УДК 504.054+691.175
https://doi.org/10.36906/2311-4444/25-1/09

A.S. Tomilov, T.V. Storchak, S.B. Gogoi, M.I. Bitner, N.A. Didenko

MICROPLASTICS IN FRESHWATER ECOSYSTEMS: SOURCES, RESEARCH METHODS AND ENVIRONMENTAL CONSEQUENCES. EXPERIENCE OF RUSSIAN RESEARCHERS AND PROSPECTS FOR POLLUTION CONTROL IN KHANTY-MANSIYSK AUTONOMOUS OKRUG – YUGRA

Томилов А.С., Сторчак Т.В., Гогои С.Б., Битнер М.И., Диденко Н.А.

МИКРОПЛАСТИК В ПРЕСНОВОДНЫХ ЭКОСИСТЕМАХ: ИСТОЧНИКИ, МЕТОДЫ ИССЛЕДОВАНИЯ И ЭКОЛОГИЧЕСКИЕ ПОСЛЕДСТВИЯ. ОПЫТ РОССИЙСКИХ ИССЛЕДОВАТЕЛЕЙ И ПЕРСПЕКТИВЫ КОНТРОЛЯ ЗАГРЯЗНЕНИЯ В ХМАО-ЮГРЕ

Abstract. This article presents an analytical review of scientific studies focusing on the issue of microplastic pollution in freshwater bodies in Russia. The study examines in detail the primary sources of microplastic particles entering aquatic environments, including domestic and industrial wastewater, rainwater runoff, urban dust, and diffuse sources such as the decomposition of plastic waste in landfills and natural environments. Special attention is given to the methods of collecting water and sediment samples employed by various research groups. Contemporary approaches to microplastic detection and identification are described, including visual methods using optical and electron microscopy, Fourier-transform infrared (FTIR) spectroscopy, and Raman spectroscopy. The review presents data on the impact of microplastics on biological organisms and ecosystems, including disruptions in trophic networks and impairments in the functioning of the endocrine, reproductive, and immune systems. Aspects of the mechanical and toxicological effects of microplastics are considered, as well as the processes of contaminant sorption onto their surfaces. The conclusion highlights the need for further standardization of research methodologies and additional investigations to gain a deeper understanding of the extent of microplastic distribution in freshwater ecosystems, particularly in regions with insufficient empirical data. The importance of developing comprehensive strategies to minimize microplastic pollution in freshwaters is emphasized.

Аннотация. В статье представлен аналитический обзор научных исследований, направленных на изучение проблем загрязнения пресноводных водоёмов России микропластиком. В исследовании подробно рассматриваются основные источники поступления частиц микропластика в водную среду, включая бытовые и промышленные сточные воды, дождевые стоки, городскую пыль, а также диффузионные источники, такие как разложение пластиковых отходов на полигонах и в природной среде. Особое внимание уделено методам сбора образцов воды и донных отложений, используемым различными исследовательскими группами. Описаны современные подходы к обнаружению и идентификации микропластика, в том числе визуальные методы с применением оптической и электронной микроскопии, Фурье-ИК-спектроскопии (FTIR), а также рамановской спектроскопии. В обзоре представлены данные о влиянии микропластика на биологические организмы и экосистемы в целом, включая нарушения трофических сетей, сбои в функционировании эндокринной, репродуктивной и иммунной систем. Рассмотрены аспекты механического и токсикологического воздействия микропластика, а также процессы сорбции загрязняющих веществ на его поверхности. В заключении подчеркивается необходимость дальнейшей унификации методик исследования и проведения дополнительных изысканий для углубленного понимания масштабов распространения микропластика в пресноводных экосистемах, особенно в регионах с недостаточным количеством эмпирических данных. Подчеркивается важность разработки комплексных стратегий по минимизации загрязнения пресных вод частицами микропластика.

Key words: microplastics; pollution; surface waters; control methods; Khanty-Mansiysk Autonomous Okrug-Yugra.

About the authors: Andrej S. Tomilov, SPIN-code: 8687-8307, ORCID: 0009-0009-0057-6898, Nizhnevartovsk State University Nizhnevartovsk, Russia, andrew.istomin400@gmail.com; Tatyana V. Storchak, ORCID: 0000-0002-5926-433X, Candidate of Biological Sciences, Nizhnevartovsk State University, Nizhnevartovsk, Russia, tatyanastorchak@yandex.ru; Dr. Subrata Borgohain Gogoi, ORCID: 0000-0001-6347-5853, Professor, Department of Petroleum Technology Dibrugarh University, Assam-786004, India, subrata@dibru.ac.in; Maria I. Bitner, SPIN-code: 5062-9728, ORCID: 0000-0002-6942-5838, Nizhnevartovsk State University, Nizhnevartovsk, Russia, m.i.sid@yandex.ru; Nadezhda A. Didenko, SPIN-code: 9525-0364, ORCID: 0000-0002-0206-437X, Nizhnevartovsk State University, Nizhnevartovsk, Russia, didenkona@yandex.ru.

Ключевые слова: микропластик; загрязнение; поверхностные воды; методы контроля; ХМАО-Югра.

Сведения об авторах: Томилов Андрей Сергеевич, SPIN-код: 8687-8307, ORCID: 0009-0009-0057-6898, Нижневартовский государственный университет, Нижневартовск, Россия, andrew.istomin400@gmail.com; Сторчак Татьяна Викторовна, ORCID: 0000-0002-5926-433X, канд. биол. наук, Нижневартовский государственный университет, Нижневартовск, Россия, tatyanastorchak@yandex.ru; Д-р Гогои Субрата Боргохайн, ORCID: 0000-0001-6347-5853, профессор, факультет нефтяных технологий Университета Дибругарх, Ассам-786004, Индия, subrata@dibru.ac.in; Битнер Мария Ивановна, SPIN-код: 5062-9728, ORCID: 0000-0002-6942-5838, Нижневартовский государственный университет, Нижневартовск, Россия, m.i.sid@yandex.ru; Диденко Надежда Алексеевна, SPIN-код: 9525-0364, ORCID: 0000-0002-0206-437X, Нижневартовский государственный университет, Нижневартовск, Россия, didenkona@yandex.ru.

Tomilov A.S., Storchak T.V., Gogoi S.B., Bitner M.I., Didenko N.A. Microplastics in Freshwater Ecosystems: Sources, Research Methods and Environmental Consequences. Experience of Russian Researchers and Prospects for Pollution Control in Khanty-Mansiysk Autonomous Okrug – Yugra // Вестник Нижневартовского государственного университета. 2025. № 1(69). С. 111-135. https://doi.org/10.36906/2311-4444/25-1/09

Tomilov, A.S., Storchak, T.V., Gogoi, S. B., Bitner, M.I., & Didenko, N.A. (2025). Microplastics in Freshwater Ecosystems: Sources, Research Methods and Environmental Consequences. Experience of Russian Researchers and Prospects for Pollution Control in Khanty-Mansiysk Autonomous Okrug – Yugra. *Bulletin of Nizhnevartovsk State University*, 1(69), 111-135. https://doi.org/10.36906/2311-4444/25-1/09

Introduction

The history of plastics began in 1862, when A. Parkes patented his invention – Parkesine, which became the first artificial plastic and a cheap and colorful substitute for ivory [42]. Since then, humanity has produced about 9 billion tons of plastic, and only 9% of it has been recycled [33]. A substantial proportion of polymeric waste is directed to municipal solid waste landfills, while a fraction becomes dispersed within the environment. It is estimated that approximately 13 million tons of plastic enter the world’s ocean basins annually [33]. The propensity of plastic fragments to remain buoyant in aquatic environments is attributable to the low density of the material, which approximates that of water. This characteristic increases the likelihood of their presence both within the water column and at the water’s surface. The degradation and fragmentation of plastics into smaller particles increases the probability of their ingestion by aquatic organisms [3]. Of particular concern is the ability of plastic particles to accumulate metals and other contaminants on their surface directly from the water column or the surface microlayer [1; 17; 39], thereby transforming microplastics into a secondary source of various pollutants. It is important to note that microplastics represent an extremely heterogeneous group of particles, exhibiting variations in shape, size, color, density, and chemical composition. Due to this heterogeneity, researchers face a major challenge in quantifying microplastics in the environment: the lack of reliable and standardized methodologies for sampling, preparation, and detection [39].

In this study, we attempted to consider the sources of microplastic in surface waters and its impact on individual organisms and ecosystems. An analysis and generalization of scientific publications on the presence of microplastic particles in surface waters of Russia and the Khanty-Mansi Autonomous Okrug – Yugra were conducted. A review of existing methods and approaches to sampling and identifying microplastic in freshwater bodies and watercourses is also presented.

