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Hydrochemical evaluation of Voronezh industrial wastewater entering the Voronezh water reservoir

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Abstract: This study aims to assess the degradation and degree of pollution of wastewater from a food processing plant discharged into the Voronezh Reservoir (Russia) and to update the scientific community and decision-makers on the progressive degradation and degree of pollution of the Voronezh reservoir. The study is based on hydrochemical elements, , among others: pH, total hardness, (Ca^{2+}, Mg^{2+}), ${SO_4}^{2-}$, Cl^-, sediment quantity, mineral content, ${CO_3}^{2-}$, ${HCO_3}^-$, COD, solubility, and BOD₅. The analytical results obtained were compared to international reference values MPC_{water}. The analysis of the hydrochemical elements mentioned above concerns wastewater from a food processing plant, which is discharged into the Voronezh Reservoir. The analysis of these hydrochemical elements in the wastewater samples was carried out in the Environmental Analysis Laboratory of Voronezh State University in 2023. We used the equipment and reagents of said laboratory. Titrimetry, colorimetry, precipitation, filtration and washing, evaporation, drying and weighing, and oxidation methods were used during the analysis of this wastewater. The results obtained from the study of wastewater from a food industry and discharged into the Voronezh reservoir show that the following elements are in high concentration: ${CO_3}^{2-}$ varying from 382.8 to 429mg/l, ${HCO_3}^-$: 704.8 to 733.9mg/l, solubility (dissolved oxygen) :2.9 mg/l, Ca^{2+}:25.25 to 25.85 mg/l, Mg^{2+}: 10.62 and 12.3mg/l and a temperature which exceeds 80^0F. The above-mentioned results of water from a food industry study exceed the MPC water reference, hence we can draw the attention of researchers, the scientific community, decision-makers and authorities with the role of protecting the Voronezh reservoir that the water studied and discharged by a food industry and flowing into the Voronezh water reservoir is polluted and also constitutes a source of pollution of the Voronezh reservoir.

1. Introduction

The artificial reservoirs created on African rivers to meet the needs for hydroelectric power, irrigation, and water security are among the largest in the world, including Lake Kariba (Zambezi), Lake Volta (Volta), and Lake Nasser (Nile). Recent projects such as the Grand Ethiopian Renaissance

Dam (GERD) demonstrate a commitment to exporting energy on a regional scale, while creating vast bodies of water (Liersch *et al.* (2017); Taye *et al.* (2016); Wang *et al.* (2014); Zhang *et al.* (2015). The authors have to give more information about the artificial reservoirs and their utilities to save health and environment… The number of published papers on Scopus on "artificial reservoir" is over 20,000 from 1918 to 2025, reflecting the importance of policymakers to provide water to the population (**Figure 1**). When water is associated with "artificial reservoir", more than 7400 articles are gathered (**Figure 2**). This bibliometric analysis is widely used to evaluate nationally or internationally the quality and/or quality of research in a given topic (van Eck and Waltman, 2014; Mulet-Forteza *et al.*, 2019; Brika *et al.*, 2021; Mouloudi *et al.*, 2023; Laita *et al.*, 2024; Kachbou *et al.*, 2025). China is the most concerned country by this topic, reaching more than 2000 articles, followed by the US (1040 articles) as shown in **Figure 3**.

