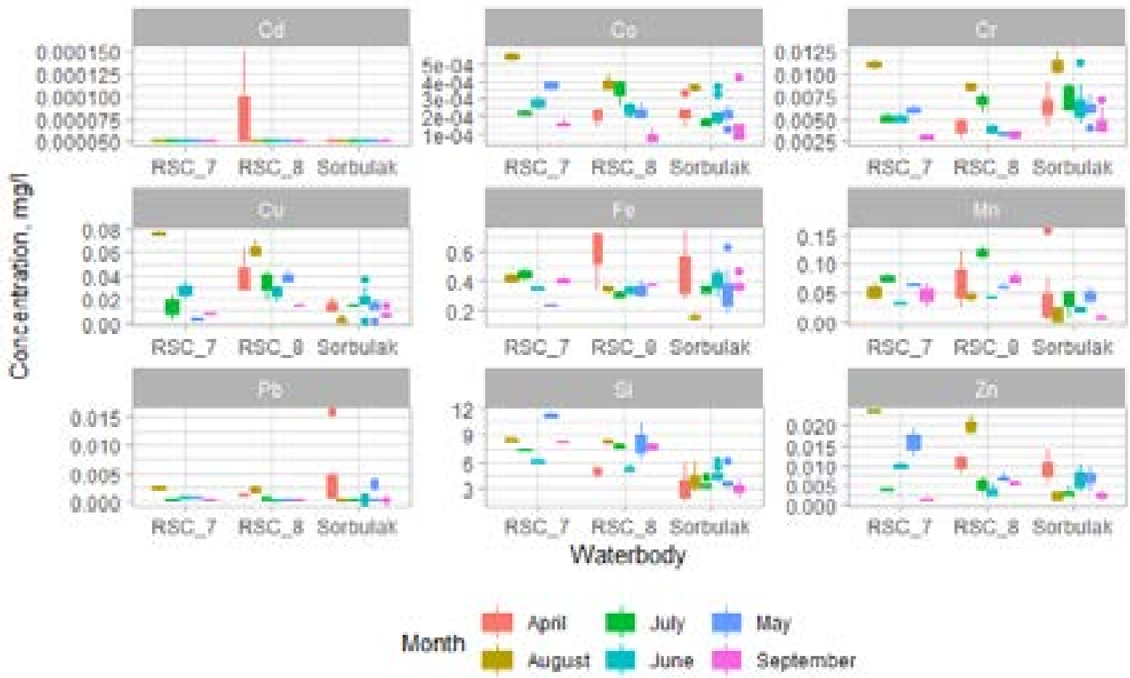


Figure 5 – Seasonal dynamics of heavy metals and silicon in wastewater reservoirs of the system of the Right-Bank Sorbulak Canal, 2021

Table 2 – Species composition and frequency of occurrence (%) of planktonic invertebrates in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

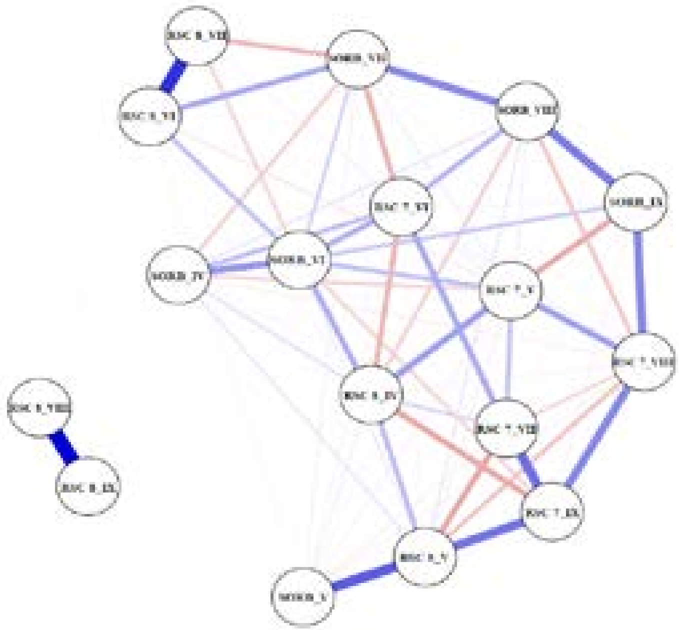
Species name	Sorbulak	RSC 7	RSC 8
Rotifera			
Anuraeopsis fissa (Gosse)			17
Asplanchna brightwelli (Gosse)			33
Asplanchna girodi (Guerne)	41		33
**Asplanchna herricki* (Guerne)	2		
**Asplanchna intermedia* (Hudson)	7		6
Bdelloida gen.sp.	4		22
Brachionus angularis (Gosse)			50
Brachionus angularis bidens (Plate)			33
**Brachionus calyciflorus* (Pallas)	2		17
Brachionus calyciflorus amphiceros (Ehrenberg)			44
Brachionus forficula (Wierzejski)		20	67
**Brachionus plicatilis* (Muller)	6		6
**Brachionus quadridentatus ancylognathus* (Schmarda)	4		33
Brachionus quadridentatus hyphalmyros (Tschugunoff)			17
**Brachionus urceus* (Linnaeus)	2		22
Brachionus variabilis (Hempel)			11