Classification. Sources of microplastic input into surface waters

Microplastics are a heterogeneous group of plastic fragments, characterized by a size of less than 5 millimeters, that are found in various environmental matrices [41]. From the perspective of ecological research, microplastics are considered a complex stressor capable of eliciting a wide range of adverse effects in the environment. While a universally accepted classification system for microplastics does not exist, a convenient differentiation based on ten size classes is commonly employed: class 1 (<20 μm); class 2 (20–40 μm); class 3 (40–60 μm); class 4 (60–80 μm); class 5 (80–100 μm); class 6 (100–500 μm); class 7 (500–1000 μm); class 8 (1000–2000 μm); class 9 (2000–5000 μm); and class 10 (>5000 μm). Microplastics are also classified according to the shape of the particles, i.e., fibers, films, or granules [24; 41].

When considering the ways in which microplastics enter the surface waters of rivers and water bodies, the following should be highlighted:

1. Domestic Wastewater (Household Sewage). The reasons for the appearance of microplastics in domestic wastewater are:

– cosmetic products with microplastic granules that have replaced natural exfoliating agents and toothpastes with plastic microbeads for removing plaque and stains [27];

– washing synthetic textiles in industrial laundries and households creates microplastics as a result of wear and tear and fiber separation [4; 28; 50]. It is estimated that about 35% of microplastics in oceans are fibers from synthetic textiles [6];

– other consumer products that can release microplastics into sewage systems include glitter and contact lens cleaning agents [27].

2. Stormwater Runoff. The reasons for the appearance of microplastics in stormwater runoff are:

– wear and tear of road markings (paint, thermoplastic, polymer tape, and epoxy resin) [5];

– wear and tear of vehicle tires during movement (tire particles consist of a matrix of synthetic polymers, specifically styrene-butadiene rubber (approximately 60%), mixed with natural rubber and many other additives) [5].

3. Urban Dust. The reasons for the appearance of microplastics in urban infrastructure (with subsequent entry into stormwater runoff) are:

– wear and tear of infrastructure (household dust, urban dust, artificial turf, paint and plastic coatings) and high-pressure washing with abrasive particles [4].

In addition to the aforementioned factors, it is important to emphasize the significant contribution of diffuse sources of plastic pollution, which represent the direct entry of polymeric materials (such as packaging, disposable tableware, household items, etc.) into aquatic environments and hydrological systems in the form of domestic waste. These materials can enter not only directly into water bodies, but also accumulate in coastal zones, spreading over significant areas. As a result of abiotic and biotic factors, the polymers undergo degradation and fragmentation, leading to the formation of microplastic particles [49].

Microplastics can penetrate aquatic ecosystems through a multitude of diverse sources, and researching the pathways of entry is an essential aspect for assessing the scale of this environmental threat.

The impact of microplastics on organisms and ecosystems

Currently, the study of the impact of microplastics on biological organisms and ecosystems is becoming important and relevant in the field of scientific research. Microplastics can affect a wide range of biological species, from microscopic life forms such as phyto- and zooplankton to larger representatives of the fauna, including fish and mammals [9]. Research results indicate that exposure to microplastics can lead to mechanical damage, toxic reactions and reproductive dysfunction in organisms [19]. Microplastics have been found to exert effects on various systems in animals and humans, namely:

– digestive system: microplastics can induce alterations in the gut microbiome, leading to an imbalance between beneficial and detrimental bacteria.

– respiratory system: inhalation of microplastics can induce oxidative stress in the respiratory tract and lungs, with observed effects including coughing, sneezing, and dyspnea due to inflammation and damage.

– endocrine system: microplastic particles can interfere with the production, release, transport, metabolism, and excretion of hormones.

– reproductive system: various endocrine disorders, including metabolic disorders, can lead to changes in fetal development or reproductive disorders (such as infertility, miscarriage, and congenital malformations).

– complex immunological effects: cumulative exposure to microplastics has induced chronic inflammation and changes in homeostasis in animal experiments, and a study on human lung cells showed that microplastics can regulate the expression of genes and proteins involved in the immune response [19].

Microplastics have been shown to alter the composition of the gut microbiome, increasing the diversity and abundance of microorganisms [20, 30]. Microplastics can disrupt the intestinal barrier, inducing inflammation and allowing translocation into the bloodstream [30, 36].

Furthermore, studies using digestion models have demonstrated that polyethylene terephthalate particles undergo biotransformation, altering the composition of the microbial community in the large intestine and forming biofilms [32]. Microplastic particles are capable of accumulating in the lumen of the gastrointestinal tract, causing disruption of the intestinal microbiocenosis, leading to dysbiosis. This process can trigger the development of systemic inflammation and serve as a trigger for a range of chronic pathologies, including conditions such as obesity, diabetes mellitus, cardiovascular diseases, and autoimmune disorders [4].

Microplastics affect not only individual species, but can also impact the ecosystem as a whole. Changes in the population size of some species can lead to destabilization of food chains and thus cause an imbalance in the structure of ecosystems. [9].

Microplastics exert an influence on “soil-plant” and “water-plant” ecosystems. The incorporation of microplastics into the soil matrix can substantially modify the physicochemical properties of the soil, such as particle aggregation, bulk density, and water-holding capacity. Furthermore, the presence of microplastic particles in the aquatic environment is capable of altering water quality parameters, including the total concentration of dissolved and suspended solids, pH level, and dissolved oxygen content [9].

The accumulation of microplastic particles on the water surface is capable of modifying the concentration of organic compounds and the rate of oxygen consumption, which potentially impacts biological processes [14]. Zooplankton that consume microplastics can exacerbate the decline in dissolved oxygen levels in the ocean through a number of mechanisms. These include a reduction in the assimilation of primary production, an increase in the export of organic matter, and enhanced remineralization processes, ultimately leading to a decrease in the oxygen content of the aquatic environment [18].

Microplastics can adsorb toxic substances from the surrounding environment onto their surface, increasing their potential hazard to organisms. Investigating these effects is crucial for assessing the risk to ecosystem health [1; 17].

A comprehensive analysis of the impact of microplastics on biological organisms and ecosystems requires an integrated approach, incorporating knowledge from fields such as biology, ecology, toxicology, and even sociology.

Microplastic in freshwater bodies and watercourses of Russia

Research on microplastics in freshwater bodies and watercourses of the Russian Federation deserves special attention. Within this analysis, publications both in domestic and foreign scientific journals have been considered.

Ivanova E.V. and Tikhonov D.A. (2022) studied the content of microplastics in water and bottom sediments of Lake Ladoga [40]. Yasinets S.V. with colleagues (2021) determined the content of microplastics in water samples from the rivers Levinka, Kova, as well as springs and tunnels near Nizhny Novgorod [34]. Pozdnyakov Sh.R. et al. (2020) studied the spatial distribution of microplastic particles in water, bottom sediments, and soils of the coastal zone of Neva Bay of the Gulf of Finland and the mouth of the Neva River [25]. Kaurova Z.G. (2021) in her work assessed the content of microplastic particles in the upper and middle reaches of the Neva River, as well as in the Mga, Tosna, and Izhora rivers [43]. Frank Yu.A. and colleagues (2021) studied the content of pollutants in water bodies in the Novosibirsk region and several populated areas of the Tomsk region, as well as in the Tom River near the cities of Kemerovo, Yurga, and Tomsk [12]. Another publication by Frank Yu.A. with colleagues (2021) is devoted to the study of water resources of the Ob-Irtysh basin, as well as the Volga and Pechora basins [49]. The presence of microplastics has been detected in the bottom sediments of the Kazanka River in Kazan [46]. Kolobov M.Yu. and Talanina E.B. focused their attention on analyzing the aquatic environment of Lake Baikal [44]. Tomsk scientists expanded the scope of their research to include the study of water and bottom sediments of the Tunguska River [50]. Subsequently, they continued this work, covering the Lower Tunguska and Yenisei rivers [11]. Finally, Lisitsyna A.A. and her colleagues undertook a large-scale project to study the water along the entire length of the Volga River, from Selizharovo to Astrakhan [21].

Fig. Locations of microplastic studies in natural freshwaters within the territory of Russia. Map constructed based on materials from scientific works by Russian researchers [11; 12; 21; 25; 34; 37; 40; 43; 44; 46; 49; 50]

Figure 1 presents a map of Russia, indicating the regions where studies on the detection of microplastic particles have been conducted. As can be seen, the rivers and water bodies of the Khanty-Mansi Autonomous Okrug-Yugra (KhMAO-Yugra) have not, to date, been the subject of investigation regarding microplastic content. The hydrographic system of the district is characterized by the presence of approximately 290,000 lakes and more than 30,000 watercourses, predominantly small rivers. The fundamental element of the hydrographic network is the Ob River, which receives a number of large tributaries, such as the Irtysh, Vakh, Agan, Bolshoy Yugan, Severnaya Sosva, and Kazym. The total length of the hydrological network is approximately 172,000 km [45].

Given the paucity of research data regarding microplastic contamination in the aquatic ecosystems of KhMAO-Yugra, and considering the significant number of surface water bodies and watercourses characterized by substantial volumes of water mass, it is necessary to emphasize the high degree of relevance of investigating this problem.

Methods and techniques for detecting microplastics in freshwater

One of the major challenges in quantifying microplastic particles in the environment is the lack of reliable and standardized methodologies [39].