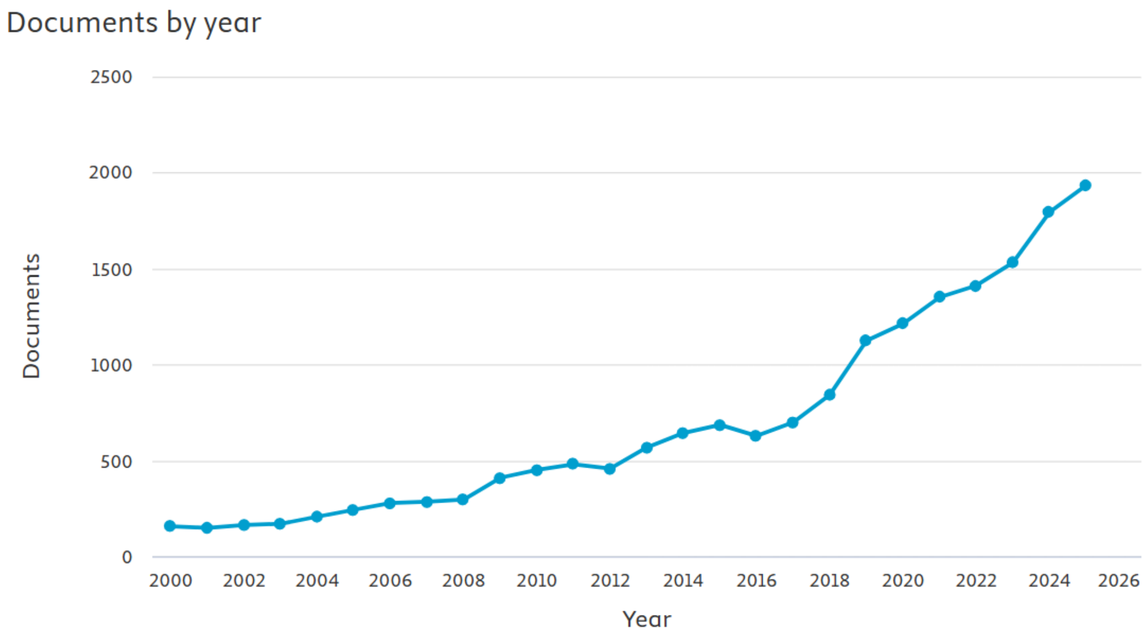

Figure 1: Evolution of articles on "artificial reservoir" from 2000 to 2025

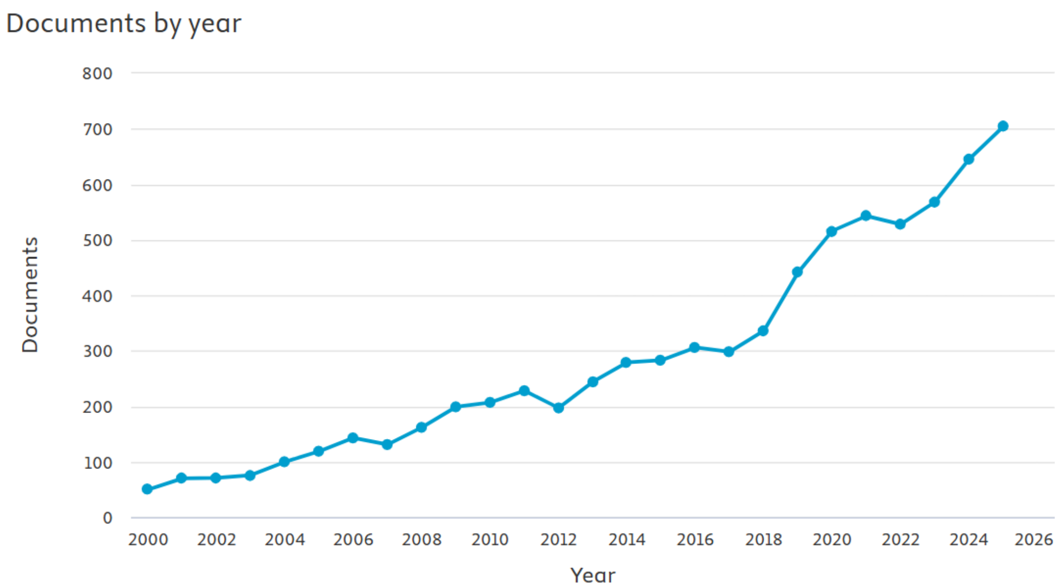

Figure 2: Evolution of articles on "artificial reservoir AND water" from 2000 to 2025

