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Microplastic pollution of the Uglich Reservoir: its content and distribution in abiotic components of the aquatic ecosystem

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Abstract. This study analyzes the pollution of the surface water layer and bottom sediments (BS) of the Uglich Reservoir by microplastics (MP). For the first time, an assessment of the content of plastic particles in the BS of this water body has been conducted. The dynamics of MP concentrations were studied, and their morphometric (size, shape) and colorimetric (color) parameters were characterized in detail. The results obtained in 2024 demonstrated the ubiquitous presence of MP particles in the studied aquatic area. The average concentration in the water column was 43.1 ± 4.8 items/m³, while in the BS this figure reached 38.2 ± 3.8 items/kg. Morphological analysis revealed a predominance of fibers in the abiotic components of the ecosystem, whereas fragments were encountered less frequently, and films were found rarely. The color spectrum of the identified MP displayed significant diversity, encompassing 10 color categories. Particles of grey, blue, and red hues were the most observed.

Keywords: dynamics of concentrations, fibers, films, fragments, bottom sediments, surface water layer

Authors' contribution. *K.V. Maydanov* — conceptualization, development of methodology and design, conducting a research and investigation process (experiment), statistics analysis of obtained data, preparation, creation and presentation of the published work, visualization and data presentation. *A.F. Tarleva* — conceptualization, development of methodology and design, conducting a research and investigation process (material collection), preparation and creation of the published work. *Y.V. Gerasimov*, *R.R. Saifullin* — editing of the published work. All authors have read and approved the final version of the manuscript.

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Загрязнение Угличского водохранилища микропластиком: его содержание и распределение в абиотических компонентах водной экосистемы

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Аннотация. Осуществлен анализ загрязнения поверхностного слоя вод и донных отложений (ДО) Угличского водохранилища микропластиком (МП). Впервые проведена оценка содержания пластиковых частиц в ДО данного водоема. Изучена динамика концентраций МП, а также детально охарактеризованы его морфометрические (размер, форма) и колориметрические (цвет) параметры. Результаты, полученные в 2024 г., продемонстрировали повсеместное присутствие МП частиц в исследуемой акватории. Средняя концентрация их в водной толще составила $43,1 \pm 4,8$ ед./м³, в то время как в ДО этот показатель достиг $38,2 \pm 3,8$ ед./кг. Морфологический анализ выявил преобладание волокон в абиотических компонентах экосистемы, в то время как фрагменты встречались реже, а пленки были обнаружены единичные. Цветовая гамма идентифицированного МП отличалась значительным разнообразием, охватывая 10 цветовых категорий. Наиболее часто отмечались частицы серого, синего и красного оттенков.

Ключевые слова: динамика концентраций, волокна, пленки, фрагменты, донные отложения, поверхностный слой воды

Вклад авторов. Майданов К.В. — концептуализация, разработка методологии исследования, проведение исследовательского процесса (эксперимент), статистический анализ полученных данных, подготовка и создание рукописи, визуализация данных. Тарлева А.Ф. — концептуализация, разработка методологии исследования, проведение исследовательского процесса (сбор материала), подготовка и создание рукописи.

Герасимов Ю.В., Сайфуллин Р.Р. — редактирование рукописи. Все авторы ознакомлены с окончательной версией статьи и одобрили ее.

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Заявление о конфликте интересов. Авторы заявляют об отсутствии конфликта интересов.

Заявление о доступности данных. Все данные, полученные в ходе этого исследования, включены в опубликованную статью.

Заявление об использовании технологий искусственного интеллекта. При создании настоящей статьи использовался онлайн-сервис на базе искусственного интеллекта (ChatGPT) для редактирования переведенного на английский язык текста. Авторы заявляют, что полностью осознают и принимают на себя всю полноту ответственности за содержание данной рукописи. Использование инструментов искусственного интеллекта носило вспомогательный характер и не заменяло экспертного суждения, критического мышления и научной добросовестности авторов.

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Introduction

The Uglich reservoir, located in the central part of Russia on the Volga River, is an important link in the cascade of the Volga reservoirs. Created in 1939, it stretches for 302 km along the riverbed, covering the territories of the Yaroslavl and Tver regions [1]. The reservoir performs a number of important functions, including regulating the Volga runoff, providing navigation, hydropower, and recreation and fishing. The area of the water mirror is 249 km², and the total volume is 1.25 km³ [2].