This review presents various techniques for the detection, identification, and classification of microplastic particles in freshwater ecosystems. Particular attention will be paid to methods of sampling and sample preparation of water samples, as well as soil samples, both benthic and shoreline.

Let us consider the sampling methods used and described by researchers in their studies. When sampling water from water bodies and watercourses, two approaches can be distinguished: water samples are collected from the surface (depth 0–20 cm); and from the water column at different levels (typically using a pump or submersible nets). For the collection of bottom sediments, dredges of various designs are typically used. The collection of surface (shoreline) sediments is carried out by collecting soil from the shoreline in different areas, taking into account the area and depth.

For the extraction of microplastic samples from surface waters, the most frequently used method is trawling with plankton nets. This approach involves the use of net structures of fixed dimensions (e.g., 50 cm × 100 cm [35]), with specific mesh size parameters (e.g., 55 μm [28]). The net is dragged across the surface of the water body at a constant speed, with regular rinsing of the net with the analyzed water at equal intervals of time (or distance) [22; 28; 35]. In some studies, a specialized "Manta" trawl is used for these purposes [8]. Another common method is the collection of specific volumes of water using glass samplers, after which the water is filtered through stainless steel sampling probes and nylon plankton nets with defined mesh sizes [10; 16; 29]. Sampling is carried out manually using a stainless steel beaker with a diameter of 20 cm [10]. Collected samples are placed in glass containers [28; 29], which are further protected from light exposure [10; 16]. Some researchers employ methods of sample preservation using 70% ethanol solution or 5% metaldehyde [8; 35]. Water sampling from various levels of the water column is performed using a submersible pump; before the start of each sampling event, the pump itself and the hose are pre-rinsed with the water being investigated. The water obtained in this way is passed through a portable plankton net [10].

It is worth noting that in most studies, researchers have strived to use plankton (nylon) nets with a mesh size of approximately 300 μm or less. Also, when discussing water sampling, it is important to note that, at present, expert groups from AMAP (Arctic Monitoring and Assessment Programme), GESAMP (Group of Experts on Scientific Aspects of Marine Environmental

Protection), and HELCOM (Baltic Marine Environment Protection Commission) have recommended only two methods of water sampling for monitoring microplastic pollution: from the surface (0–20 cm) – using nets (neuston net, “Manta” trawl); from the subsurface layer (from a depth of 1–6 m) – using a pump or a ship’s flow-through system with a filter system or cascade of filters [47].

Sampling of bottom sediments was typically carried out using dredges of various designs. In a number of studies, samples were collected using a Van Veen grab and placed in glass bottles using a stainless steel spoon [10; 28]. In the work of our compatriots studying microplastics in Lake Ladoga, an Ekman dredge was used. With its help, the surface layer of soil with a thickness of 5–10 cm was removed, after which, using a metal spoon, the soil was placed in glass jars [40].

Sampling of surface (shoreline) sediments was carried out by collecting soil at different sections of the riverbank, within a predetermined sampling area, by removing and transferring the soil to glass samplers using steel spatulas or spoons [13].

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) proposes the following protocol for sampling from the shoreline of a water body: the sampling site should be chosen randomly; the size of the site is determined by the researchers and may be, for example, one square meter; the depth of soil extraction is 50 mm. It is recommended to collect five samples, with a distance of at least five meters between sampling points [15].

Extraction of microplastics: sample preparation for analysis

When considering methods for extracting microplastics and preparing samples for analysis, two approaches to sample preparation can be distinguished: preparation of water samples and preparation of sediment samples (both bottom and shoreline).

Most researchers [2; 28; 29; 48; 49] utilize the methodology established by the National Oceanic and Atmospheric Administration (NOAA) [23] for preparing water samples, as detailed translations and overviews of this method have been provided by our compatriots from the P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences [39]. However, in some cases, this methodology is slightly modified [16; 22; 48]. In brief, the common features of the applied methodologies can be summarized into three main stages of sample preparation: sequential sieving (samples are initially passed through a series of sieves or a cascade of sieves and thoroughly rinsed with distilled water), oxidation of organic matter using peroxide (the collected fraction undergoes decomposition of organic material using hydrogen peroxide (30%) in the presence of Fe^{2+} ions), and density separation (conducted in a NaCl solution in a separating funnel). Subsequently, particles are collected on membrane filters, which are then dried [2; 39; 49].

For the preparation of sediment samples, researchers employ similar methods that represent a modification of the methodology developed by the National Oceanic and Atmospheric Administration (NOAA) [28; 40; 48]. The aforementioned NOAA methodology proposes slightly different approaches to the preparation of bottom and shoreline sediment samples. The preparation of shoreline sediment samples begins with drying the sample, followed by density separation (which involves the collection and filtration of the surface layer of liquid). Subsequently, liquid oxidation of the collected filtrate is performed to remove organic material, after which a second density separation is conducted [23; 39].

The preparation of bottom sediment samples also begins with drying the sample, followed by mixing and softening the dried sediment. The next step involves sieving the sample, after which density separation is performed, followed by liquid oxidation using hydrogen peroxide, and the collected material undergoes a final density separation [23; 39]. It is important to note that in either case (regardless of whether it is bottom or shoreline sediment), the resulting sample is weighed and subjected to visual analysis using a microscope [23; 39].

When discussing the difficulties associated with the preparation of water or sediment samples, it should be noted that researchers face the problem of extracting microplastics from these samples due to the presence on their surface of particles that can be mistakenly identified as calcite, quartz, clay materials, or even diatoms. In this regard, the development of methods for the destruction of biological material and the complete removal of mineral components from the surface of particles without damaging the microplastic fragments themselves is required [29; 43].

Thus, despite the widespread use of the NOAA method, in a number of studies, it is applied with certain modifications [28; 39; 48]. A critical analysis of the methods of sampling, preparation, and analysis of samples used by various research groups around the world was presented in the work of J.C. Prata et al. [26].

Detection and identification of microplastic particles

The method of visual detection is effective when working with relatively large particles (300 μm and above). It is often used as a preliminary stage of investigation. Various types of microscopes are employed for this purpose, including optical, digital, and fluorescent models equipped with high-resolution digital cameras. Additionally, specialized software for image analysis and data processing may be utilized [31]. Domestic researchers [11-13; 21; 25; 34; 37; 40; 43; 44; 46; 48-50] and foreign researchers [2; 8; 16; 29; 35] have resorted to visual detection methods. In several studies, scanning electron microscopy was used to obtain images of the surface structures of microplastics [28; 29].

Fourier-transform infrared (FTIR) spectroscopy is based on the interaction of infrared radiation with molecules. Synthetic polymers, characterized by a regular repetition of monomeric units in their structure, exhibit infrared spectra with distinctly defined absorption bands. This property makes FTIR an effective method for investigating microplastics. Polymer identification is performed by comparing the obtained absorption spectrum of the sample with reference spectra [31; 38]. This method has been actively utilized by both foreign and domestic researchers [8; 10; 13; 25; 29; 35; 44].

Differential scanning calorimetry (DSC), which allows for the registration of phase transitions in polymer materials, has been used to identify microplastics in 34 samples from the Volga River [21].

Raman spectroscopy shares several similarities with infrared (IR) Fourier spectroscopy but differs in the mechanism of spectral band formation. In the case of Raman scattering, changes in the polarizability of molecules under the influence of electromagnetic radiation lead to the appearance of characteristic spectral lines, whereas in IR Fourier spectroscopy, the recorded absorption is associated with changes in the dipole moment of the molecules. Molecular vibrations in this method form observable bands (corresponding to energy transitions), and when the transition energies are represented as a spectrum, they can be used for molecular identification by comparing with reference spectra [31]. This method is actively used in both domestic research [25, 44] and international scientific literature [28; 29].

In addition to the previously discussed analytical approaches, it is important to note less common methods characterized by high costs, lengthy analysis times, and complex equipment and sample preparation [7; 31]:

– pyrolysis gas chromatography-mass spectrometry (Pyr-GC-MS);
– thermal extraction and desorption gas chromatography-mass spectrometry (TED-GC-MS);
– scanning electron microscopy combined with energy-dispersive X-ray spectroscopy (SEM-EDX);
– quantitative nuclear magnetic resonance spectroscopy.

Considering the diversity of methodological approaches employed in microplastic research, it seems possible to systematize the data. For this purpose, a table is presented containing information on sampling methods, identification, and types of polymer compounds detected in studies by both Russian and foreign authors. When presenting data on polymer types and their concentrations, it should be taken into account that the research results can vary significantly depending on factors such as the environment and object of study, sampling methods, particle identification methods, and the methodology of sample preparation. For example, the concentration, types, and sizes of microplastics can manifest differently in various aquatic environments, in bottom sediments, beach sands, and in body tissues. The choice of sampling method, such as net trawls with different mesh sizes, manual collection, and water filtration, influences which particles will be captured and, consequently, the results of the analysis. Different methods may be more or less effective for sampling particles of different sizes. Sample preparation steps, such as the removal of organic matter or individual particles by density, can introduce systematic errors and affect the final results.