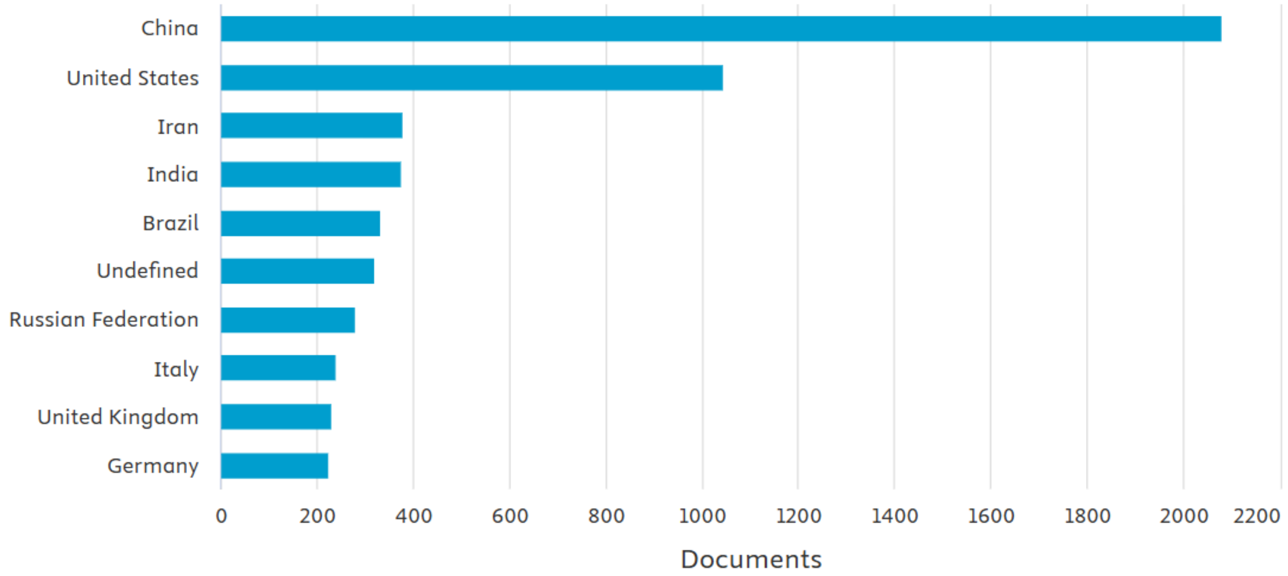

Figure 3: Top ten countries contributing on "artificial reservoir AND water" from 2000 to 2025

The Voronezh Reservoir is an artificial reservoir located on the Voronezh River, entirely within the city of Voronezh, in the Voronezh Region of Russia. It was created between 1971 and 1972 to supply the city with water for industrial purposes. At its inception, it had a surface area of 70 km², a volume of 204 million m³, an average depth of 3.3 m, a maximum depth of 19.4 m, a length of 30 km, and an average width of 1.7 km. The current dimensions of the reservoir are: surface area: 59.9 km²; volume: 0.1993 km³ (Dmitrieva, V.A. 2015).

The purpose of creating the Voronezh Reservoir was to supply industrial and domestic water to Voronezh businesses, for irrigation, navigation, recreation, and domestic use. From a chemical composition standpoint, the reservoir water is classified as calcium and magnesium bicarbonate water. The water's mineral content varies by section, ranging from 0.14 to 0.72 g/L; in some years, it has reached 0.9 g/L (Smirnova *et al.* (1986).

The Voronezh Reservoir plays an important role in the economy of the Voronezh region; however, the significant human pressure it is subjected to generates certain environmental risks: anthropogenic pollution due to inadequate treatment facilities and industrial discharges, geodynamic factors degrading surface water quality: sand accumulation from runoff and storm drains, and bank erosion and the proliferation of dense vegetation in the northern part of the reservoir contributes to flooding (Avakyan, A.B. 1987).

The main sources of pollution in the Voronezh Reservoir are discharges of untreated or insufficiently treated wastewater from industrial facilities, food processing and manufacturing industries, residential and utility buildings, surface runoff from urban and rural areas, and runoff of pesticides and fertilizers from fields (Seydaliev *et al.* (2017).

