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Article

Micro- and Macroplastics Pollution in the Aquatic Environment of Markakol Lake Located in the Protected Area on the Mountain Slopes of the Southern Part of the Kazakh Altai Mountains

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Abstract. The paper presents primary material on determining the presence of micro- and macroplastics in Markakol Lake, one of the high-mountainous and unique water bodies of Kazakhstan, conditionally undisturbed, but vulnerable to anthropogenic pollution. In the course of work, micro- and macroplastics were detected in all selected samples in the water area of the lake and its main tributaries, the Urunkhaika, Topolevka, Tikhushka, Matabai, Elovka rivers. When determining micro- and macroplastics, we were guided by the method of analysis in aquatic environment, NOAA research program, developed by American scientists Masura J. et al, which is used in many countries. Concentrations and sizes of MP found in the water of the main tributaries of the rivers Urunkhaika in concentrations up to 211.4 $\mu\text{g}/\text{m}^3$, Tikhushka – 97.9 $\mu\text{g}/\text{m}^3$, Zhirelka – 67.8 $\mu\text{g}/\text{m}^3$, Topolevka – 157.2 $\mu\text{g}/\text{m}^3$, Matabai – 78.3 $\mu\text{g}/\text{m}^3$. Concentrations of MP in the surface water layer of the lake detected during 15 minute trawling at distances from 438 m to 841 m occur in sieve mesh sizes of 1.0 mm – 316.7 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 520.8 $\mu\text{g}/\text{m}^3$. The total concentration of detected micro- and macroplastics coming with tributaries was – 150 $\mu\text{g}/\text{m}^3$, in the lake water area – 837.4 $\mu\text{g}/\text{m}^3$. The sizes of plastic debris found both in river waters and along the lake water area ranged from mesoplastic debris (fishing line net fragments, foam balls, plastic bags, plastic bottles, wrappers, food labels and packaging, etc.) to microplastic particles detected using a microscope with 40X magnification in size ranges of 25 mm, 1.0 mm and 0.315 mm. Sources of MP depend on local human activities (fishing, transportation, waste disposal etc.).

Keywords: plastic garbage; microplastics; pollution; aquatic environment; concentration

1. Introduction

At all times, mankind has sought to discover new materials that could be strong, resistant to the effects of aggressive external factors and durable at the same time. Thus, in 1862 the English scientist A. Parkes presented a new material "parkesin", created from cellulose nitrate. In 1863, in New York, D. Hyatt invented the first analog of cellulose from plastic, calling it "celluloid". Almost 10 years later, polyvinyl chloride (PVC) was discovered in 1872 and cellophane in 1908. The 30s of the last century will be a breakthrough, so, in 1933, plastic (polyvinylidene chloride, PVDC), used in the production

of food film, was produced. In 1938, Teflon was discovered by R. Plunkett and used in the production of tableware. The active period of production and use of polyethylene began in 1939 as a lighter insulating material for American radars, and later in the production of bottles, various containers, garbage bags, etc. [1,2].

The world community did not anticipate that the revolutionary discovery of plastic materials would become a disaster half a century later, that the large-scale and intensive use of plastic products for industrial and economic purposes, the high demand due to relative cheapness, ease of production and processing led to an irreversible process of environmental pollution by plastic garbage. Thus, one of the greatest inventions of the 20th century, has become a major problem.

The first reports on the detection of micro- and macroplastics during phytoplankton sampling date back to the early 1970s [3,4] by the American marine biologist E. Carpenter during a research cruise in the Sargasso Sea. In 1972, he published his observations in the journal *Science* [3]. The study was the first confirmation of global plastic pollution, not only of polyethylene origin, but also of other human products. At the World level, microplastics were officially recognized as an ecosystem pollutant only in the early 2000s.

In 2004, marine biologist from Plymouth University (England) - Professor Richard Thompson gave a term to small plastic particles that were formed in the process of decomposition of larger particles - microplastics [5,6]. American scientists - M. Gregory and A. Andradi, plastic garbage is divided into mega- (more than 10 centimeters), macro- (more than two centimeters), meso- (from five to 20 millimeters) and microplastic (less than five millimeters) [7,8].