However, the reservoir's intensive use for decades has led to a number of environmental issues that require close attention. One of the most pressing problems is water pollution from both point and diffuse sources. The main polluters are industrial plants, agricultural land and public water supplies located in the reservoir basin [3]. As a result, the concentration of organic substances, nutrients (nitrogen, phosphorus), heavy metals and synthetic substances has increased, affecting water quality and aquatic ecosystems [4].

In recent years, increasing attention has been paid to the pollution of marine and freshwater bodies of water. Studies show that microplastics (MP), when released into the aquatic environment, can accumulate in hydrobiotic organisms, disrupting

their physiological processes and threatening the entire food chain [5]. Information on the study of MP content and distribution in the basin of the Uglich reservoir is unique in the available literature, so there is an urgent need to intensify scientific research work to assess the extent of water pollution and develop measures for its prevention.

The purpose of the study is to assess the spatial distribution of MP in surface water layers and the bottom sediments (BS) of the Uglich reservoir, as well as to conduct its quantitative and qualitative analysis.

Materials and methods

Sampling station. In September 2024, 19 samples were obtained from two mediums during expeditionary studies: 15 samples were taken from the surface water layer and 4 were BS. Sampling was carried out from the research vessel “Akademik Topchiev” on 5 stations, which are distributed throughout the water reservoir. Significant factors such as the proximity to major population centres and the location of tributary sections of rivers (Table) were considered in determining station coordinates.

Characterization of sampling sites and regionalization of the Uglich Reservoir basin

Point Code	Coordinates	Large rivers	Nearest settlement	Water samples	Bottom sediment samples
UgR–1	56°47.313' N 37°14.830' E	Dubna river	Dubna (Moscow oblast)	+	+
UgR–2	57°04.189' N 37°31.207' E	Medveditsa river	Between Kimry and Kalyazin (Tver Oblast)	+	+
UgR–3	57°16.111' N 37°43.375' E	Kashinka river	Kalyazin	+	+
UgR–4	57°23.339' N 38°6.504' E	Tursha and Puksha rivers	Between Kalyazin and Uglich (Yaroslavl oblasts)	+	–
UgR–5	57°28.364' N 38°17.049' E	Mimosnya river and the Grekhov Stream	Uglich	+	+

Source: compiled by K.V. Maydanov, A.F. Tarleva.

Collection of material. Sampling was carried out by means of a three-fold filtration of 100 litres of water through a planktonic network with a filter hole size of 74 µm at each station. Samples of BS with a mass of about 1.5–2.0 kg were selected using the metal dye cutter of the Petersen system with a known capture area of 1/40 m² (this figure was used for the possibility of recalculating the MP content per surface area). The samples obtained were immediately transferred to glass containers with metal lids and preserved by cryogenic storage until laboratory testing [6].

Sample preparation, extraction and methods for analysis of MP particles. The procedure for laboratory preparation of water and BS samples followed by

separation of MPs was carried out in accordance with the authors' methodological recommendations, which included 4 consecutive steps: flotation, filtration, screening and purification of organic material from the samples [7; 8]. For the BS, the raw mass of each sample was determined before work, after which each sample was dried at 80–85°C until an air-to-dry state was reached and used for subsequent research on MPs. Identification of microplastic particles was carried out by a visual method using light microscopy (stereoscopic microscope Biomed MS-2 ZOOM), through which quantitative indicators and morphological features including the type of polymer were determined, color and size characteristic. The morphological classification presented in the monograph [6] was used to describe the qualitative features of MP.

Quality control. Errors due to reagent contamination during sampling preparation were offset by analysis of control solutions prepared from distilled water at a ratio of 1:7 (one control sample per 7 water samples). “The ‘blank’ control sample was replaced with distilled water that had been finely filtered, and all further test preparation steps were carried out in full compliance with the procedures applied to the experimental samples and using the same reagents. In order to minimize the risk of further contamination of MP samples during reagent preparation, additional filtration of distilled water acting as a solvent was carried out through a metal sieve with a cell size of 25 μm . All reagents were also filtered just before being connected to the sample.

