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Assessment of the Impact of Sewage Storage Ponds on the Water Environment in Surrounding Area †

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Abstract: The paper presents the results of research on the environmental impact of sewage ponds serving the city of Kostanay (Kazakhstan). The scope of the research included the determination of basic quality parameters of raw and treated wastewater, an analysis of the chemical composition of groundwater in the vicinity of sewage ponds, and the analysis of the water quality of the Tobol River. The obtained results indicate that sewage from storage ponds, infiltrating into the ground, caused groundwater pollution in the area of about 100 km^2 around the reservoirs. Due to the fact that the groundwater aquifer in the vicinity of sewage ponds feeds the Tobol River, it also affects water quality in the river, which does not meet the requirements for most of the analyzed parameters.

Keywords: sewage ponds; sewage disposal; groundwater contamination; environmental impact

1. Introduction

The requirements for the rational use and protection of water resources and the prevention of their pollution are among the most important objectives of environmental protection and sustainable development policy [1,2]. Accumulation of treated or pre-treated sewage in artificial or natural storage tanks as well as supplementing underground aquifers with sewage, and then using them for various needs can be one of the ways of rational water management [3]. On the other hand, sewage storage tanks can have an adverse effect on the environment. For this reason, the environmental impact of sewage ponds should be the subject of special attention both during the reconstruction and operation of existing treatment plants and at the design stage of new facilities [4].

The purpose of the presented research was to conduct comprehensive analyses to assess the ecological state and the nature and degree of the impact of reservoirs collecting and storing wastewater from the city of Kostanay (Kazakhstan) on the groundwater and surface water environment in their surroundings.

2. Materials and Methods

2.1. Sewage Disposal System in Kostanay

The city of Kostanay is located in the steppe zone in the north of the Turgay Plateau, in the southwestern part of the West Siberian Plain, on the Tobol River. As of 1 January 2019, the population was 243,031 people.

The sewer system in the city is managed by the company "Kostanay-SU", which is also responsible for the water supply system. All the wastewater from the households and industry is pumped to treatment facilities located 14 km north of the city. There, the wastewater goes initially to the mechanical treatment section, which consists of three pairs of earth (clay) horizontal settling tanks. After the sedimentation process, the wastewater flows through a gravity collector, approximately 1 km long, to the system of sewage ponds. The annual amount of wastewater delivered to the system in 2018 was 15,187,000 m^3, which gives an average of 41,600 m^3 per day.

The main sewage pond, which consists of Lakes Rybnoye and Mazarevo, was built in 1966 and has a total volume of 94.1 km^3. In 1989, the system was expanded. In order to provide additional capacity for wastewater storage, a set of ponds adjacent to the main reservoir from the north (Kurgan Reservoir with a total volume of 11.73 km^3) and eastern (Lakes Popova, Kolesnikov, and Tomarkol with a total volume of 14.8 km^3) was designed. The reservoirs are filled in cascades, from the highest level of 183.80 m above sea level (m a.s.l.) in Lake Rybnoye to the lowest level of 175.00 m a.s.l. in Lake Popov. The basic spatial distribution of the wastewater treatment system in Kostanay is shown on the map in Figure 1.