Table continuation

Species name	Sorbulak	RSC 7	RSC 8
Colurella colurus (Ehrenberg)			22
**Euchlanis deflexa* (Gosse)	2		
Euchlanis dilatata (Ehrenberg)	2		6
Euchlanis lyra (Hudson)			6
**Euchlanis phryne* (Myers)	4	10	
Euchlanis pyriformis (Gosse)			6
Filinia longiseta (Ehrenberg)	2		50
**Filinia major* (Colditz)	37	10	50
**Filinia terminalis* (Plate)	35		83
Hexarthra mira (Hudson)	19	40	
**Hexarthra intermedia* (Wiszniewski)	63	20	17
Keratella cochlearis (Gosse)			22
**Keratella quadrata* (Muller)	96	60	83
Keratella tropica (Apstein)			11
Keratella tropica reducta (Fadeew)			6
Lecane (Monostyla) bulla (Gosse)			22
Lecane (Monostyla) closterocerca (Schmarda)			17
Lecane (s.str.) luna (Muller)	13		44
Lepadella (s.str.) triptera (Ehrenberg)			11
Leydigia leydigii (Schoedler)	2		
**Lophocharis oxysternon* (Gosse)	2		
**Mytilina ventralis* (Ehrenberg)	6		22
**Notommata collaris* (Ehrenberg)	2		
Notommatidae gen.sp.	2	20	28
**Polyarthra dolichoptera* (Idelson)	22		17
Polyarthra major (Burchhardt)	13		
Pompholyx sulcata (Hudson)	17		50
Synchaeta kitina (Roussel.)	37		
Synchaeta stylata (Wierzejski)	19		
**Trichocerca (s.str.) caspica* (Tschugunoff)	11		33
Trichocerca rattus (Muller)			17
Trichocerca similis (Wierzejski)			28
**Trichocerca stylata* (Gosse)	2		
Trichotria similis (Stenroos)	2		
Trichotria truncata (Whitel.)			6

Table continuation

Species name	Sorbulak	RSC 7	RSC 8
Tripleuchlanis plicata (Rodew.)			6
Cladocera			
**Alona rectangula* (Sars)	11	30	17
**Bosmina (Bosmina) longirostris* (O.F. Muller)	98	10	94
**Ceriodaphnia dubia* (Richard)	2		
Ceriodaphnia pulchella (Sars)	2		
**Ceriodaphnia reticulata* (Jurine)	17		
Chydorus sphaericus (O.F. Muller)	31	100	22
Daphnia (Daphnia) galeata (G.O. Sars)	96		39
**Daphnia (Daphnia) longispina* (O.F. Muller)	20		
Daphnia (Ctenodaphnia) magna (Straus)	78	80	17
Daphnia (Daphnia) pulex (De Geer)	74	100	44
Diaphanosoma cf. dubium (Manuilova)			72
**Diaphanosoma mongolianum* (Veno)	63	10	6
Macrothrix hirsuticornis (Norman et Brady)		10	
Moina brachiata (Jurine)	2		
Moina sp.			6
Pleuroxus aduncus (Jurine)	4	20	
Copepoda			
Acanthocyclops robustus (Mirabdullayev et Defaye)	100	80	67
Cyclops scutifer (Sars)			
**Cyclops strenuus* (Fischer)	31		22
**Cyclops vicinus* (Uljanin)	98	50	89
**Eucyclops serrulatus* (Lilljeborg)	2	40	
**Mesocyclops leuckarti* (Claus)		10	
**Thermocyclops vermifer* (Lindberg)			61
Sinodiaptomus sarsi (Rylov)		20	67
Diaptomidae gen.sp.		10	28
Ergasilidae gen.sp.	7		
Others			
Oligochaeta gen.sp.	2	10	
Ostracoda gen.sp.	2	90	17
Nematoda gen.sp.	2		6
Total:	**52**	**23**	**57**
Note. *Species not previously recorded in Sorbulak and ponds.			