Most researchers prefer three main methods for the identification and chemical analysis of microplastics: the visual method, Fourier-transform infrared (FTIR) spectroscopy, and Raman spectroscopy. Other approaches are used less frequently or are practically not used due to the significant costs of equipment, as well as the complexity and duration of the analysis. Some methods allow only the determination of polymer type classes or have limitations on particle size.

Among the detected types of polymers, polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET), and polyvinyl chloride (PVC) are most often encountered, which reflects their widespread use as materials for the production of plastic products.

The conducted review of scientific studies presented in this article has allowed for the systematization of current knowledge on the problem of microplastic pollution of freshwater ecosystems in Russia. It has been established that the main sources of microplastic input into the aquatic environment are domestic and industrial wastewater, storm water, urban dust, and also the processes of plastic waste decomposition in landfills and the natural environment. However, the absence of models describing the dynamics of microplastic input and distribution indicates the need for further research in this direction.

The article considers modern methods of sampling water and bottom sediments, as well as approaches to the identification and quantitative analysis of microplastics. Despite significant progress in the development of methods, the need for the unification of approaches remains to ensure the comparability of data obtained by various research groups.

Particular attention is paid to the ecological consequences of plastic pollution, including its impact on biological organisms and the functioning of ecosystems. It has been established that microplastics can cause disruptions in trophic networks, as well as have a negative impact on the endocrine, reproductive, and immune systems of aquatic organisms. Furthermore, the sorption of pollutants on the surface of microplastics enhances its toxicological potential.

In the context of Yugra, where the volume of surface waters is significant and data on microplastic pollution are absent, the conduct of comprehensive studies appears to be extremely relevant. This will allow for the assessment of the scale of the environmental threat and the development of strategies to minimize the pollution of freshwater ecosystems. Overall, the article emphasizes the need for further study of the microplastic problem, including the development of methodological approaches, the conduct of monitoring, and the creation of effective pollution control measures.

Table

Identification and analysis of polymer types in microplastics: a review of scientific studies and their results

No	Research Object	Source Link	Sampling Method (and Mesh Size)	Result (Concentrations, Form)	Particle Identification Method	Detected Polymer Types
1.	Twelve beaches along a 40 km stretch of coastline in southwest England	[1]	Manual collection from beaches	Metals associated with granules have been detected. Metal concentrations vary. Shape: granules.	Inductively coupled plasma-mass spectrometry, Fourier-transform infrared (FTIR) spectroscopy	No specific polymer types were specified. The work is devoted to the analysis of metals on the surface of microplastic particles
2.	Water from 29 tributaries of the Great Lakes, North America	[2]	Use of trawl nets with a 333 µm mesh.	Concentration: 0.05–32 particles/m³, with a mean of 4.2 particles/m³. Particle Size: Particle sizes ranged from 0.33 mm to 20 mm. Shape: fibers (mean 71% of particles) were the predominant shape, followed by fragments (mean 17%).	Visual identification, microscopy	Specific polymer types not identified
3.	Microplastic accumulation on shorelines worldwide	[6]	Collection of samples from surface sediments on beaches	Concentrations varied. Fragments and fibers were detected; particle size < 1 mm.	Fourier-transform infrared (FTIR) spectroscopy	PE, PP, PS, PET and others
4.	Microplastic pollution in surface water of Lake Victoria, Africa	[8]	Surface water sampling using a Manta trawl net with a 300 µm mesh size.	Concentration: 0.02–2.19 particles/m³. Particle size: 0.3–4.9 mm. Shape: microspheres, fibers, and fragments.	Microscopy and Fourier-transform infrared (FTIR) spectroscopy	PE, PP, PS, LDPE, HDPE and others

5.	Spatiotemporal distribution of microplastics in the Nakdong River, South Korea	[10]	Surface water sampling using a beaker, subsurface water sampling (1-meter depth) using a pump, and bottom sediment sampling using a Van Veen grab	Concentration: – Water: concentrations ranged from 293 to 4760 particles/m³. – Sediment: 1971 particles/kg dry weight. Particle shape distribution: – Water: fragments (69%), fibers (30%), spheres and films (< 1%). – Sediment: fragments (84%), fibers (15%), spheres and films (1%).	Fourier-transform infrared (FTIR) spectroscopy	PE, PP, PS, PET, PA
6.	The Lower Tunguska River (also known as the Katanga River), a right tributary of the Yenisey River, Siberia, Russia	[11]	Surface water sampling using a Manta trawl net with a 330 µm mesh size. Bottom sediments were collected using a steel spoon	Concentration: – Water: 1.20 ± 0.70 to 4.53 ± 2.04 particles/m³ – Sediment: 235 ± 83.0 to 543 ± 94.1 particles/kg dry weight Particle shape: irregular microfragments, microfibers, microfilms, microspheres.	Visual identification, microscopy	Specific polymer types were not identified
7.	Surface waters of the Ob and Tom Rivers, Siberia, Russia	[12]	Surface water sampling using a Manta trawl net with a 330 µm mesh size	Concentration: The mean concentration for both rivers ranged from 44.2 to 51.2 particles/m³. Particle shape: microfibers, microfilms, and microspheres.	Visual identification, microscopy	Specific polymer types were not identified
8.	Beach sands of the Ob River, Western Siberia, Russia	[13]	Sand was collected using a clean stainless steel scoop within a 625 cm² (25 × 25 cm) stainless steel frame	Concentration: Microplastic concentration in the sand samples ranged from 480 ± 413 to 2080 ± 924 particles/m³ (mean 1067 ± 929) by volume. Particle shape: irregular fragments, fibers, and films.	Microscopy, Fourier-transform infrared (FTIR) spectroscopy, Gas chromatography-mass spectrometry (GC-MS)	PE, PP, PS, PET, PA, PU

9.	Поверхностные воды реки Вэй, Китай Surface waters of the Wei River, China	[16]	Water samples were collected using glass samplers and subsequently filtered through a plankton net with a 64 µm mesh size	Concentration: Microplastic concentration ranged from 0.40 to 1.20 particles/L. Particle shape: fibers were the dominant type (83.4%).	Microscopy	Specific polymer types were not identified
10.	Volga River, Russia	[21]	urface water sampling using a Manta trawl net with a 300 µm mesh size	Concentration: Microplastic concentration ranged from 0.16 to 4.10 particles/m³. Particle shape distribution: Fragments (41%) and films (37%) were the most prevalent, while fibers accounted for 22%.	Microscopy, Differential scanning calorimetry (DSC)	PVC, PE, PS, PP
11.	Haihe River, China	[22]	Surface water sampling using a Manta trawl net with a 333 µm mesh size	Concentration: Microplastic concentration ranged from 0.69 to 74.95 particles/m³. Particle shape**:** fibers, films, foam, fragments, and spheres.	Scanning electron microscopy (SEM), Fourier-transform infrared (FTIR) spectroscopy	PE, EPS, PA, PP
12.	Coastal mangrove ecosystems of Singapore	[24]	During low tide, the top 3–4 cm of sediment were collected using a clean stainless steel spatula within a 1.5 m sided square	Concentration: The mean microplastic concentration across seven sites was 36.8 ± 23.6 particles/kg dry sediment. Fibers were the most abundant type of microplastic, followed by films and granules.	Microscopy, Fourier-transform infrared (FTIR) spectroscopy	Various polymer types: PE, PP, PA6, PVC
13.	Surface waters and sediments of the Vaal River, South Africa	[28]	Surface water was sampled using a plankton net with a 55 µm mesh size. Sediment samples were collected using a 500 mL Van Veen grab	Concentration: Mean concentrations were 0.61 ± 0.57 particles/m³ in surface water and 4.6 × 10² ± 2.8 × 10² particles/kg dry weight in sediments. Particle composition: fragments and fibers comprised over 80% of the microplastics in both water and sediment samples.	Scanning electron microscopy (SEM), Raman spectroscopy	PE, PP, LDPE, HDPE and others

14.	Surface waters and sediments of the Vistula River, Poland	[29]	Sediment samples were collected from the riverbanks at a depth of approximately 0.5 m using a stainless steel shovel within an area of approximately 100 cm² (4–5 cm deep). Water was filtered through a stainless steel probe equipped with a plankton net with a 55 µm mesh size	Concentration: Microplastic concentrations ranged from 1.6 particles/L to 2.55 particles/L in water and from 190 particles/kg to 580 particles/kg in sediment. Particle composition: fibers constituted 97% and 93% of all particle types in the water and sediment samples, respectively.	Visual identification, Raman spectroscopy	PE, PP and others
15.	Water in the Three Gorges Dam reservoir, China	[35]	Surface water was sampled using a plankton net with a 112 µm mesh size	Concentration: Microplastic concentrations ranged from 3407.7×10^3 to 13617.5×10^3 units per square kilometer in the main stream of the Yangtze River, and from 192.5×10^3 to 11889.7×10^3 units per square kilometer in the estuary. Particle shape: spherical particles were the most abundant.	Scanning electron microscopy (SEM), Fourier-transform infrared (FTIR) spectroscopy	PE, PS, PP
16.	Intra-annual dynamics of microplastic pollution in the surface waters of the Tom River, Russia	[37]	Surface water sampling using a Manta trawl net with a 330 µm mesh size	Concentration: Microplastic concentrations ranged from 0.70 ± 0.20 units/m³ to 8.67 ± 4.80 units/m³. Particle composition: particles were primarily composed of irregular microfragments (10–35%), fibers, and spheres. In April, spheres were the predominant particle type, constituting >63% of the total.	Microscopy	Specific polymer types were not identified