Given the reservoir's ecological and socio-economic importance, numerous studies have focused on aquatic biodiversity and fisheries (Seydaliev *et al.* (2017). A significant amount of pollutants flowing into the Voronezh reservoir originates from areas where insufficiently treated wastewater from industrial enterprises and the stormwater drainage system of the city of Voronezh is discharged (Chuvychkin *et al.* (2018). The accumulation of pollutants in the reservoir's water and bottom sediments has a negative impact on the water quality of underground infiltration water intakes. The main factor determining the chemical composition of the reservoir's water is surface runoff, which fills and recharges it. The hydrochemical parameters of the Voronezh Reservoir depend on the natural conditions of the catchment area, the nature of anthropogenic impacts, as well as the hydrogeological regime of the active water exchange zone and the meteorological conditions of the year (Mishon, V. M. 2008).

Considering the reservoir's significance, an environmental analysis of industrial wastewater quality was conducted in 2023 on three different samples, after the snowmelt, to assess the current state of the Voronezh Reservoir. These studies focused mainly on the concentrations of calcium, magnesium, chloride, sulfate, carbonate and bicarbonate ions, pH, total hardness, mineralization, dissolved oxygen, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

2. Methodology

2.1 Sample Procurement and Preparation

The wastewater samples were collected from a food processing plant located in Voronezh, Russia. This plant, situated near the Voronezh Reservoir, discharges its wastewater into the reservoir. This wastewater from this food industry was collected in three different environments and analyzed at the Environmental Analysis Laboratory of the Faculty of Geography, Geoecology and Tourism of Voronezh State University (VSU).

2.2 Materials

All chemical reagents utilized in this study were of analytical grade from the environmental laboratory of the Faculty of Geography, Geoecology and Tourism. The experiments were carried out using double distilled water, pH buffer solution, EDTA solution, Eriochrome Black T, sodium borate, $BaCl_2$, HCl, $AgNO_3$, K_2CrO_4, HNO_3, H_2SO_4, Ag_2SO_4, $HgSO_4$, ferroin, and methyl orange. The equipment used included a pH meter, pH electrode, magnetic stirrer, burette, Erlenmeyer flask, filter paper, evaporator, analytical balance, oven, desiccator, reflux condenser, and thermometer.

2.3 Experiments

The elements analyzed are pH, carbonate, bicarbonate, sulfate and chlorine ions, total hardness, quantity of sediments, minerality, COD, solubility, temperature and the analyzed samples were taken from wastewater from the food industry, the COD/BOD ratio of which is typically approximately 2:1; and BOD_5 was determined by calculation using COD, so $BOD_5 = COD/2$.

The methods used are as follows: titrimetry, colorimetry, precipitation, filtration and washing, evaporation, drying and weighing and oxidation methods.

Wastewater samples from a food industry were analyzed using a bathometer, in accordance with GOST 31861-2012 Water.

Methodology for measuring calcium content in natural and treated wastewater samples by titrimetric method. PND F 14.1:2.95-97 (or titrimetric determination of calcium in natural waters); Methodology for measuring chloride content in natural and treated wastewater samples by argentometric method. PND F 14.1:2.96-97; Methodology for measuring hardness in natural and treated wastewater samples by titrimetric method. PND F 14.1:2.98-97; Methodology for measuring carbonate and bicarbonate content in natural water samples by titrimetric method. Determination of sulfates by volumetric iodometric method in natural waters. PND F 14.2.99-97; Methodology for measuring the mass concentration of sulfate ions in samples of natural and waste water using the turbidimetric method. PND F 14.1:2.159-2000; potentiometric (p^H); conductometric (total mineralization), colorimetric and calculation-community or quantitative determination of magnesium in waters using the calculation method (Mg^{2+}) (Cotruvo *et al.* (2017).

The method involves treating a water sample with sulfuric acid and potassium dichromate at a specified temperature in the presence of silver sulfate, an oxidation catalyst, and mercury (II) sulfate, which is used to reduce the effect of chlorides. COD values are then determined in a specified concentration range by measuring the optical density of the test solution at a specified wavelength using a calibration curve for the optical density of the solution versus the COD value.