Abbreviation. Sorb – Sorbulak, RSC 7 and 8 – pond 7 and 8. Roman numbers (IV-IX) denote the months of April-September, respectively.

Figure 6 – The similarity of the species composition of planktonic invertebrates in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

Table 3 – Quantitative variables of zooplankton communities in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

Variable	Water body			Variable	Water body		
	Sorbulak	RSC 7	RSC 8		Sorbulak	RSC 7	RSC 8
Rotifera Abundance	152.1	51.9	334.6	Copepoda Biomass	2.89	0.47	6.55
Cladocera Abundance	140.7	69.3	83.2	Total Biomass	9.62	10.37	9.72
Copepoda Abundance	405.0	56.6	416.5	Average Species Number	12.0	8.5	17.4
Total Abundance	697.8	177.3	834.4	Shannon Ab	2.01	1.98	2.12
Rotifera Biomass	0.12	0.05	0.74	Shannon Bi	1.76	0.88	1.31
Cladocera Biomass	6.61	9.83	2.44	Average mass of an individual	0.0175	0.0853	0.0142

The seasonal dynamics of the quantitative indicators of zooplankton had their characteristics in each water body (Figures 7, 8). In Sorbulak, after the maximum in April, an abundance of planktonic invertebrates decreased in May and June, followed by a rise in July and a further decline by September. In RSC 7, the quantitative indicators of zooplankton gradually increased from May to September. In RSC 8, two zooplankton abundance peaks (May and September) and one biomass peak (June) were recorded.

The composition of the dominant species in the zooplankton of the surveyed reservoirs included the cyclopoid copepods *A. robustus* everywhere, in Sorbulak together with *C. vicinus* (Table 4). As the water temperature rose seasonally, the role of heat-loving species of cladocerans increased in the zooplankton community, while the importance of rotifers *S. kitina* decreased. The composition of the dominant species in the zooplankton of RSC 8 was the most peculiar and variable. In addition to the cyclops *A. robustus*, the rotifers *F. major, F. terminalis, K. quadrata,* and the cyclops *C. vicinus* played a significant role in the zooplankton of this reservoir in spring, and the predatory rotifer *A. brightwelli*, crustaceans *B. longirostris, D. dubium,* and *S. sarsi*.