17.	Assessment of microplastic particle content in Lake Ladoga	[40]	Water samples were filtered through a system with a metallic sieve with a 60 µm mesh size. Sediment samples were collected using an Ekman grab sampler	Concentration: The mean microplastic concentration in the surface layer of the water column was 83 ± 86 particles/m³, and in the bottom sediments, 30 ± 18 particles/kg dry weight. Particle composition: fibers were the predominant particle type, accounting for 98% of all microplastics.	Visual identification, Raman spectroscopy	PE, PP, PET
18.	Water in the upper and middle reaches of the Neva River, Russia	[43]	Microplastic samples were collected from the water using a Juday plankton net with a 35 µm mesh size	Concentration: Microplastic concentration in the water ranged from 0.23 ± 0.04 units/L to 7.58 ± 0.8 units/L. Particle composition: microplastics were predominantly composed of thin filaments, granules, irregular plastic fragments, and fragments	Microscopy	Specific polymer types were not identified
19.	Multi-year dynamics of microplastic content in the surface waters of Lake Baikal, Russia	[44]	Specialized nets with a 300 µm mesh size were used	Concentration: The average microplastic concentration was 61,000 particles/km² during the period from 2017 to 2020. Particle composition: fibers were the predominant type.	Microscopy, Fourier-transform infrared (FTIR) spectroscopy	PE, PS, PP
20.	Waters and tributaries of Lake Ladoga, Russia	[48]	A filtration system with a metallic sieve with a 60 µm mesh size was used. Sediment samples were collected using an Ekman grab sampler	Concentration: The highest microplastic concentration in water was recorded in Pitkyaranta Bay (353 particles/m³). The highest concentrations in sediments were observed in the Volkhov River (160 particles/kg). Particle composition: particles were mainly composed of fibers, fragments, and films.	Visual identification, Raman spectroscopy	PE, PET, PC

21.	Screening for microplastic content in the surface waters of Russian rivers	[49]	A Manta trawl net with a 330 μm mesh size was used for sampling	Concentration: The mean microplastic content ranged from 4.56 ± 0.86 units/m³ in the Ishim River to 36.7 ± 9.44 units/m³ in the Chusovaya River. Particle composition: microplastics were composed of irregular fragments, fibers, spheres, and films.	Microscopy	Specific polymer types were not identified
22.	River ecosystem of the Lower Tunguska River, a tributary of the Yenisey River, Russia	[50]	Manta trawl net with a 330 μm mesh size was used for water sampling. Sediment samples were manually collected using a metal spoon	Concentration: Microplastic concentration ranged from 1.20 ± 0.70 to 4.53 ± 2.04 units/m³ in water, and from 235 ± 83.0 to 543 ± 94.1 units/kg in sediments. Particle composition: fibers were the predominant type.	Microscopy	Specific polymer types were not identified

Note: PE – polyethylene, PP – polypropylene, PS – polystyrene, PET – polyethylene terephthalate, PVC – polyvinyl chloride, LDPE – low-density polyethylene, HDPE – high-density polyethylene, EPS – expanded polystyrene, PU – polyurethane, PA6 – polyamide 6.

References

1. Ashton, K., Holmes, L., & Turner, A. (2010). Association of metals with plastic production pellets in the marine environment. *Marine pollution bulletin*, 60(11), 2050–2055. https://doi.org/10.1016/j.marpolbul.2010.07.014.

2. Baldwin, A. K., Corsi, S. R., & Mason, S. A. (2016). Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology. *Environmental science & technology*, 50(19), 10377–10385. https://doi.org/10.1021/acs.est.6b02917.

3. Boerger, C.M., Lattin, G.L., Moore, S.L., & Moore, C.J. (2010). Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Marine Pollution Bulletin*, 60, 2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007.

4. Bora, S.S., Gogoi, R., Sharma, M.R., Anshu, Borah, M.P., Deka, P., & Teli, A.B. (2024). Microplastics and human health: unveiling the gut microbiome disruption and chronic disease risks. *Frontiers in Cellular and Infection Microbiology*, 14, 1492759. https://doi.org/10.3389/fcimb.2024.1492759.

5. Boucher, J., & Friot, D. (2017). Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN, 43. https://doi.org/10.2305/IUCN.CH.2017.01.en.

6. Browne, M.A., Crump, P., Niven, S.J., Teuten, E., Tonkin, A., Galloway, T., & Thompson, R. (2011). Accumulation of microplastic on shorelines woldwide: sources and sinks. *Environmental science & technology*, 45(21), 9175-9179. https://doi.org/10.1021/es201811s.

7. Dümichen, E., Eisentraut, P., Celina, M., & Braun, U. (2019). Automated thermal extraction-desorption gas chromatography mass spectrometry: A multifunctional tool for comprehensive

characterization of polymers and their degradation products. *Journal of Chromatography A*, 1592, 133-142. https://doi.org/10.1016/j.chroma.2019.01.033.

8. Egessa, R., Nankabirwa, A., Ocaya, H., & Pabire, W.G. (2020). Microplastic pollution in surface water of Lake Victoria. *Science of the Total Environment*, 741, 140201. https://doi.org/10.1016/j.scitotenv.2020.140201.

9. Enyoh, C.E., Shafea, L., Verla, A.W., Verla, E.N., Qingyue, W., Chowdhury, T., & Paredes, M. (2020). Microplastics exposure routes and toxicity studies to ecosystems: an overview. *Environmental analysis, health and toxicology,* 35(1). https://doi.org/10.5620/eaht.e2020004.

10. Eo Soeun, E.S., Hong SangHee, H.S., Song YoungKyoung, S.Y., Han GiMyung, H.G., & Shim WonJoon, S.W. (2019). Spatiotemporal distribution and annual load of microplastics in the Nakdong River, South Korea. *Water Research,* 160, 228-237. https://doi.org/10.1016/j.watres.2019.05.053.

11. Frank, Y.A., Vorobiev, D.S., Kayler, O.A., Vorobiev, E.D., Kulinicheva, K.S., Trifonov, A.A., & Soliman Hunter, T. (2021). Evidence for microplastics contamination of the remote tributary of the Yenisei River, Siberia – The pilot study results. *Water*, *13*(22), 3248. https://doi.org/10.3390/w13223248.

12. Frank, Y.A., Vorobiev, E.D., Vorobiev, D.S., Trifonov, A.A., Antsiferov, D.V., Soliman Hunter, T., & Strezov, V. (2020). Preliminary screening for microplastic concentrations in the surface water of the Ob and Tom Rivers in Siberia, Russia. *Sustainability*, 13(1), 80. https://doi.org/10.3390/su13010080.

13. Frank, Y.A., Sotnikova, Y.S., Tsygankov, V.Y., Rednikin, A.R., Donets, M.M., Karpova, E.V., & Vorobiev, D. S. (2024). Pollution of Beach Sands of the Ob River (Western Siberia) with Microplastics and Persistent Organic Pollutants. *Journal of Xenobiotics*, 14(3), 989-1002. https://doi.org/10.3390/jox14030055.

14. Galgani, L., & Loiselle, S.A. (2019). Plastic accumulation in the sea surface microlayer: an experiment-based perspective for future studies. *Geosciences*, 9(2), 66. https://doi.org/10.3390/GEOSCIENCES9020066.

15. GESAMP (2019). Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J., Turra A. and Galgani F. editors), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). *Rep. Stud. GESAMP*. 99, 130. URL: http://gesamp.org.

16. Jiao, J., Hu, H., Chen, G., & Yang, Z. (2021). Microplastics in surface waters of the Wei River, China. In *E3S Web of Conferences*, 251, 02090. EDP Sciences. https://doi.org/10.1051/e3sconf/202125102090.

17. Karapanagioti, H.K., & Klontza, I. (2008). Testing phenanthrene distribution properties of virgin plastic pellets and plastic eroded pellets found on Lesvos island beaches (Greece). *Marine environmental research*, 65(4), 283-290. https://doi.org/10.1016/j.marenvres.2007.11.005

18. Kvale, K., Prowe, A.E., Chien, C.T., Landolfi, A., & Oschlies, A. (2021). Zooplankton grazing of microplastic can accelerate global loss of ocean oxygen. *Nat. Commun*., 12, 2358. https://doi.org/10.1038/s41467-021-22554-w.

19. Lee, Y., Cho, J., Sohn, J., & Kim, C. (2023). Health effects of microplastic exposures: current issues and perspectives in South Korea. *Yonsei Medical Journal,* 64(5), 301. https://doi.org/10.3349/ymj.2023.0048.