Statistical evaluation. The study calculated the arithmetic mean and standard error for each series of samples to be analyzed from the empirical data obtained. To estimate statistically significant differences in the total number of microparticles between results obtained in different series, the Tukey criterion was applied. The validity of the results of the mathematical-statistical processing was set at 95% ($p < 0.05$). For statistical analysis, the specialized software R v. 4.5.0 was used [9].

Results of the study

Surface layer of water. All samples analyzed were found to contain microplastic particles. The concentration of MPs in the aquatic environment ranged from 40.0 ± 5.1 units/ m^3 (UgR-3 point below the mouth of the Kashinka river) to 65.6 ± 8.1 units/ m^3 (UgR-5 point covering the outfall of rivers) (Figure 1).

The minimum values of the MP are fixed in the mean flow of the reservoir, particularly at the entrance to the Kashinka river, and also at the UgR-2 stations at the mouth of the Medvedica river and UgR-4 located below the mouths of the Tursha and Puksha rivers, where particle density was 43.3 ± 3.9 units/ m^3 and 42.2 ± 8.7 units/ m^3 respectively. On the other hand, in the upper section of the

reservoir, the following picture was observed: at the point UgR-1, located 10 km below Ivankovskaya HPP, the accumulation of MP was significantly higher compared to the above stations and reached 55.6 ± 4.1 units/m³ (*). The highest concentration of microparticles in the water was recorded in the adjoining mud of the reservoir at UgR-5 (*).