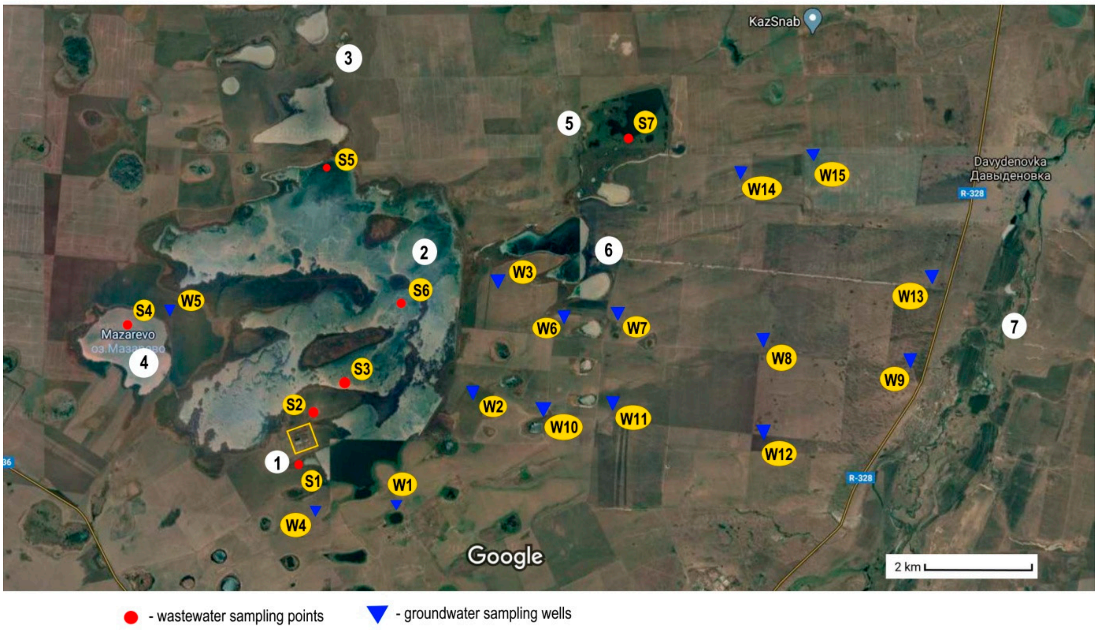


Figure 1. Arrangement of sewage treatment facilities and sewage and groundwater sampling points for analysis. (1) Mechanical pretreatment units; (2) Rybnoye Lake; (3) Kurgan Lake; (4) Mazarevo Lake; (5) Popov Lake; (6) Kolesnikov and Tomarkol Lake; (7) Tobol River; (S1–S7) wastewater sampling points; (W1–W15) groundwater sampling wells.

2.2. The Scope and Methodology of the Research

Research work was conducted in 2018–2019 as part of the project "Research and development of innovative wastewater treatment technology in the city of Kostanay, ensuring its environmental safety". The scope of research included, among others: determination of raw and treated wastewater quality at various points in the treatment system; determining the location and quality of groundwater aquifer in the vicinity of sewage ponds; and determination of the water quality in the Tobol River, in the profile fed with groundwater from the surroundings of sewage ponds.

Wastewater and groundwater samples were collected in accordance with ST RK GOST R 51592-2003 [5] and GOST 31942-2012 [6] from the locations indicated in Figure 1. Analyses of wastewater and groundwater quality were carried out in laboratories of the "Institute of Hydrogeology and Geo-ecology named after U.M. Ahmedsafin" and the municipal enterprise "Kostanay SU" in accordance with applicable standards.

3. Results, Discussion, and Conclusions

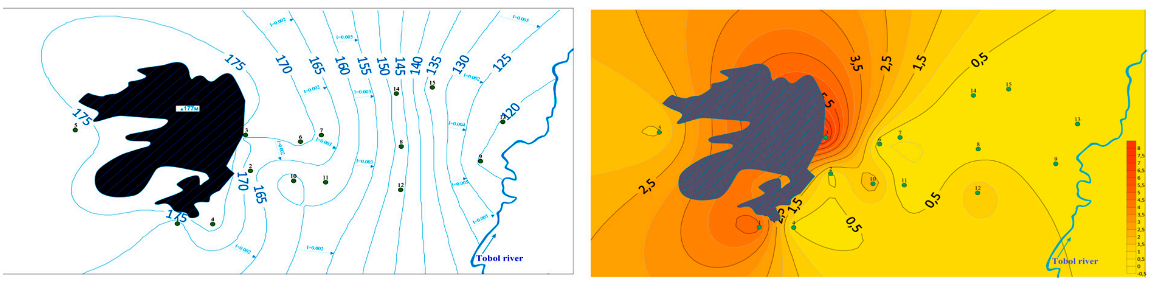
The average values of the wastewater quality parameters are summarized in Table 1. The analysis of the results obtained indicates that the efficiency of wastewater treatment in sewage ponds increases with the duration of sewage retention; the lowest concentrations of pollutants occurred at the sampling points furthest from the wastewater influent (points S4 and S7). However, it should be clearly stated that the effect of wastewater treatment in both settling tanks and sewage ponds is insufficient.