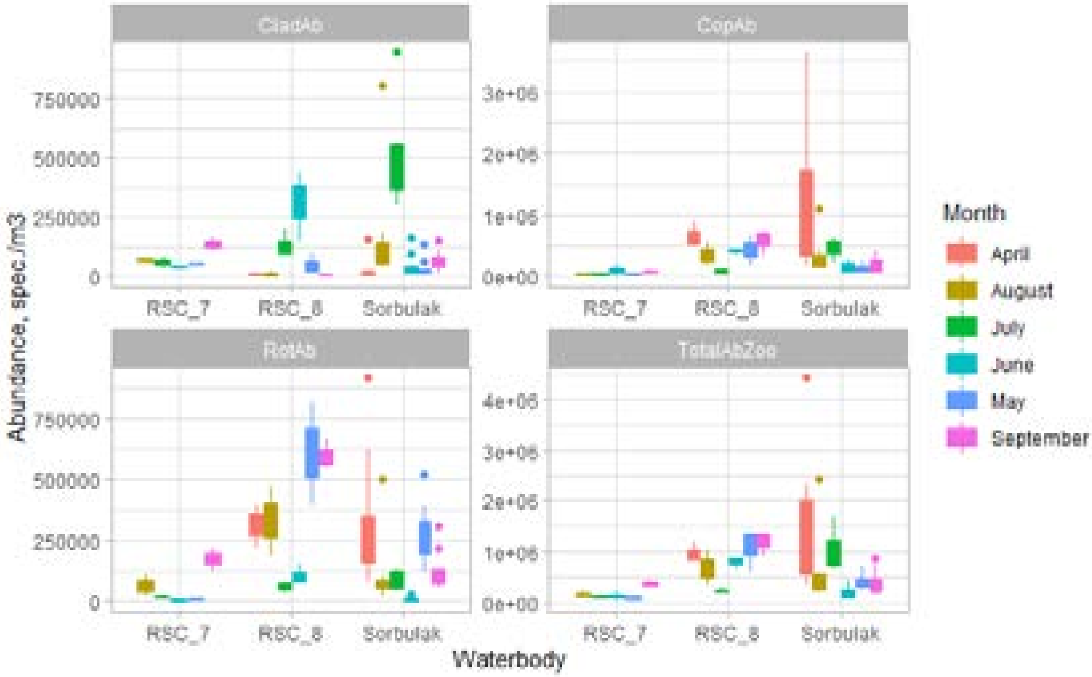


Figure 7 – Seasonal dynamics of zooplankton abundance in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

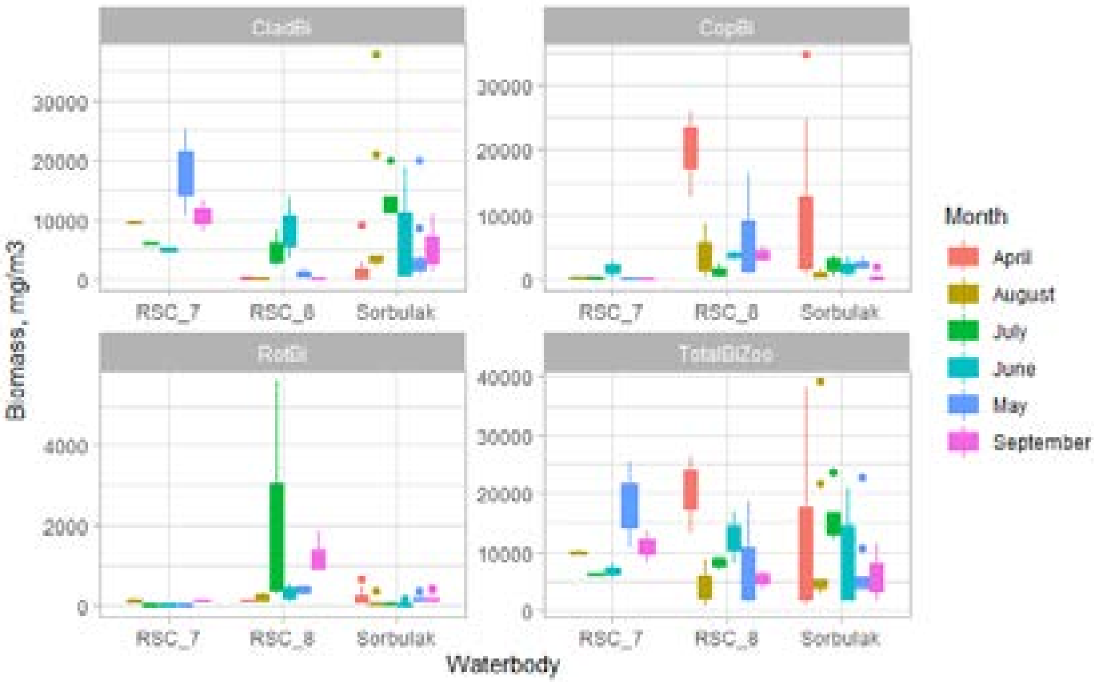


Figure 8 – Seasonal dynamics of zooplankton biomass in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