20. Li, B., Ding, Y., Cheng, X., Sheng, D., Xu, Z., Rong, Q., & Zhang, Y. (2020). Polyethylene microplastics affect the distribution of gut microbiota and inflammation development in mice. Chemosphere, 244, 125492. https://doi.org/10.1016/j.chemosphere.2019.125492.

21. Lisina, A.A., Platonov, M.M., Lomakov, O.I., Sazonov, A.A., Shishova, T.V., Berkovich, A.K., & Frolova, N.L. (2021). Microplastic abundance in Volga River: Results of a pilot study in summer 2020. *Geography, Environment, Sustainability*, 14(3), 82-93.

22. Liu, Y., Zhang, J., Cai, C., He, Y., Chen, L., Xiong, X., & Liu, W. (2020). Occurrence and characteristics of microplastics in the Haihe River: an investigation of a seagoing river flowing through a megacity in northern China. *Environmental Pollution*, 262, 114261. https://doi.org/10.1016/j.envpol.2020.114261.

23. Masura, J., Baker, J., Foster, G., & Arthur, C. (2015). Laboratory Methods for the Analysis of Microplastics in the Marine Environment: Recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48. http://dx.doi.org/10.25607/OBP-604.

24. Nor, N.H.M., & Obbard, J.P. (2014). Microplastics in Singapore's coastal mangrove ecosystems. *Marine pollution bulletin*, 79(1-2), 278-283. https://doi.org/10.1016/j.marpolbul.2013.11.025.

25. Pozdnyakov, S.R., Ivanova, E.V., Guzeva, A.V., Shalunova, E.P., Martinson, K.D., & Tikhonova, D.A. (2020). Studying the concentration of microplastic particles in water, bottom sediments and subsoils in the coastal area of the Neva Bay, the Gulf of Finland. *Water resources*, 47, 599-607. https://doi.org/10.1134/S0097807820040132.

26. Prata, J.C., Da Costa, J.P., Duarte, A.C., & Rocha-Santos, T. (2019). Methods for sampling and detection of microplastics in water and sediment: A critical review. *TrAC Trends in Analytical Chemistry*, 110, 150-159. https://doi.org/10.1016/j.trac.2018.10.029.

27. Prata, J.C. (2018). Microplastics in wastewater: State of the knowledge on sources, fate and solutions. *Marine pollution bulletin*, 129(1), 262-265. https://doi.org/10.1016/j.marpolbul.2018.02.046.

28. Ramaremisa, G., Ndlovu, M., & Saad, D. (2022). Comparative assessment of microplastics in surface waters and sediments of the Vaal River, South Africa: abundance, composition, and sources. *Environmental Toxicology and Chemistry*, 41(12), 3029-3040. https://doi.org/10.1002/etc.5482.

29. Sekudewicz, I., Dąbrowska, A.M., & Syczewski, M.D. (2021). Microplastic pollution in surface water and sediments in the urban section of the Vistula River (Poland). *Science of The Total Environment*, 762, 143111. https://doi.org/10.1016/j.scitotenv.2020.143111.

30. Sheveleva, S.A., Markova, Y.M., Efimochkina, N.R., Minaeva, L.P., Bykova, I.B., Zinurova, E.E., & Khotimchenko, S.A. (2023). Microbial risks associated with microplastics in the food chain and possible control measures (literature review). Part 1. Dietary intake and influence on the gut microbiota. *Hygiene and Sanitation*, 102(12), 1334-1347. https://doi.org/10.47470/0016-9900-2023-102-12-1334-1347.

31. Stock, F., B. Narayana, V.K., Scherer, C., Löder, M.G., Brennholt, N., Laforsch, C., & Reifferscheid, G. (2020). Pitfalls and limitations in microplastic analyses. In *Plastics in the Aquatic Environment-Part I: Current Status and Challenges* (pp. 13-42). Cham: Springer International Publishing. https://doi.org/10.1007/698_2020_654.

32. Tamargo, A., Molinero, N., Reinosa, J.J., Alcolea-Rodriguez, V., Portela, R., Bañares, M.A., & Moreno-Arribas, M.V. (2022). PET microplastics affect human gut microbiota communities during

simulated gastrointestinal digestion, first evidence of plausible polymer biodegradation during human digestion. *Scientific Reports*, 12(1), 528. https://doi.org/10.1038/s41598-021-04489-w.

33. The UN Environment (UNEP). Annual Report. 2023. 24 p. URL: https://clck.ru/3HPbPt (дата обращения: 05.12.2024).

34. Yasinskii, S.V., Venitsianov, E.V., Kashutina, E.A., Sidorova, M.V., Ershova, A.A., & Makeeva, I.N. (2021). Contribution of microparticles to the transport of pollution by rivers and groundwaters in a large city. In *IOP Conference Series: Earth and Environmental Science*, 834 (1), 012047. IOP Publishing. https://doi.org/10.1088/1755-1315/834/1/012047.

35. Zhang Kai, Z.K., Gong Wen, G.W., Lv JiZhong, L.J., Xiong Xiong, X.X., & Wu ChenXi, W.C. (2015). Accumulation of floating microplastics behind the Three Gorges Dam. *Environmental Pollution*, 204, 117-123. https://doi.org/10.1016/j.envpol.2015.04.023.

36. Besednova, N.N., Shchelkanov, M.Yu., Zaporozhets, T.S., Galkina, I.V., Gmoshinsky, I.V., & Tutelyan, V.A. (2023). The influence of micro and nanoplastics on the gastrointestinal mucosa and intestinal microbiome. *Nutrition Issues*, 6 (550), 6-17. (in Russ.). https://doi.org/10.33029/0042-8833-2023-92-6-6-17.

37. Vorob`ev, E.D., Trifonov, A.A., Raxmatullina, S.N., Vorob`ev, D.S., Frank, Yu.A. Vnutrigodovaya dinamika soderzhaniya mikroplastika v poverxnostny`x vodax reki Tomi. // Materialy` I Vserossijskoj konferencii s mezhdunarodny`m uchastiem po zagryazneniyu okruzhayushhej sredy` mikroplastikom «MicroPlasticsEnvironment-2022» (MRE-2022), 02–06 avgusta 2022 g., p. Shira, Xakasiya / obshh. red. Yu.A. Frank. 58–62. (in Russ.).

38. Efimova, A.I., Zajcev, V.B., Boldy`rev, N.Yu., & Koshkarev, P.K. (2008). Infrakrasnaya fur`e-spektrometriya: Uchebnoe posobie. M.: Fizicheskij fakul`tet MGU. 133 p. (in Russ.).

39. Zobkov, M.B., & Esyukova, E.E. (2018). Mikroplastik v morskoj srede: obzor metodov otbora, podgotovki i analiza prob vody`, donny`x otlozhenij i beregovy`x nanosov. *Okeanologiya*, 58(1), 149-157. (in Russ.). https://doi.org/10.7868/S0030157418010148.

40. Ivanova, E.V., & Tixonova, D.A. (2022). Ocenka soderzhaniya chasticz mikroplastika v Ladozhskom ozere. *Trudy` Karel`skogo nauchnogo centra Rossijskoj akademii nauk*, (6), 58-67. (in Russ.). https://doi.org/10.17076/lim1582.

41. Kazmiruk, V.D., & Kazmiruk, T.N. (2017). Mikroplastik v donny`x otlozheniyax: metody` opredeleniya. *Voda: ximiya i e`kologiya*, *(1)*, 87-92. (in Russ.).

42. Karimov, E.X., & Daminev, R.R. (2012). Razvitie polimerov: ot gevei k makromolekule. *Istoriya i pedagogika estestvoznaniya*, 4, 18-26. (in Russ.).

43. Kaurova, Z. (2021). Soderzhanie mikroplastikovy`x chasticz v vode v verxnem i srednem techenii reki Neva. *Norwegian Journal of Development of the International Science*, (76-1), 3. (in Russ.).

44. Kolobov, M.Yu., & Talanina, E.B. (2022). Mnogoletnyaya dinamika soderzhaniya mikroplastika v poverxnostny`x vodax ozera Bajkal // Materialy` I Vserossijskoj konferencii s mezhdunarodny`m uchastiem po zagryazneniyu okruzhayushhej sredy` mikroplastikom «MicroPlasticsEnvironment-2022» (MRE-2022), 02–06 avgusta 2022 g., p. Shira, Xakasiya / obshh. red. Yu.A. Frank. 53–57. (in Russ.).

45. Lezin V.A. (2011). Vodnye resursy rek i ozer Tjumenskoj oblasti. Vestnik Tjumenskogo gosudarstvennogo universiteta. *Jekologija I prirodopol'zovanie*, 12, 62-69. (in Russ).

46. Nikitin, O.V., Laty`pova, V.Z., Ashixmina, T.Ya., Kuz`min, R.S., Nasy`rova, E`.I., Xaripov, I.I., & Minnegulova, L.M. (2020). Granulometricheskij sostav i soderzhanie mikroskopicheskix chasticz sinteticheskix polimerov v presnovodny`x e`kosistemax. In *Utilizaciya otxodov proizvodstva i potrebleniya: innovacionny`e podxody` i texnologii* (pp. 62-67). (in Russ.).