2.3 Characterization of the sampling medium

The sampling medium is the wastewater from the food industry "Voronezh Bread", an industry located near the Voronezh water reservoir, in the city center of Voronezh in the Russian Federation. **Figure 4** shows the city of Voronezh, the industry and the Voronezh water reservoir.

Figure 4: City of Voronezh, the "Voronezh Bread" industry and the Voronezh water reservoir (Satellite picture, 2023).

This figure (**Figure 5**) characterizes the 3 wastewater sampling environments of a food industry in relation to the Voronezh water reservoir

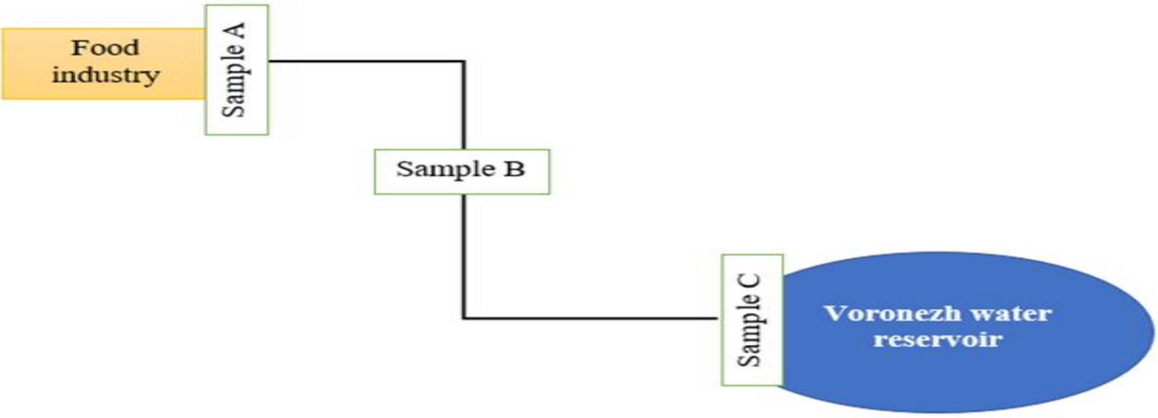

Figure 5: Food industry, Voronezh water reservoir and 3 sampling points.

- Sample A was taken at the source of the food processing plant;
- Sample B was taken midway between the food processing plant and the Voronezh water reservoir;
- Sample C was collected at the mouth of the Voronezh water reservoir.

3. Results and Discussion

The results of water analyses performed on samples taken from wastewater from a food processing plant are presented in the following (**Table 1**).

Table 1: Results of water analyses carried out in May 2023 on 3 wastewater samples from a food processing plant

Elements analyzed/Sample	Sample A	Sample B	Sample C
pH	8.53± 0.35	8.76±0.35	8.88±0.35
Total hardness, mg/l	34.068±4.008	38.076±4.008	36.072±4.008
Ca^{2+}, mg/l	25.25±0.6	25.85±0.6	25.45±0.6
Mg^{2+}, mg/l	8.82±2.1	12.23±2.1	10.62±2.1
SO_4^{2-} , mg/l	44±15	80±15	53±15
Cl^- , mg/l	322.7±64.5	387.2±64.5	354.9±64.5
Cl^- , mg/l	22.56±2.58	25.14±2.58	23.85±2.58
CO_3^{2-}, mg/l	382.8±46.2	429±46.2	409.2±46.2
HCO_3^{1-}, mg/l	704.8±29.1	733.9±29.1	720.7±29.1
Quantity of sediment, g/l	0.25±0.06	0.31±0.06	0.29±0.06
Mineralization, mg/l	193±14	187±14	179±14
COD, mg O_2/l	3.84±2.81	7.04±2.81	7.68±2.81
Solubility, mg/l	< 2.9	<2.9	<2.9
Temperature, ^{o} F	>80	>80	>80
BOD_5, mg O_2/l	(3.84/2) = 1.92	(7.04/2) = 3.52	(7.68/2) = 3.84

Water samples were collected from three different locations, and the results corresponding to several chemical parameters of water from a spring located on private property on the right bank of the reservoir are shown in **Table 1**.