Table 4 – The composition of the dominant species in the zooplankton of wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

Water body	Month	Species name	Abundance, %	Biomass, %
Sorbulak	April	*Synchaeta kitina*	12.5	1.1
		Daphnia (Daphnia) galeata	1.5	13.8
		Cyclops vicinus	17.5	76.4
		Acanthocyclops robustus	58.9	5.1
	May	*Filinia major*	17.1	0.5
		Keratella quadrata	41.5	1.9
		Daphnia (D.) galeata	7.7	57.3
		Acanthocyclops robustus	11.6	0.9
		Cyclops vicinus	16.5	33.5
	June	*Daphnia (C.) magna*	3.6	64.4
		Acanthocyclops robustus	53.1	9.9
		Cyclops vicinus	22.5	11.7
	July	*Bosmina (B.) longirostris*	24.8	13.5
		Diaphanosoma mongolianum	19.4	45.3
		Daphnia (D.) pulex	1.0	13.3
		Acanthocyclops robustus	33.7	12.1
	August	*D. mongolianum*	12.9	43.7
		Daphnia (Daphnia) pulex	3.7	31.3
		A. robustus	55.5	7.3
	September	*Acanthocyclops robustus*	26.4	7.8
		Daphnia (Daphnia) pulex	15.9	50.7
		D. mongolianum	2.5	26.2
RSC 7	May	*Daphnia (C.) magna*	17.5	61.2
		Daphnia (D.) pulex	30.1	38.2
		Cyclops vicinus	32.1	0.17
	June	*Acanthocyclops robustus*	70.2	24.1
		Daphnia (C.) magna	2.9	34.7
		Daphnia (D.) pulex	15.1	39.3
	July	*Chydorus sphaericus*	29.6	8.6
		Daphnia (D.) pulex	21.7	84.6
		Acanthocyclops robustus	36.4	3.5
	August	*Hexarthra mira*	31.4	1.1
		Daphnia (Daphnia) pulex	29.1	93.3
		A. robustus	22.0	3.1
	September	*Keratella quadrata*	36.1	0.9
		Chydorus sphaericus	19.6	10.5
		Daphnia (Daphnia) pulex	15.9	87.5
		Acanthocyclops robustus	18.0	0.6

Table continuation

Water body	Month	Species name	Abundance, %	Biomass, %
RSC 8	April	*Filinia major*	16.2	0.3
		Filinia terminalis	11.0	0.1
		Cyclops vicinus	62.4	96.7
	May	*Keratella quadrata*	42.5	4.5
		Acanthocyclops robustus	17.6	4.3
		Cyclops vicinus	22.2	77.9
	June	*Bosmina (Bosmina) longirostris*	16.0	5.7
		Diaphanosoma cf. dubium	19.3	58.5
		Acanthocyclops robustus	32.4	10.7
		Sinodiaptomus sarsi	7.6	10.3
	July	*Asplanchna brightwelli*	5.8	25.7
		Diaphanosoma dubium	46.9	57.4
		Acanthocyclops robustus	13.9	2.7
		Sinodiaptomus sarsi	7.8	12.4
	September	*Brachionus forficula*	35.0	0.7
		Thermocyclops vermifer	46.3	30.2
		Sinodiaptomus sarsi	3.8	59.7
	September	*Brachionus forficula*	36.2	2.3
		Asplanchna girodi	1.9	19.3
		Thermocyclops vermifer	49.1	69.9

Figure 9 shows the seasonal dynamics of the structural variables of zooplankton communities. The highest values of the Shannon index and the average mass of an individual in all reservoirs were recorded in the summer months. In Sorbulak, the species richness of zooplankton communities increased from April to September, and it was at its maximum in the summer months in the ponds.

The seasonal dynamics of nitrogen and phosphorus compounds in the surveyed wastewater reservoirs did not follow clear patterns, which is associated with the predominant supply of biogenic elements to the reservoirs with wastewater. A weakly pronounced downward trend in nitrogen and phosphorus concentrations from April to September indicates a specific contribution of surface runoff, the volume of which is associated with seasonal variability in precipitation [54]. In the absence of seasonal patterns, the synchronous change in the concentrations of heavy metals is also associated with their joint inflow with wastewater.