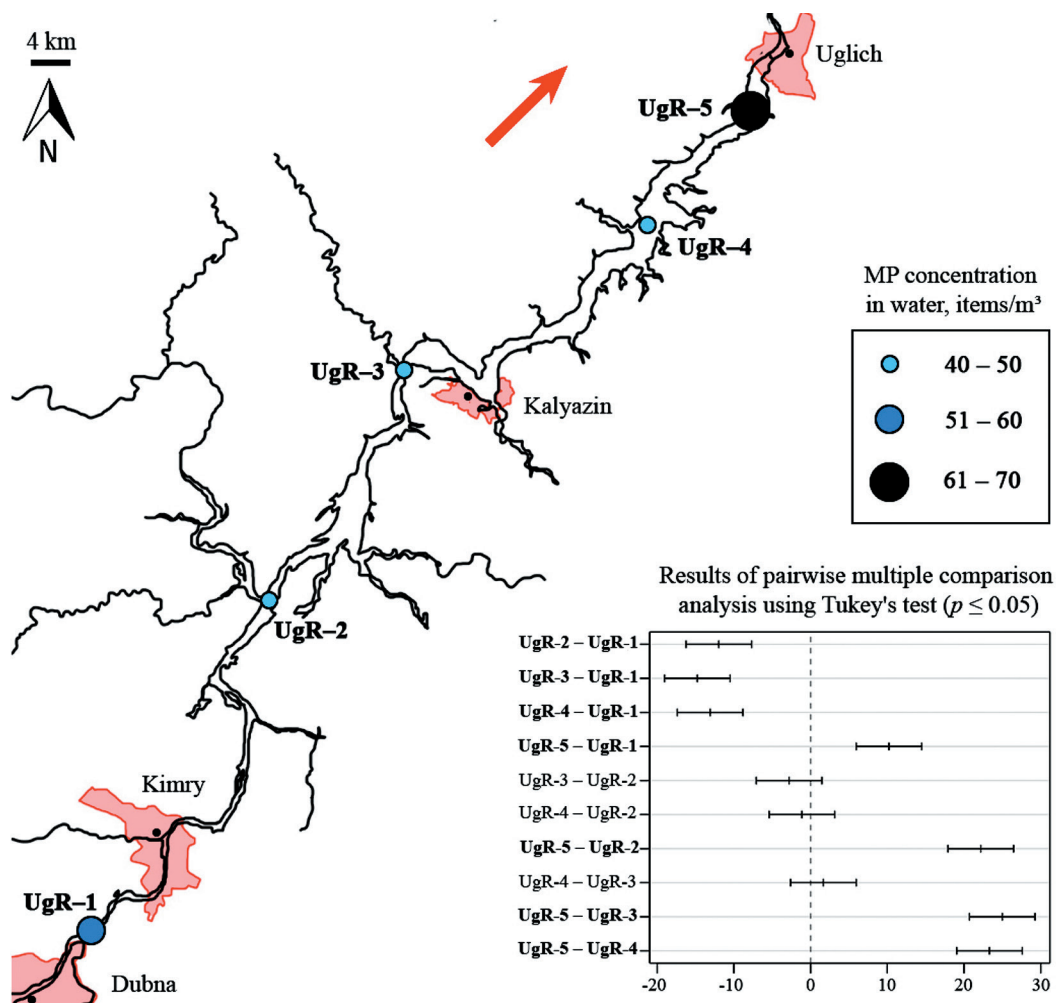


Figure 1. Microplastic particle concentration in water of the Uglich Reservoir (units/m³): black dots indicate major settlements (red line demarcates settlement boundaries), red arrow corresponds to the direction of the Volga River flow in this regulated section. The graph presents the results of pairwise multiple comparison analysis using Tukey's HSD test for $p \leq 0.05$.

Source: compiled by K.V. Maydanov.

Analysis of samples collected from the water surface revealed a variety of morphological forms of MP (Figure 2). The dominant type of particles found in samples were fibers, which accounted for 87.4% of the total number of particles identified. Fragments of the irregular (angular) shape were recorded at only three stations (UgR-3, UgR-4, UgR-5) and accounted for 10.81% of the total number of

particles detected. The films, which are thin plates, were found only in the sealing part of the reservoir and accounted for a small share — 1.8%.

In addition, a detailed analysis of the MP dimension and colour range was carried out. The size range of plastic particles at all sampling points ranged from 0.1 to 4.9 mm, with the predominant part less than 2 mm in length.

An analysis of the color distribution relative to the morphological structure showed that among the fibers, gray (30.1%), transparent (15.8%), black (15.3%) and blue (14.8%) particles were most common. At the same time, for the fragments the most characteristic were the green (41.7%) and blue (29.2%) colors (Figure 3).

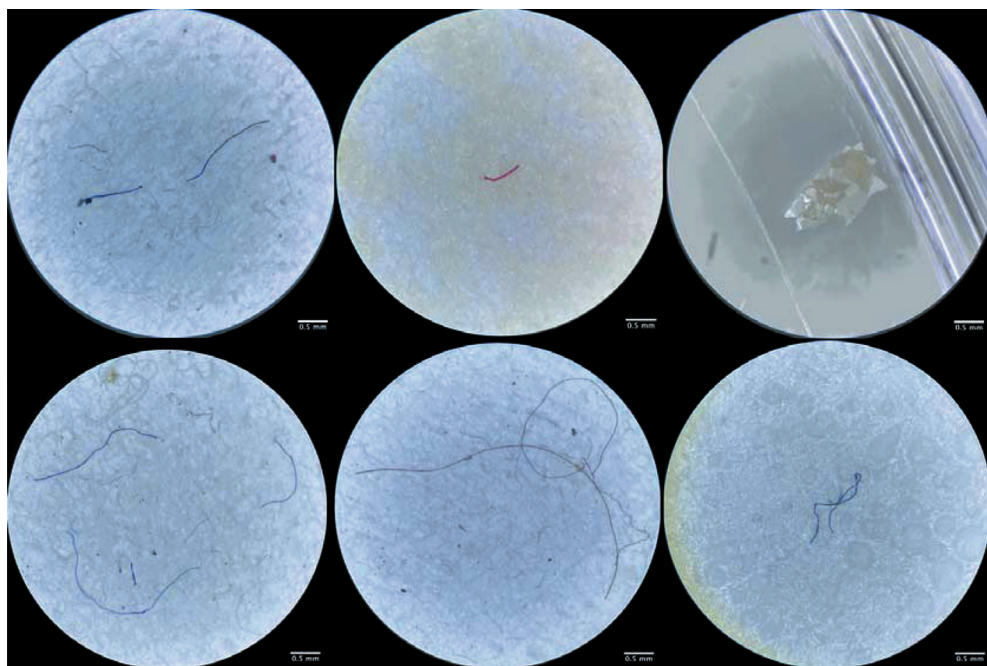


Figure 2. Microplastic particles in water samples from the Uglich Reservoir: the scale bar in the photographs corresponds to 0.5 mm.

Source: photo by K.V. Maydanov.