47. Paxomova, S.V., Ershova, A.A., Zhdanov, I.A., & Yakushev, E.V. (2024). Metody` issledovaniya zagryazneniya mikroplastikom prirodny`x vod: sovremennoe sostoyanie i rekomendacii. Okeanologicheskie issledovaniya, 52(1), 80-120. (in Russ.). https://doi.org/10.29006/1564-2291.JOR-2024.52(1).5.

48. Pozdnyakov, Sh.R., Ivanova, E.V., & Tixonova, D.A. (2022). Issledovanie zagryazneniya mikroplastikom akvatorii i pritokov Ladozhskogo ozera // Materialy` I Vserossijskoj konferencii s mezhdunarodny`m uchastiem po zagryazneniyu okruzhayushhej sredy` mikroplastikom «MicroPlasticsEnvironment-2022» (MRE-2022), 02–06 avgusta 2022 g., p. Shira, Xakasiya / obshh. red. Yu.A. Frank. 19–23. (in Russ.).

49. Frank, Yu.A., Vorob`ev, E.D., Raxmatullina, S.N., Trifonov, A.A., & Vorob`ev, D.S. (2022). Skrining soderzhaniya mikroplastika v poverxnostny`x vodax rossijskix rek. *E`kologiya i promy`shlennost` Rossii*, 26(9), 67-71. (in Russ.). https://doi.org/10.18412/1816-0395-2022-9-67-71.

50. Frank, Yu.A., Vorob`ev, E.D., Trifonov, A.A., Lemeshko, Ya.R., & Vorob`ev, D.S. (2022). Zagryaznenie rechnoj e`kosistemy` mikroplastikom na primere pritoka Eniseya, r. Nizhnyaya Tunguska / Materialy` I Vserossijskoj konferencii s mezhdunarodny`m uchastiem po zagryazneniyu okruzhayushhej sredy` mikroplastikom «MicroPlasticsEnvironment-2022» (MRE-2022), 02–06 avgusta 2022 g., p. Shira, Xakasiya / obshh. red. Yu.A. Frank. 95–100. (in Russ.).

Литература

1. Ashton K., Holmes L., Turner A. Association of metals with plastic production pellets in the marine environment // Marine Pollution Bulletin. 2010. Vol. 60. P. 2050–2055. https://doi.org/10.1016/j.marpolbul.2010.07.014.

2. Baldwin A.K., Corsi S.R., Mason S.A. Plastic debris in 29 Great Lakes tributaries: relations to watershed attributes and hydrology // Environmental science & technology. 2016. Vol. 50. № 19. P. 10377–10385. https://doi.org/10.1021/acs.est.6b02917.

3. Boerger C.M., Lattin G.L., Moore S.L., Moore C.J. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre // Marine Pollution Bulletin. 2010. Vol. 60. P. 2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007.

4. Bora S.S., Bora S.S., Gogoi R., Sharma M.R., Anshu Borah M.P., Deka P., Teli A.B. Microplastics and human health: unveiling the gut microbiome disruption and chronic disease risks // Frontiers in Cellular and Infection Microbiology. 2024. Vol. 14. P. 1492759. https://doi.org/10.3389/fcimb.2024.1492759.

5. Boucher J., Friot D. Primary Microplastics in the Oceans: A Global Evaluation of Sources. Gland, Switzerland: IUCN, 2017. 43 p. https://doi.org/10.2305/IUCN.CH.2017.01.en.

6. Browne M.A., Crump P., Niven S.J., Teuten E., Tonkin A., Galloway T., Thompson R. Accumulation of microplastic on shorelines woldwide: sources and sinks // Environmental science & technology. 2011. Vol. 45. № 21. P. 9175-9179. https://doi.org/10.1021/es201811s.

7. Dümichen E., Eisentraut P., Celina M., Braun U. Automated thermal extraction-desorption gas chromatography mass spectrometry: A multifunctional tool for comprehensive characterization of polymers and their degradation products // Journal of Chromatography A. 2019. Vol. 1592. P. 133-142. https://doi.org/10.1016/j.chroma.2019.01.033.

8. Egessa R., Nankabirwa A., Ocaya H., Pabire W.G. Microplastic pollution in surface water of Lake Victoria // Science of the Total Environment. 2020. Vol. 741. P. 140201. https://doi.org/10.1016/j.scitotenv.2020.140201.

9. Enyoh C.E., Shafea L., Verla A.W., Verla E.N., Qingyue W., Chowdhury T., Paredes M. Microplastics exposure routes and toxicity studies to ecosystems: an overview // Environmental analysis, health and toxicology. 2020. Vol. 35. № 1. https://doi.org/10.5620/eaht.e2020004.

10. Eo S., Hong S.H., Song Y.K., Han G.M., Shim W.J. Spatiotemporal distribution and annual load of microplastics in the Nakdong River, South Korea // Water Research. 2019. Vol. 160. P. 228-237. https://doi.org/10.1016/j.watres.2019.05.053.

11. Frank Y.A., Vorobiev D.S., Kayler O.A., Vorobiev E.D., Kulinicheva K.S., Trifonov A.A., Soliman Hunter T. Evidence for microplastics contamination of the remote tributary of the Yenisei River, Siberia – The pilot study results // Water. 2021. Vol. 13. №. 22. P. 3248. https:// doi.org/10.3390/w13223248.

12. Frank Y.A., Vorobiev E.D., Vorobiev D.S., Trifonov A.A., Antsiferov D.V., Soliman Hunter T., Strezov V. Preliminary screening for microplastic concentrations in the surface water of the Ob and Tom Rivers in Siberia, Russia // Sustainability. 2020. Vol. 13. №. 1. P. 80. https://doi.org/10.3390/su13010080.

13. Frank Y.A., Sotnikova Y.S., Tsygankov V.Y., Rednikin A.R., Donets M.M., Karpova E.V., Belanov M.A., Rakhmatullina S., Borovkova A.D., Polovyanenko D.N., et al. Pollution of Beach Sands of the Ob River (Western Siberia) with Microplastics and Persistent Organic Pollutants // Journal of Xenobiot. 2024. Vol. 14. P. 989–1002. https://doi.org/10.3390/jox14030055.

14. Galgani L., Loiselle S.A. Plastic accumulation in the sea surface microlayer: an experiment-based perspective for future studies // Geosciences. 2019. Vol. 9. №. 2. P. 66. https://doi.org/10.3390/GEOSCIENCES9020066.

15. Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J., Turra A. and Galgani F. editors), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) // Rep. Stud. GESAMP. 2019. № 99, 130 p. URL: http://gesamp.org.

16. Jiao J., Hu H., Chen G., Yang Z. Microplastics in surface waters of the Wei River, China // E3S Web of Conferences. EDP Sciences, 2021. Vol. 251. P. 02090. https://doi.org/10.1051/e3sconf/202125102090.

17. Karapanagioti H.K., Klontza I. Testing phenanthrene distribution properties of virgin plastic pellets and plastic eroded pellets found on Lesvos island beaches (Greece) // Mar. Environ. Res. 2008. Vol. 65. P. 283–290. https://doi.org/10.1016/j.marenvres.2007.11.005.

18. Kvale K., Prowe A.E., Chien C.T., Landolfi A., Oschlies A. Zooplankton grazing of microplastic can accelerate global loss of ocean oxygen // Nat. Commun. 2021. Vol. 12. P. 2358. https://doi.org/10.1038/s41467-021-22554-w.

19. Lee Y., Cho J., Sohn J., Kim C. Health effects of microplastic exposures: current issues and perspectives in South Korea // Yonsei Medical Journal. 2023. Vol. 64. № 5. P. 301. https://doi.org/10.3349/ymj.2023.0048.

20. Li B., Ding Y., Cheng X., Sheng D., Xu Z., Rong Q., Zhang, Y. Polyethylene microplastics affect the distribution of gut microbiota and inflammation development in mice // Chemosphere. 2020. Vol. 244. C. 125492. https://doi.org/10.1016/j.chemosphere.2019.125492.

21. Lisina A.A., Platonov M.M., Lomakov O.I., Sazonov A.A., Shishova T.V., Berkovich A.K., Frolova N.L. Microplastic abundance in Volga River: Results of a pilot study in summer 2020 // Geography, Environment, Sustainability. 2021. Vol. 14. № 3. P. 82-93. https://doi.org/10.24057/2071-9388-2021-041.

22. Liu Y., Zhang J., Cai C., He Y., Chen L., Xiong X., Liu W. Occurrence and characteristics of microplastics in the Haihe River: an investigation of a seagoing river flowing through a megacity in northern China // Environmental Pollution. 2020. Vol. 262. P. 114261. https://doi.org/10.1016/j.envpol.2020.114261.

23. Masura J., Baker J., Foster G., Arthur C. Laboratory methods for the analysis of microplastics in the marine environment: Recommendations for quantifying synthetic particles in waters and sediments. NOAA Technical Memorandum NOS-OR&R-48. 2015. 39 p. http://dx.doi.org/10.25607/OBP-604.