With territorial proximity and feeding on one source, the structure and seasonal dynamics of zooplankton communities in the surveyed wastewater reservoirs had specific features. With a relatively high commonality of the species composition of planktonic invertebrates, the composition of the dominant species was specific in each of the reservoirs and unstable over time. Species compounds also changed compared with previous data [37,41]. By 2021, the species richness of zooplankton in Sorbulak increased due to 18 species of rotifers, three species of cladocerans, and one species of copepods that were not previously recorded (Table 3). All species of rotifers recorded in 2017, except for *Hexarthra mira*, fell out of the composition of the zooplankton of the ponds; and the composition of rotifers was completely renewed. Previously unrecorded, three species of cladocerans and four species of copepods appeared. A possible reason for a significant increase in the species richness of zooplankton in reservoirs may be the excessive supply of biogenic elements that stimulate the development of phytoplankton. Favorable trophic conditions allow a more significant number of planktonic invertebrate species to exist simultaneously [55]. This conclusion is also supported by an increase in zooplankton species richness due to rotifers from the genera *Brachionus, Keratella*, and *Filinia*, which are characteristic of water bodies enriched in biogenic elements [37]. Seasonal and interannual variability in the species composition of planktonic invertebrates is a reflection of unstable environmental conditions, which is generally typical for water bodies fed by wastewater [10].

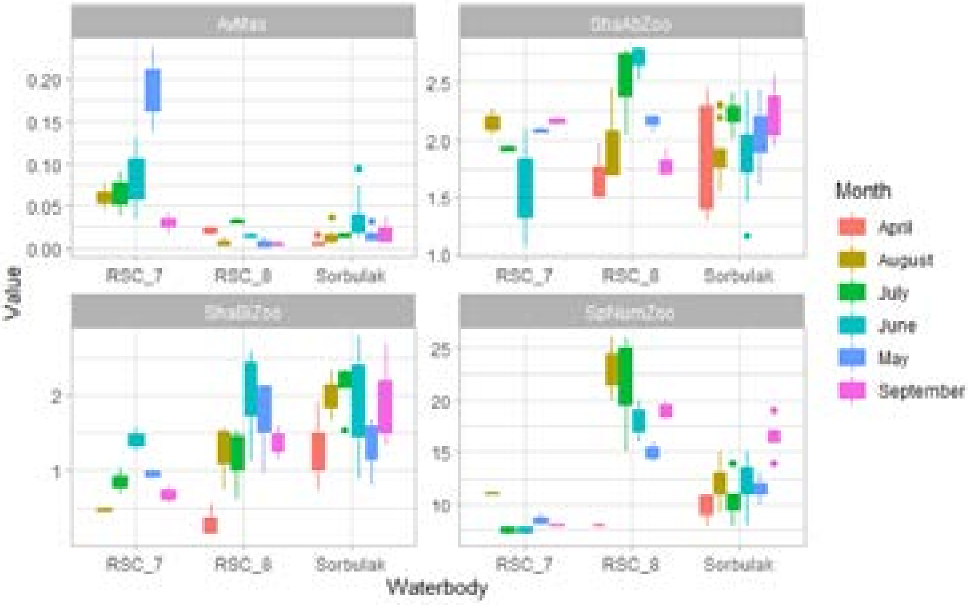


Figure 9 – Seasonal dynamics of structural variables of zooplankton in wastewater reservoirs of the Right-Bank Sorbulak Canal system, 2021

The constant influx of nutrients contributed to maintaining a high abundance and biomass of zooplankton in the surveyed wastewater reservoirs, which is generally typical for water bodies of this type [56-57]. The decrease in the level of toxic pollution of reservoirs in recent decades played a significant role [37,41]. At very low concentrations of all metals in 2021, the copper content increased from 0.001 mg/dm^3 in 2017 [37] to 0.0117-0.0359 mg/dm^3 in 2021. The primary source of heavy metals in wastewater is an activity of industrial enterprises [58], including the textile industry. From 2019 to 2021, the production of textiles in Almaty increased from 5.0 to 23.7% [59]. The use of heavy metals and, in particular, copper for fabric dyeing may be one of the reasons for the sharp increase in the content of this metal in wastewater in the past few years.