Bottom sediments. The study found widespread presence of MP particles at all sampling stations. Their maximum concentration was recorded at the UgR-3 point — the site of the Kashinka river influx in the Volga river — and amounted to 47.6 units/kg (400 units/m² — equivalent in bottom area). The type of soil at this point was characterized as gray sandstone. In samples of the sand type of soil taken from the mouth of the Medvedica river, the MP content reached 40 units/kg (320 units/m²), and at the UgR-1 point above, concentration was 29.9 units/kg (240 units/m²). Analysis of samples taken from the sealing part of the reservoir, where the soil is presented in grey, revealed an MP content at 35.1 units/kg, which corresponds to 160 units/m². Thus, the results indicate the highest degree of BS pollution in the central part of the Uglich reservoir in the area of soil transition from sandy to gray sandstone.

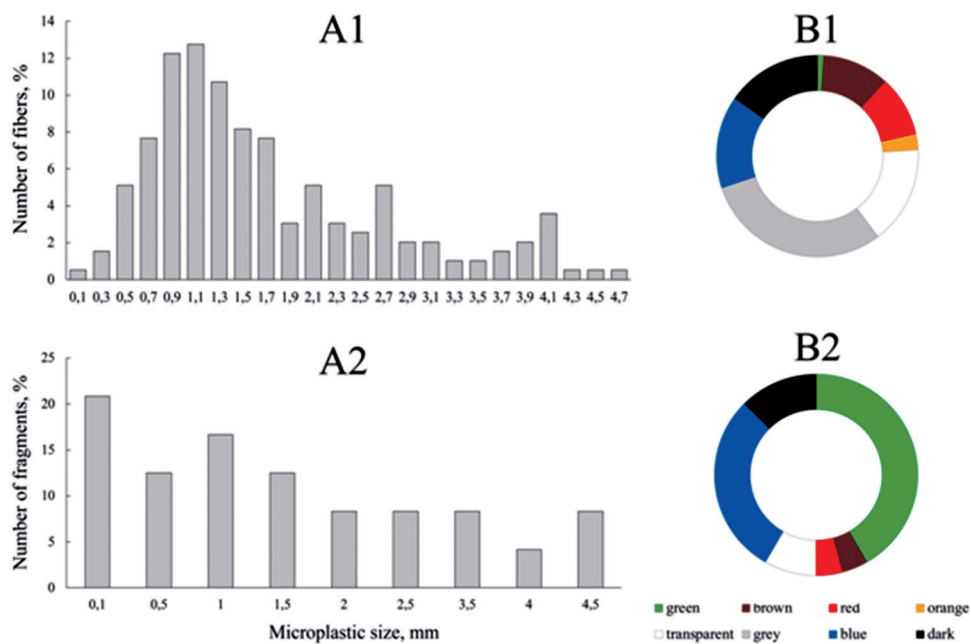


Figure 3. The percentage composition within the size range and the overall color distribution of microplastic particles from water samples, in relation to their morphological structure, across all sampling points (A1, B1 — fibers and A2, B2 — fragments)

Source: compiled by K.V. Maydanov.

Analysis of the morphological structure of the detected MP particles revealed fiber dominance (59.1%), in turn fragments and films made up 27.3 and 13.6% respectively. It is noteworthy that at the UgR-5 point only fibers were found, while at other sampling points there was a variety of morphological forms (Figure 4).