The main directions of research among scientists of the EU, USA and Japan mainly concerned the accumulation capacity of MP in marine ecosystems. At the same time, if we take into account that about 80 % of plastic accumulated in the sea is carried from the land by rivers to the oceans [9]. Microplastic pollution of inland water bodies (lakes, rivers, reservoirs) is insufficiently studied [10–13]. Nevertheless, in the last decade, studies of microplastics in freshwater systems have been developing intensively. Studies in Asia [14,15] and Europe [16] show that microplastics concentration and diversity are higher in bottom sediments than in the aquatic phase, and the migration of microplastics from river systems to the ocean depends on water velocity. Besseling et al. [17] demonstrated that larger plastics accumulate in sediments, while microplastics and nanoplastics flow downstream. Modeling studies have estimated that between 0.41 and 4 million tons of plastic are currently released from polluted rivers into the ocean each year worldwide [11,18–20]. The results of a study conducted on the Rhine River [11] established the riverine transport of MP pollution to the North Sea, which is quite polluted with microplastics [4]. In addition to the Rhine River, the Thames River [21,22] also contributes, in different concentrations along and across rivers, indicating different sources of pollution such as sewage treatment plants, tributaries and spillways. A study conducted in Australia [23] showed that the total mass of microplastics entering the marine environment from Melbourne's urban surface water was calculated using the average number of particles/L per river multiplied by the average daily and annual river discharge. On average, 9 ± 15 MP/L and 22 ± 11 MP/L (Werribee River) were detected in each of the rivers (Patterson, Werribee, Maribyrnong and Yarra), which account for ~97% of the surface water discharge to the marine environment of Port Philip Bay, expressed mainly by RA and RR.

Studies of toxic impact of MP discussed abroad, unfortunately, in our country is practically not studied. In this regard, in order to improve understanding of the degree and scale of plastic pollution of freshwater ecosystems, this pilot work to determine the content of micro- and macroplastics in Kazakhstan is conducted for the first time. From a review of foreign and domestic literature on pollution of the MP environment [24], a single mention of the presence of plastic waste in Kazakhstan was voiced in the work of Baimukanov M., which presents the results of a pilot work on the assessment of pollution by plastic particles, including micro- and macroplastics, which were carried out in pilot mode. The author notes the need to study the problem of plastic pollution and its potential impact on the biodiversity of both the Caspian Sea and other water bodies in Kazakhstan [25].

When selecting the object of study, the work of Malygina N. et al. was taken as an example, who for the first time for Siberian lakes similar to the object of our study, located in the mountainous part

of the Altai and West Siberian Plain, give an assessment of the MP content in the aquatic environment [26]. The authors focused their attention on six lakes, (Talmen, Julukul, Teletskoye, Zluduri, Degtyarka, and Kuchukskoye). All mountain lakes are fully or partially included in specially protected natural areas (Katunsky and Altai reserves), in which they tried to analyze the concentration, composition and spatial distribution of MP. Despite the fact that some of these lakes are unaffected by human activity and others are located in protected areas without permanent population, MPs were found in all lakes studied. MP concentrations ranged from 4 to 26 MP per liter. Fragments and films with sizes ranging from 31 to 60 nm were predominant among the recorded MP forms. Sources of MPs depend on local human activities (fishing, transportation, waste disposal). Therefore, quite high concentrations were observed even in remote lakes. The results of the study established a baseline that emphasizes the need for increased attention to waste management and water use in freshwater environments [26].

Thus, from all available high-mountain lakes of Kazakhstan, different in size, subject to anthropogenic impact, also conditionally undisturbed, but nevertheless vulnerable to anthropogenic pollution, the choice fell on Markakol Lake, the largest lake in the Altai Mountains (Figure 1).