Except RSC 8, the dominant zooplankton complex did not change in all wastewater reservoirs. In RSC 8, only the cyclops *A. robustus* remained among the dominants of previous years. In contrast, the previously dominant rotifers *Hexarthra mira* and cladocerans *D. pulex* and *D. magna* dropped out of the composition of dominants. The number of species resistant to organic pollution (*Asplanchna girodi, A.brightwelli, B. forficula, Keratella quadrata, B. longirostris, D. dubium, C. vicinus, S. sarsi, T. Vermifer*) increased [37, 60-62]. Changes in the composition of dominant complexes can be associated with the variability of hydrochemical conditions [63] and antagonistic relationships between planktonic invertebrates. For example, in a mesotrophic lake in Brazil, *B. longirostris* cannot coexist with rotifers *Hexarthra* [64]. Due to the great competition, rotifers are forced to look for additional sources of food. *Hexarthra* uses the food contained in the filtration apparatus of *B. longirostris*, thereby negatively affecting the population of this crustacean. Perhaps for this reason, in 2017, *B. longirostris* was not recorded in the zooplankton of RSC 7 and 8 during the period of dominance of the rotifer *Hexarthra mira* [37,41]. The absence of *B. longirostris* in Sorbulak [37, 40] may also be related to its inability to compete for food with large *D. magna* [65-66].

The Shannon diversity index and the average individual mass are integral variables that characterize the structure of biological communities [33]. In 2021, the average values of the Shannon index (1.98-2.12 bit/ind and 0.88-1.76 bit/mg) indicated a moderate and low diversity of zooplankton communities in the wastewater reservoirs. Such index values are typical for zooplankton in eutrophic lakes [33, 67], where several small-sized species dominate and for oligotrophic conditions when several large species dominate [62]. High values of the average individual mass (0.0142-0.0853 mg) in the zooplankton of all wastewater reservoirs corresponded to the values characteristic of oligotrophic conditions [33]. Taking into account the long-term accumulation of pollutants [35] and the results of chemical analysis in 2021, it can be concluded that the values of the integral variables of zooplankton did not fit into the existing classifications [33, 62]. Our results once again confirm that the successions of water bodies differ significantly under the influence of natural and anthropogenic factors. The differences are not only in the multiple accelerations of anthropogenic eutrophication of water bodies [68], but also in the stochastic effect of toxic compounds that shift the aquatic ecosystem to earlier stages of successional development [69]. Obviously, it is the main reason for the contradictions described above between the structure of zooplankton communities and the chemical parameters of the studied water bodies. Undoubtedly, our results are preliminary and aimed at drawing attention to the study of the succession of wastewater bodies as a particular type of aquatic ecosystem.

Conclusion

The seasonal dynamics of pollutants in the wastewater reservoirs of the Right-Bank Sorbulak Canal system are determined mainly by their inflow with wastewater, with a smaller contribution of natural factors. Zooplankton was represented by 80 species, of which the most common rotifers *Keratella quadrata*, cladocerans *Bosmina longirostris, Daphnia magna, D. p*ulex, cyclopoid copepods *Acanthocyclops robustus,* and *Cyclops vicinus*. High quantitative variables of zooplankton (177.3-834.4 thousand ind./m^3 and 9.6-10.4 g/m^3) are mainly characteristic of reservoirs enriched with nutrients. The composition of the dominant complexes included species that endure an increased amount of organic matter. Shannon diversity index values ranged from 1.98 to 2.12 bits/ind and 0.88 to 1.76 bits/mg. The average individual mass in zooplankton was 0.0142-0.0853 mg. The seasonal zooplankton dynamics had their characteristics in each surveyed water body. The obtained results and comparison with the data of previous studies testified to the instability of the species composition of zooplankton communities, which may reflect the variability of environmental conditions. The identified contradictions between the structure of zooplankton communities and the chemical parameters of the examined water bodies emphasize the need for further comprehensive studies of water bodies with mixed pollution and show certain differences between anthropogenic and natural successions of aquatic ecosystems.

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