24. Nor N.H., Obbard J.P. Microplastics in Singapore's coastal mangrove ecosystems // Marine Pollution Bulletin. 2014. Vol. 79(1-2). P. 278-283. https://doi.org/10.1016/j.marpolbul.2013.11.025.

25. Pozdnyakov S.R., Ivanova E.V., Guzeva A.V., Shalunova E.P., Martinson K.D., Tikhonova D.A. Studying the concentration of microplastic particles in water, bottom sediments and subsoils in the coastal area of the Neva Bay, the Gulf of Finland // Water resources. 2020. Vol. 47. № 4. P. 599-607. https://doi.org/10.1134/S0097807820040132.

26. Prata J.C., Da Costa J.P., Duarte A.C., Rocha-Santos T. Methods for sampling and detection of microplastics in water and sediment: A critical review // TrAC Trends in Analytical Chemistry. 2019. Vol. 110. P. 150-159. https://doi.org/10.1016/j.trac.2018.10.029.

27. Prata J.C. Microplastics in wastewater: State of the knowledge on sources, fate and solutions // Marine Pollution Bulletin. 2018. Vol. 129(1). P. 262-265. https://doi.org/10.1016/j.marpolbul.2018.02.046.

28. Ramaremisa G., Ndlovu M., Saad D. Comparative assessment of microplastics in surface waters and sediments of the Vaal River, South Africa: abundance, composition, and sources // Environmental Toxicology and Chemistry. 2022. Vol. 41. № 12. P. 3029-3040. https://doi.org/10.1002/etc.5482.

29. Sekudewicz I., Dąbrowska A. M., Syczewski M. D. Microplastic pollution in surface water and sediments in the urban section of the Vistula River (Poland) // Science of The Total Environment. 2021. Vol. 762. P. 143111. https://doi.org/10.1016/j.scitotenv.2020.143111.

30. Sheveleva S.A., Markova Y.M., Efimochkina N.R., Minaeva L.P., Bykova I.B., Zinurova E.E., Khotimchenko S.A. Microbial risks associated with microplastics in the food chain and possible control measures (literature review). Part 1. Dietary intake and influence on the gut microbiota // Hygiene and Sanitation. 2023. Vol. 102. №. 12. P. 1334-1347. https://doi.org/10.47470/0016-9900-2023-102-12-1334-1347.

31. Stock F.B., Narayana V.K., Scherer C., Löder M.G., Brennholt N., Laforsch C., Reifferscheid G. Pitfalls and limitations in microplastic analyses // Plastics in the Aquatic Environment-Part I: Current Status and Challenges. Cham: Springer International Publishing, 2020. P. 13-42. https://doi.org/10.1007/698_2020_654.

32. Tamargo A., Molinero N., Reinos J.J., Alcolea-Rodriguez V., Portela R., Bañares M.A., Moreno-Arribas M.V. PET microplastics affect human gut microbiota communities during simulated gastrointestinal digestion, first evidence of plausible polymer biodegradation during human digestion // Scientific Reports. 2022. Vol. 12. №. 1. P. 528. https://doi.org/10.1038/s41598-021-04489-w.

33. The UN Environment (UNEP). Annual Report. 2023. 24 p. URL: https://clck.ru/3HPbPt (дата обращения: 05.12.2024).

34. Yasinskii S.V., Venitsianov E.V., Kashutina E.A., Sidorova M.V., Ershova A.A., Makeeva I.N. Contribution of microparticles to the transport of pollution by rivers and groundwaters in a large city // IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2021. Vol. 834. № 1. P. 012047.

35. Zhang Kai Z.K., Gong Wen G.W., Lv JiZhong L.J., Xiong Xiong X.X., Wu ChenXi W.C. Accumulation of floating microplastics behind the Three Gorges Dam // Environmental Pollution. Vol. 204. 2015. P. 117-123. https://doi.org/10.1016/j.envpol.2015.04.023.

36. Беседнова Н.Н., Щелканов М.Ю., Запорожец Т.С., Галкина И.В., Гмошинский И.В., Тутельян В.А. Влияние микро и нанопластика на слизистую оболочку желудочно-кишечного тракта и кишечный микробиом // Вопросы питания. 2023. №6 (550). С. 6-17. https://doi.org/10.33029/0042-8833-2023-92-6-6-17

37. Воробьев Е.Д., Трифонов А.А., Рахматуллина С.Н., Воробьев Д.С., Франк Ю.А. Внутригодовая динамика содержания микропластика в поверхностных водах реки Томи // Материалы I Всероссийской конференции с международным участием по загрязнению окружающей среды микропластиком «MicroPlasticsEnvironment-2022» (MPE-2022), 02–06 августа 2022 г., п. Шира, Хакасия / общ. ред. Ю.А. Франк. Томск: Издательство Томского государственного университета, 2022. С. 58–62.

38. Ефимова А.И., Зайцев В.Б., Болдырев Н.Ю., Кашкаров П.К. Инфракрасная фурье-спектрометрия: Учебное пособие. М.: Физический факультет МГУ, 2008. 133 с.

39. Зобков М.Б., Есюкова Е.Е. Микропластик в морской среде: обзор методов отбора, подготовки и анализа проб воды, донных отложений и береговых наносов // Океанология. 2018. Т. 58. № 1. С. 149-157. https://doi.org/10.7868/S0030157418010148.

40. Иванова Е.В., Тихонова Д.А. Оценка содержания частиц микропластика в Ладожском озере // Труды Карельского научного центра РАН. 2022. № 6. С. 58–67. https://doi.org/10.17076/lim1582.

41. Казмирук В.Д., Казмирук Т.Н. Микропластик в донных отложениях: методы определения // Вода: химия и экология. 2017. № 1(103). С. 87-92.

42. Каримов Э.Х., Даминев Р.Р. Развитие полимеров: от гевеи к макромолекуле // История и педагогика естествознания. 2012. № 4. С. 18-26.

43. Каурова З.Г. Содержание микропластиковых частиц в воде в верхнем и среднем течении реки Нева // Norwegian Journal of development of the International. 2021. №. 76-1. С. 3.

44. Колобов М.Ю., Таланина Е.Б. Многолетняя динамика содержания микропластика в поверхностных водах озера Байкал // Материалы I Всероссийской конференции с международным участием по загрязнению окружающей среды микропластиком «MicroPlasticsEnvironment-2022» (MPE-2022), 02–06 августа 2022 г., п. Шира, Хакасия / общ. ред. Ю.А. Франк. Томск: Издательство Томского государственного университета, 2022. С. 53–57.

45. Лезин В.А. Водные ресурсы рек и озер Тюменской области. Вестник Тюменского государственного университета // Экология и природопользование. 2011. 12. С. 62-69.

46. Никитин О.В., Латыпова В.З., Ашихмина Т.Я., Кузьмин Р.С., Насырова Э.И., Харипов И.И., Миннегулова Л.М. Гранулометрический состав и содержание микроскопических частиц синтетических полимеров в пресноводных экосистемах // В сборнике: Утилизация отходов производства и потребления: инновационные подходы и технологии. Материалы II Всероссийской научно-практической конференции. (г. Киров 17 ноября 2020 г.) Киров, 2020. С. 62-67.

47. Пахомова С.В., Ершова А.А., Жданов И.А., Якушев Е.В. Методы исследования загрязнения микропластиком природных вод: современное состояние и рекомендации // Океанологические исследования. 2024. Т. 52. № 1. С. 80–120. https://doi.org/10.29006/1564-2291.JOR-2024.52(1).5.

48. Поздняков Ш.Р., Иванова Е.В., Тихонова Д.А. Исследование загрязнения микропластиком акватории и притоков Ладожского озера // Материалы I Всероссийской конференции с международным участием по загрязнению окружающей среды микропластиком «MicroPlasticsEnvironment-2022» (MPE-2022), 02–06 августа 2022 г., п. Шира, Хакасия / общ. ред. Ю.А. Франк. Томск: Издательство Томского государственного университета, 2022. С. 19–23.

49. Франк Ю.А., Воробьев Е.Д., Рахматуллина С.Н., Трифонов А.А., Воробьев Д.С. Скрининг содержания микропластика в поверхностных водах Российских рек // Экология и промышленность России. 2022. Т. 26. № 9. С. 67–71. https://doi.org/10.18412/1816-0395-2022-9-67-71.

50. Франк Ю.А., Воробьев Е.Д., Трифонов А.А., Лемешко Я.Р., Воробьев Д.С. Загрязнение речной экосистемы микропластиком на примере притока Енисея, р. Нижняя Тунгуска // Материалы I Всероссийской конференции с международным участием по загрязнению окружающей среды микропластиком «MicroPlasticsEnvironment-2022» (MPE-2022), 02–06 августа 2022 г., п. Шира, Хакасия / общ. ред. Ю.А. Франк. Томск: Издательство Томского государственного университета, 2022. С. 95–100.

дата поступления: 17.12.2024 дата принятия: 06.02.2025