Lake Markakol belongs to the lakes of intra-mountain hollows of the mountainous region in Eastern Kazakhstan [27–29]. The lake is located at an altitude of 1447 m above sea level, has an oval-extended shape and extends from northeast to southwest. It has a catchment area of 1180 km. Its total surface area is 460.4 km², its maximum depth is 23.8 m and its volume is 6.6 km³. The lake is 38 km long and 19 km wide [28]. There are 27 streams and rivers flowing into the lake, the main ones are Topolevka, Matabai, Urunhaika, Yelovka, Zhiren-Baital, and the Kalzhyr River has its origin.

The lake is located on the territory of the Markakol National Nature Reserve, which is part of the Altai-Sayan Ecological Region. The reserve was organized by the Decree of the Council of Ministers of the Kazakh SSR from August 4, 1976 No 365 for the preservation and study of natural complexes of the southern part of the Altai Mountains, development of methods for the restoration of biocenoses of the black taiga, study of the ecology and dynamics of fish numbers in the Markakol Lake. Due to its unique landscape and biological diversity, the territory of the Markakol Reserve is protected as a key area of the International Program GEF, UNDP, WWF, NABU and GTZ for the conservation of Altai-Sayan biologically diverse ecological region and is included in the 200 priority global ecological regions identified by the International Organization "WWF Living Planet" [30]. Kazakhstan, as a party to the Convention on the Conservation of Biological Diversity (Rio de Janeiro, June 5, 1992) approved by the RK on August 19, 1994 No 918, has its obligations on the conservation of biological diversity [31]. At the 34th session of the International Coordinating Council of the program "Man and the Biosphere" Markakol Reserve was accepted into the UNESCO World Network of Biosphere Reserves. All of the above-mentioned indicates the attention of the world community to the issues of biodiversity conservation in Kazakhstan.



Figure 1. Markakol Lake.

The purpose of this study is to determine the presence of micro- and macroplastics, its spatial distribution and variability in the aquatic ecosystem of Markakol Lake.

The novelty of the study is substantiated by the fact that the problem of environmental pollution by microplastics for Kazakhstan is unexplored.

Practical significance lies in the fact that the results of the work can be used in the development of larger-scale projects in the field of microplastic problems. Analyzing the presence of microplastics in water bodies of the Republic of Kazakhstan will contribute to the research on the presence of microplastics and its impact on the aquatic environment.

2. Study Materials and Methodology

Sampling was carried out (August 07-30, 2023) along the lake water area on the surface water layer, plankton net of mesh size 333-335 μm by trawling method [32] up to 1 km for the presence of micro- and macroplastics at a depth of 1.0 m and more, also on tributaries with a sample collection duration of 15 minutes (Figure 2).