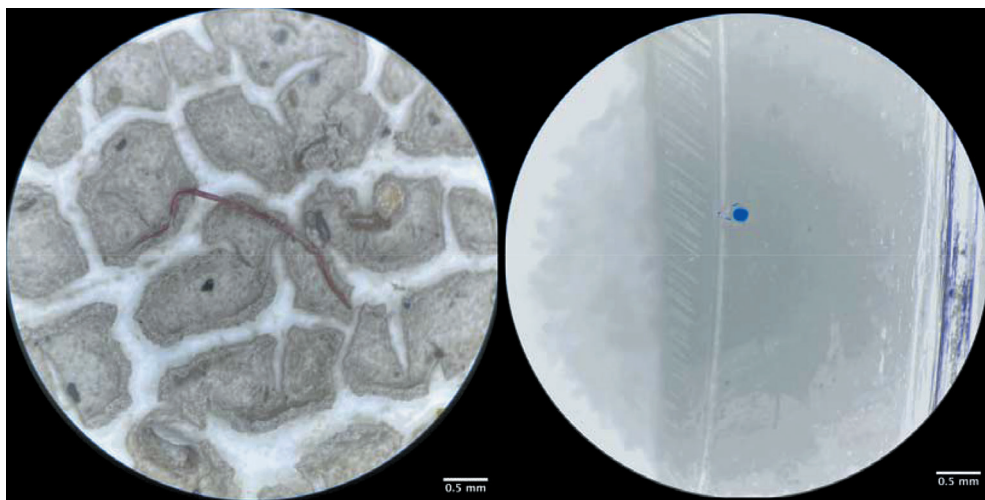


Figure 4. Microplastic particles in bottom sediments samples from the Uglich Reservoir: the scale bar in the photographs corresponds to 0.5 mm.

Source: photo by K.V. Maydanov.

Evaluation of the dimensional characteristic of the MP detected showed that the particle length varies from 0.7 to 4.9 mm. The largest number of fibers (65.4%) were between 1.8 and 3.4 mm, while the particles of 2.7–2.9 mm size (66.7%) predominated among the films. The vast majority of fragments (63.4%) were in the 3.7–4.9 mm size range.

Analysis of the colour gamut revealed blue predominance among fibers and fragments (53.8 and 58.3%, respectively), while red was the most common color among films (33.4%) (Figure 5).

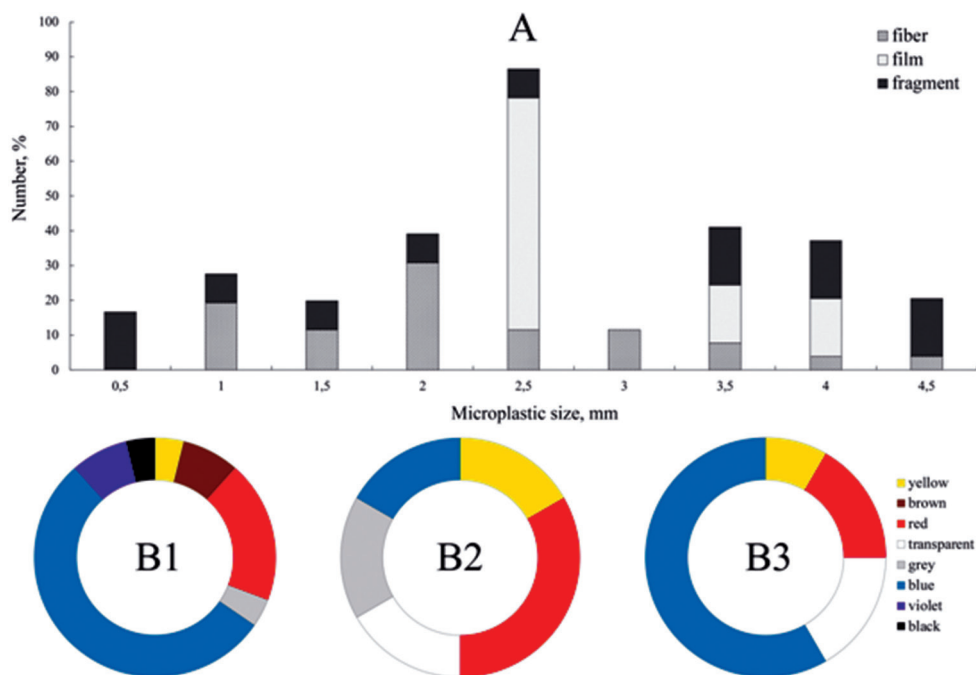


Figure 5. The percentage content in the size range (A) and the general distribution of colors of microplastic particles from sediment samples relative to their morphological structure across all sampling points:

B1 — fibers; B2 — films; B3 — fragments

Source: compiled by K.V. Maydanov.

Discussion and outcomes

The results of this study showed the ubiquitous presence of MP in the water basin of the Uglich reservoir, fixed both in the surface water layer and in the BS. The analysis of the data obtained allowed to determine the average concentration of MP in water for the Uglich reservoir at 43.1 ± 4.8 ppm. The MP content in the BS, in turn, is estimated at 38.2 ± 3.8 units/kg. The observed variability of MP concentrations at different sampling stations may be due to the random distribution of particles in the reservoir due to their physico-chemical properties, influenced by hydrodynamic processes occurring in the water body, and the mechanical composition of the soil for BS.