The results of the analyzed water samples, originating from one of the industries discharging their water into the Voronezh Reservoir, are compared with the maximum permissible concentration to determine whether the water from this industry pollutes the Voronezh Reservoir:

The mineral content in polluted industrial wastewater can range from 500 to 5000 mg/L, and this mineralization can include inorganic ions (e.g., Ca, Mg, Na, K), heavy metals (e.g., Pb, Hg, Cd), and anions (e.g., Cl, Sulfate, Nitrate) (Cotruvo *et al.* (2017); Hach Co. 2015a). In our analysis, the mineralization varied from 179 to 193 mg/L, a minimal but not negligible value because it contains the aforementioned elements, which may or may not be polluting. Even this small amount of mineralization can reduce water quality, spread disease, and contaminate food chains.

The amount of sediment in the study water ranged from 0.25 g/L to 0.31 g/L, while polluted industrial wastewater could contain 100 to 1000 mg/L. Sediment in polluted water can be composed of organic matter, heavy metals, organic pollutants, etc. Like mineralization, the amount of sediment in water can reduce water quality, spread disease, and contaminate food chains (Droste, 1997; Devesa *et al.* 2018; Droste, 2019; El Hammari *et al.* 2022).

The hydrogen ion index (pH) ranges between 8.53 and 8.88 and remains within the maximum permissible limits for fishing waters but not required for drinking water (Smirnova *et al.* (1986). Total hardness (Ca and Mg) ranges from 34 to 38 mg-eq/L and remains above the MPC limits for fishery and drinking water bodies (Hach Co. 2015b; Kozisek, F. 2020).

Calcium ions Ca^{2+} range from 25.25 to 25.85 mg/l, Ca ions for polluted groundwater or surface water range from 20 to 200 mg/l and 50 to 500 mg/l for industrial wastewater, which shows that the source of water pollution under study could be due to an introduction of polluted groundwater or surface water (Campbell, A.K. 1990; Hach Co. 2019; Hofman *et al.* (2006).

Magnesium ions (Mg^{2+}) range from 8.82 to 12.23 mg/L. The concentration of polluted industrial wastewater varies from 10 to 100 mg/L, and this concentration confirms that the sample taken from the middle and the mouth of the Voronezh water reservoir is polluted. Mg ions are necessary for the body, but high concentrations can cause problems for human health. The sample taken at the industrial source is not polluted, while the others are polluted. This could be due to other polluted groundwater or surface water flowing into the study water (Hofman *et al.* (2006); Jiang *et al.* (2016); Kass *et al.* (2012).

Sulfate ions SO_4^{2-} range from 44 to 80 mg/l. The WHO standard for a concentration of sulfate ions in water is 250 mg/l and industrial polluted wastewater has a concentration ranging from 50 to 1000 mg/l, even if there is an unknown introduction of sulfate ions for the sample taken from the middle and the mouth of the Voronezh water reservoir, the sulfate ions in the study water are in acceptable quantities for domestic water (Peterson H.G. 1999; Edwards *et al.* (2011).

Chloride ions Cl^- range from 22.56 to 23.85 mg/l. The polluted wastewater has a concentration $\geq$50 mg/l; it is observed that the study water is not polluted with the element chlorine (Meride *et al.* (2016).

Carbonate (CO_3^{2-}) ions in the study water range from 382.8 to 429 mg/L. In the polluted water, carbonate ions range from 10 to 200 mg/L, and bicarbonate (HCO_3^{2-}) ions in the study water range from 704.8 to 733.9 mg/L, with the exception of bicarbonate ions, which are present in excess. Bicarbonate ion concentrations in the polluted water vary from 50 to 500 mg/L; therefore, the study water is industrial wastewater polluted with bicarbonate ions. Even though bicarbonate ions are essential for health, their presence in excess can cause health problems, particularly gastrointestinal disorders (Davis, M.L. 2010; Cadena *et al.* (1974); Crittenden *et al.* (2012).