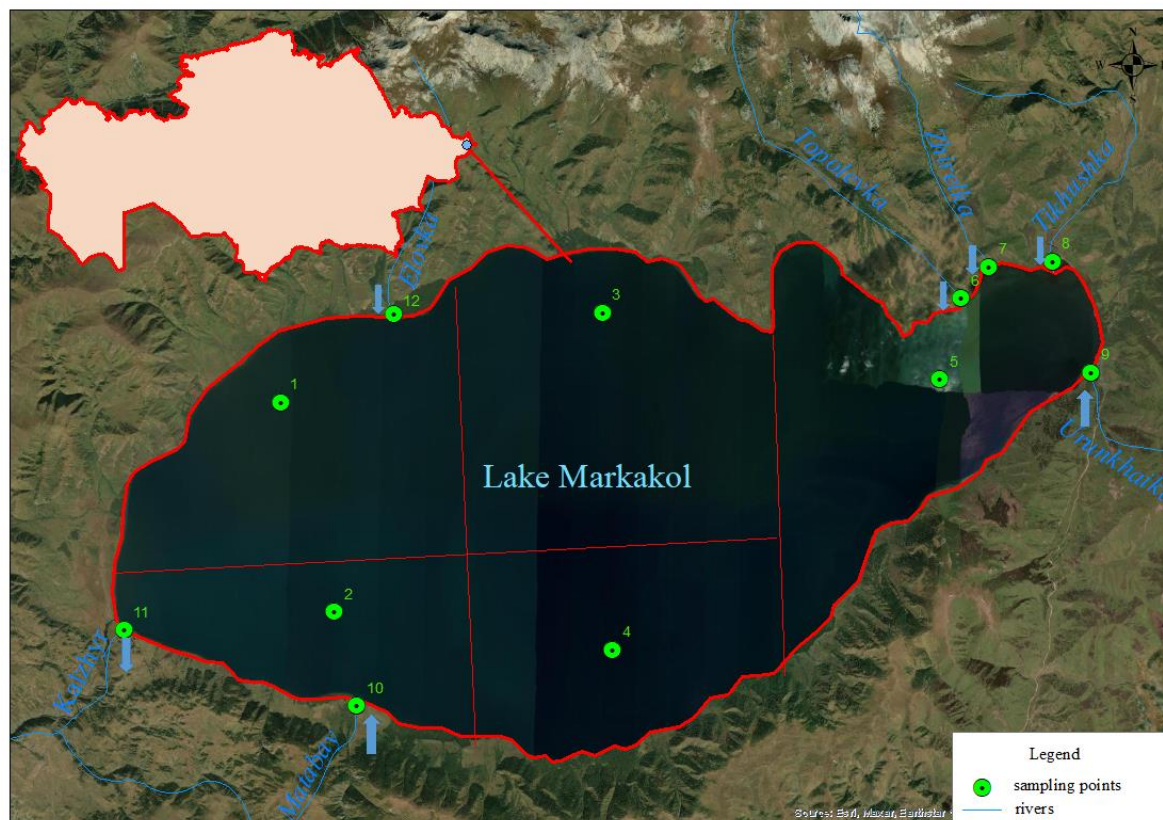


Figure 2. Sampling locations (Markakol Lake, Kazakhstan).

The plankton net is characterized by the diameter of rings 140 mm x 400 mm and length 1000 mm with a beaker for 100 ml with an overlapping tap made of brass (brass beaker), sieve fabric mesh size - 335 μm .

Due to the fact that at the present time the definition of particle size and their attribution to micro- and macroplastics has not been finally formed: with a diameter < 10 mm [33], < 5 mm [34–36], 2–6 mm [37], < 2 mm [38], < 1 mm [39–41], < 500 μm [42], etc., but most scientists [42–44] agree that these are particles ranging from 0.5 to 5.0 mm in the largest dimension. Some works suggest a lower limit of 0.3 mm [45,46] due to the widespread use of plankton nets with mesh size around 333–335 μm for water sampling [47,48]. In addition to these size groups, other smaller, nanoscale particles (e.g., 1 nm to 1 μm [47], < 50 μm [49]) are likely to be present, but since techniques for their qualitative and quantitative analysis have not yet been fully developed [49], the study of this project will investigate microplastic particles ranging in size from 0.5 to 5.0 mm and macroplastic particles up to 25.0 mm and larger [43].

The problem of MP pollution, both in the world ocean and freshwater inland water bodies, began to be actively raised in the scientific community [50–57], together with the need to develop standardized techniques. Many scientists have started and are successfully working in this direction [55–57], but in general, to date, this problem remains unsolved.

2.1. Methods for Determining Micro- and Macroplastics

Methods for determining MP are proposed in the methodological manual by Zobkov M.B. and Esiukova E.E. [58–60], which are one of the first documents in Russian. These methods [43,55] translated into Russian by the authors of methods Masura J., Baker J., Foster G., Arthur C. [55] and Hidalgo-Ruz, V., L. Gutow, R.C. Thompson, M. Thiel [43] with some corrections and explanations of the translators, both for marine waters and freshwater bodies for quantitative analysis of micro- and macroplastics in water and bottom sediments (NOAA Marine Debris Survey Program). This manual is one of the first guidance documents to offer a step-by-step methodology for analyzing

microplastics in the marine environment. A significant advantage of the proposed methodology is the use of uniform procedures for analyzing both water samples and bottom and shore sediments, which allows for comparable results between the two, allowing conclusions to be drawn about fluxes of matter between different marine zones. The methodology has three sections, each of which describes the procedure for analyzing a sample of the appropriate composition (water, sand or sediment sample), with formulas for calculating MP concentrations.