Our analysis of the MP concentrations in the abiotic components of the Uglich reservoir compared with previously published data indicates compliance with low pollution levels. Thus, according to the results of a global study of water samples from 168 rivers average MP concentrations reached 11128 units/m^3 , and in UP 96 rivers 1161 units/kg [10; 11] Research by the scientists from Kazan (Volga Region) Federal University conducted in Meshinsky Bay at the Kuybyshev Reservoir in 2021 showed that MP concentrations in water were $20.5 \pm 22.3 \text{ units/m}^3$, and in the case of the BS in clay — $44.7 \pm 41.8 \text{ units/kg}$, and corresponded to a low level of pollution [12]. In turn, data by A.A. Ershova [13] show high pollution of the river basin of the Volga river in the area of Nizhny Novgorod: the average content of MPs in water was 600 units/m^3 [13]. According to researchers of the Faculty of Geography at MSU named after M.V. Lomonosov in October 2020 analysis of water in the vicinity of the Dubna town revealed a negligible MP content, not exceeding 0.5 units/m^3 , with a maximum recorded value of 0.75 units/m^3 . Below the current of the Dubna town, there was an increase in the concentration of microplastics several times, with fluctuations ranging from 0.27 to 0.75 units/m^3 . The lowest MP content was recorded in the area of the Uglich city and amounted to 0.215 units/m^3 [14]. It is important to emphasize that the discrepancy between the results obtained in this work and the data presented in the scientific paper is due to differences in sampling methodology and use of different equipment. In particular, the work [14] used a Manta network with a filter cell size of $300 \text{ }\mu\text{m}$, which could affect the selectivity of MP particle selection.

Based on the global practice of studying MP particles, the most common morphological types are fibers and fragments [15]. Results of morphological analysis revealed the dominance of fiber particles of MP in all studied samples taken in 2024 at the Uglich reservoir. The detection of this type of MP in high concentrations allows to make a suggestion about sources of inputs into the water, related to the use of textile materials and artificial polymers in their composition, various fishing gear. Moreover, the fiber morphology of the material, characterized by an elongated shape and a large surface area, favors organic matter adsorption. This process, in turn, contributes to increased density and subsequent deposition into the BS.

The size of the MP particles detected varied over a wide range, probably due to different mechanisms for decomposition of polymeric materials occurring in aquatic environments. The analysis of MP size distribution gives the following average values: $1.86 \pm 0.13 \text{ mm}$ in the surface water layer and $2.77 \pm 0.34 \text{ mm}$ in the BS. Analysis with Kazan (Volga Region) Federal University data, where the MP dimensions in water were $2.074 \pm 1.885 \text{ mm}$ and BS — $0.145 \pm 0.212 \text{ mm}$, showed a discrepancy in the dimensional characteristics of MP in BS, which may be due to

differences in stratification of sampling areas: In the present study, samples of BS were mainly taken in the ration zone, while in the cited work selection was made in the coastal part of the water basin [12].

The MP color palette was characterized by considerable diversity: the particles detected were divided into 10 color categories, with gray, blue and red colors being the most common. In the BS samples of the Azov Sea, transparent and black particles dominated, amounting to 90 and 7.5% respectively, while the proportion of blue, white, red, yellow, pink and purple particles was negligible — about 2% [16]. The analysis of BS samples from Lake Baikal revealed the presence of MP 12 color groups. Black (52.9%), blue (28.7%) and green (10.8%) particles predominated among the fibers, while the fragments were predominantly white (40.4%), blue (25.3%) and red (15.2%) [17]. Differences in colour characteristics may serve as indicators of the sources of MP inputs into a water body and also reflect possible mechanisms for its degradation.

Conclusion

In 2024, the results of the studies carried out demonstrated the widespread distribution of MP in the water ecosystem of the Uglich reservoir, confirming its role as a pollutant of the abiotic components of the environment. The presence of polymeric particles, varying in morphological characteristics and size, has been clearly recorded both in the surface layers of the water column and in the BS, indicating a global scale of contamination. The pollution of aquatic ecosystems is a significant issue that requires strategies to reduce its impact. The results of this study demonstrate the wide distribution of this pollutant in the BS and water masses of the Uglich reservoir, contributing to the formation of a database for monitoring and regulation of ecological condition. These data also deepen the understanding of the scale and characteristics of pollution.

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