Table 1. Average values of selected wastewater quality parameters in the Kostanay wastewater treatment plant.

	Sampling Points [1]						
Parameter	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**
	[mg/dm³]						
BOD_{total}	282.5	231.3	190.7	20.4	49.5	40.7	18.0
COD	470.0	310.0	275.0	38.5	45.5	54.3	30.0
TSS	199.5	54.6	43.5	26.0	31.0	66.5	31.5
$N\text{-}NH_4$	76.56	84.9	31.87	2.14	0.64	1.16	0.86
$N\text{-}NO_3$	0.83	0.54	1.04	0.39	0.59	1.03	0.86
Phosphates	8.7	6.5	5.93	0.72	3.28	4.2	0.46

[1] S1–influent to settling tanks; S2–effluent from settling tanks; S3–influent to Rybnoye Lake; S4–Mazarevo Lake; S5–effluent from Rybnoye to Kurgan Lake; S6–Rybnoye Lake; S7–Popov Lake.

Measurements made in wells W1–W15 allowed for the analysis of the depth of the water table in the groundwater aquifer and assessed its qualitative changes in the studied area. Isoline maps illustrating the variability of these parameters (Figure 2) were prepared using Surfer software.



(a) (b)

Figure 2. Isolines of the groundwater table and ammonia nitrogen in the surroundings of sewage ponds: (**a**) Groundwater table, in m above sea level; (**b**) Ammonia nitrogen, in mg/dm³.

The course of hydroisohypses shows that the groundwater aquifer is fed by infiltration from sewage ponds and has an inclination toward the Tobol River basin, which drains groundwater from the surrounding area. Isolines representing concentrations of selected quality parameters in groundwater show similar patterns, reducing their values as they move away from these reservoirs. It also indicates that the presence of pollutants in groundwater is mainly caused by infiltration from sewage ponds.

Table 2 summarizes the values of the groundwater quality indicators in wells located radially toward the Tobol River, water quality in the river, and the maximum admissible concentrations

(MAC) in surface waters intended for fishing/fish farming. The presented results show that water quality in the Tobol River does not meet the requirements for most of the examined parameters.

Table 2. Average values of the selected quality parameters of groundwater and the Tobol River.

Sampling Point	TSS	BOD_{total}	COD	SO_4^-	Cl^-	Fe	$N\text{-}NH_4$	$N\text{-}NO_3$	Mn
	[mg/dm³]								
Groundwater									
W2	11.5	20.5	27.0	650.0	117.5	0.36	0.35	5.03	0.8
W11	5.2	6.9	8.64	570.0	60.0	1.36	0.04	3.77	1.12
W9	4.4	8.38	10.6	456.3	125.0	0.5	0.05	0.11	0.17
Tobol river									
Tobol R.	29.5	3.4	3.8	230.0	180.7	0.3	0.56	0.4	0.04
MAC [1]	10.0	3.0	15.0	100.0	300.0	0.1	0.5	40.0	0.01

[1] MAC–maximum admissible concentration in surface waters for fishery.

Analyzing the results obtained, it can be concluded that the existing treatment plant in the city of Kostanay is not operating as required. The efficiency of the settling tanks is very low and the quality of wastewater in the storage ponds does not meet current standards.

Based on the results of the groundwater quality analysis of samples taken from an area of approximately 100 km^2, adjacent to existing treatment facilities, it was found that groundwater pollution is caused by infiltration from the storage ponds. In addition, the Tobol River water quality parameters exceeded the maximum admissible concentrations (MAC) for many parameters, which, in conjunction with the observed direction of groundwater movement, may also indicate a negative impact of sewage ponds on the quality of the river water.

The obtained results clearly indicate the need to design and build new treatment facilities that will ensure proper protection of the aquatic environment against secondary pollution in the areas adjacent to the treatment plant.

Author Contributions: M.M. conceived and designed the experiments; T.R. and K.O. performed the experiments; M.M., T.R., K.O. and D.A. analyzed the data; K.O. and D.A. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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