The sample analysis process goes through the stages of sieving, drying, liquid oxidation in hydrogen peroxide, density separation (flotation), and visual sorting with a microscope. The sieving operations are performed several times for each analysis. This fact speeds up the process considerably, compared to filtration, since sieves with a mesh size of 0.315 mm are used, which is well applicable for plastic granules, which are the raw material of plastic production (films, sheets, fishing lines and fibers).

We chose the methods of analysis developed by American scientists J. Masura, D. Baker, G. Foster, and S. Arthur on the basis of their research from the currently available methods for determining MP [55].

As recommended by the authors Masura J. et al. [55], both during sampling and laboratory processing of samples, the use of clothing made of synthetic materials should be avoided in order to eliminate the risks of plastic particles from fabric and applied equipment made of plastic in the sample and its secondary contamination. When samples are analyzed with a microscope, some naturally occurring materials may be misidentified as microplastics. Materials that are naturally occurring are more likely to be present not only at the sampling stage, but also at each of the processing steps. Such materials can be easily confused with microplastic particles. To identify naturally occurring materials, it is recommended to squeeze the suspect particle and if it breaks its integral structure, it should be excluded from the sample using tweezers.

To increase accuracy in samples that contain large amounts of organic matter (grass, sawdust, tree bark, pine needles, etc.) they should be sieved through a sieve with mesh sizes of 25.0 mm, 10.0 mm, 5.0 mm, 1.0 mm and 0.315 mm and removed when found.

The final result of the method is the measured mass of microplastic in the initial amount of substance.

Plastic forms determined by this method include: hard and soft plastics, films, fishing lines, fibers, and sheets. The method consists of filtration of suspended material collected using a surface plankton net. The sieved material is dried to determine the mass of solids in the sample. The solids undergo wet oxidation in hydrogen peroxide medium in the presence of the catalyst, Fe (II) to dissolve labile organic matter. The plastic remains unaffected. The remaining undissolved fragments are subjected to density separation in NaCl solution to separate the plastic particles from the rest through flotation using a separator. After the separator, the plastic particles are collected on a 0.3 mm filter, dried, and the plastic is separated using a microscope at 40X magnification and weighed to determine its concentration.

The method is applicable to the determination of many plastics in water and sediments, including polyethylene (0.91-0.97 g/cm³), polypropylene (0.94 g/cm³), polyvinyl chloride (1.4 g/cm³), and polystyrene (1.05 g/cm³).

2.2. Progress of Determination of Micro- and Macroplastics by Aqueous Analysis (NOAA Research Program)

Equipment and materials used [55]:

- Stainless steel sieves of 20 cm diameter and 5 cm depth each with mesh sizes of 25 mm; 10 mm; 5.0 mm (ISO 3310-2 2000/50); 1.0 mm and 0.315 mm (GOST R 51568-99 200/50);
- Spritzing with distilled water;
- Laboratory beaker 500 ml;
- Analytical scale (up to 0.1 mg) (OHAUS SPS6001F, USA);
- Metal spatula;
- Drying cabinet (up to 90 °C) (SNOL 24/200 LSP01, Lithuania);
- Fe (II) solution (0.05 M molar). Prepared by adding 7.5 g FeSO₄*7H₂O (concent. 278.05 g/mol) to 500 ml distilled water and 3 ml concentrated sulfuric acid 30% hydrogen peroxide solution;

- Magnetic stirrer (IKA C-MAG HS 7 digital);
 - Laboratory electric stove;
 - Laboratory hour glass;
 - Sodium chloride (food grade salt);
 - Metal tweezers;
 - Density separator assembled from a glass funnel (d-122 mm) with a latex tube worn at the bottom and clamped with a clamp;
 - Tripod;
 - Rubber ring;
 - Aluminum foil;
 - Glass bouquets with a volume of 4 ml;
- Microscope with magnification 40X (Levenhuk MED D35T LCD, trinocular).