The solubility of the industrial wastewater study water has a concentration <2.9mg/l. By comparing the concentrations of solubilities in the polluted water: dissolved oxygen (DO) for wastewater has a concentration ranging from 0-2mg/l, calcium carbonate for wastewater has a concentration ranging from 100-500mg/l and 20-100mg/l for surface water, calcium sulfate for wastewater has a concentration ranging from 200-1000mg/l and 50-200mg/l for surface water, sodium chloride for wastewater has a concentration ranging from 100-500mg/l and 20-100mg/l, we find that 2.9mg/l corresponds to the oxygen for the wastewater (Hussain *et al.* (2014).The amount of oxygen that can be held in a certain volume of water depends on the pressure of atmospheric oxygen at the air-water interface, the temperature of the liquid and the concentration of other substances dissolved in water. A certain level of COD is necessary for the normal sedimentation process; It is maintained through mechanical aeration of the so-called "activated sludge"—the dissolved oxygen level in the bacteria-saturated water drops too low, the bacteria die, and decomposition begins if the COD level is excessive (Peterson H.G. 1999).

The BOD value for the study water is 3.84 mg O_2/l and the polluted water has a BOD between 1-10 mg O_2/l for groundwater, 5-50 mg O_2/l for surface water and 50-500 mg O_2/l for wastewater. Based on these reference values for polluted waters, the water sample is not polluted in terms of BOD (Meride *et al.* (2016). Conversely, the COD value for the study water is 7.68 mg O_2/l and the polluted water has a COD between 10-50 mg O_2/l for groundwater, 20-200 mg O_2/l for surface water and 100-1000 mg O_2/l for wastewater and the study water concerns discharges from the food industry, which shows that the industrial wastewater studied is not polluted with COD (Meride *et al.* (2016). Temperatures exceeding 80°F affect the survival and reproduction of aquatic species, promote the growth of bacteria and algae, degrade water quality, increase chemical and biological contaminants, and pose risks to human health in particular and the environment in general, while also influencing solubility (Hussain *et al.* (2014). Sulfate and chlorine ions are present in the Voronezh water reservoir and are within standard with MPC, but total hardness and Mg and Ca ions are in excessive concentrations (Chuvychkin *et al.* (2018).

Table 2: Water quality class depending on pH

Degree of pollution	Quality class	pH value
Extremely clean	1	7,0
Clean	2	6,0-6,9 / 7,1-7,9
Satisfactorily clean	3	5,6-5,9 / 8,0-8,3
Polluted	4	5,5-5,6 / 8,4-8,7
Dirty	5	5,3-5,4 / 8,8-9,5

p^H measurements showed that all water samples had values between 8.53 and 8.88, thus failing to meet the required MPC standards for drinking water. Based on pH values, natural surface waters are classified into the following quality classes (**Table 2**) and the waters studied belong to the fourth class, "polluted" (Muravyov, A. G. 2009).

Correlation Matrix of Pearson

	A	B	C
A	1		
B	,997**	1	
C	,999**	,999**	1

**. The correlation is significant at the 0.01 level (two-sided)

A correlation that is significant at the 0.01 level ($p < 0.01$) means that the probability that the analyzed variables are not related is less than 0.01. This is a fairly high significance level. The presence of such a correlation indicates that the analyzed variables are more strongly related than would be expected by chance.

Conclusion

In conclusion, the increase in carbonate and bicarbonate ion content confirmed by A.L. Chuvychkin, L.A. Yablonskikh, and T.A. Devyatova (Chuvychkin *et al.* (2018)) in their studies on the Voronezh water reservoir aligns with our research on wastewater from a food processing plant discharged into the Voronezh water reservoir.

The total hardness in our study also exceeds the standard. The value of the Quantity of sediment of water attracts considerable attention where it is necessary to conduct other in-depth studies to find all the components detected in this amount of sediment. A comprehensive study is required to determine all the constituents and their concentrations in the mineralization, because it can contain inorganic ions (example: Ca, Mg, Na, K), heavy metals (example: Pb, Hg, Cd) and anions (example: Cl, Sulfate, Nitrate).

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Conflict of Interest: The authors declare that there are no conflicts of interest.

Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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