Raw sieving. Pass the sample through 25 mm, 10 mm, 5.0 mm, 1.0 mm, 0.315 mm stainless sieves set one above the other. Rinse the sample bottle from the syringe to transfer any remaining solids to the sieves, and rinse the sieves of salt. Rinse the sieves well with distilled water. Ensure that all material has been well rinsed, sorted, and the water has drained away. Remove any material remaining on the top sieve.

Moving Solids. Weigh a clean and dry 500 ml laboratory beaker on an analytical scale. Transfer the solids into the beaker using a metal spatula and minimal rinsing from the syringe. Ensure that all particles are transferred to the laboratory beaker. Place the laboratory beaker in a desiccator, temperature 90 °C, time 24 hours, or longer if necessary. Upon completion, the sample should be dry.

Determination of total mass of solids. Determine the mass of the laboratory beaker with dried solids on an analytical scale (to the nearest 0.1 mg). Subtract the mass of the empty beaker from the resulting mass. This is the total mass of microplastic and natural materials.

Liquid oxidation in hydrogen peroxide. Add 20 ml of 0.05 M Fe(II) liquid solution to a chemical beaker containing solids. Add 20 ml of 30% hydrogen peroxide. Let the mixture stand at room temperature for 5 minutes. Lower the magnet of the magnetic stirrer into the beaker and cover the beaker with an hour laboratory glass. Heat to 75 °C on a laboratory hot plate. As soon as gas bubbles begin to appear on the surface, remove the beaker from the stove and place it in a laboratory cabinet until boiling stops. If the contents overflow the beaker, distilled water should be added to slow the reaction. Heat the beaker to 75 °C and maintain the temperature for another 30 minutes. If natural organic matter is still observed, add another 20 ml of 30% hydrogen peroxide. Repeat until no more natural organic matter is observed. Add 6 g of salt (NaCl) for every 20 ml of sample to increase the density of the solution. Heat the solution to 75 °C until the salt dissolves. Transfer the resulting solution to a density separator. Rinse the laboratory beaker with distilled water to dislodge any remaining solids. Cover the separator with aluminum foil. Allow to stand overnight.

Visually inspect the sludge for microplastic particles. If found, drain the sludge and pick out the microplastic with tweezers. Drain the remaining solution in the separator funnel through a 0.315 mm sieve. Rinse the separator with distilled water several times to ensure that all solids are transferred to the sieve. Dry the sieve at room temperature for 24 hours, lightly covered with aluminum foil.

Analyze the microplastic with a microscope. Sign and weigh a clean and dry lidded bouquet on an analytical scale. Using a microscope with 40X magnification and tweezers, pick out identifiable microplastic from the surface of the sieve and place it in the tared bouquet.

Gravimetric Analysis. Weigh the bust with microplastic on an analytical scale. Subtract the mass of the box from the obtained value. The obtained result is the mass of microplastic.

3. Results of the Study

Concentration and sizes of MP found in the water of the main tributaries and along the lake water area are given in Figures 3–5 and in the Table 1. Large amounts of plastic litter were found in the north-eastern part of the lake, in the Urunhaika River up to 211.4 µg/m³ in sieve mesh sizes 25 mm – 143.1 µg/m³, 1.0 mm – 56.8 µg/m³ and 0.315 mm – 11.5 µg/m³ mainly of polyethylene origin.

In the water of rivers flowing from the northern part of the lake, MP was detected in concentrations of: Tikhushka – 97.9 $\mu\text{g}/\text{m}^3$ in sieve mesh size 1.0 mm – 67.7 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 30.2 $\mu\text{g}/\text{m}^3$, Zhirelka – 67.8 $\mu\text{g}/\text{m}^3$ in sieve mesh size 1.0 mm – 43.8 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 24.0 $\mu\text{g}/\text{m}^3$, Topolevka – 157.2 $\mu\text{g}/\text{m}^3$ in sieve mesh size 1.0 mm – 130.9 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 26.2 $\mu\text{g}/\text{m}^3$.

In the southern part, the Matabai River flows into the lake with a total MP concentration of 78.3 $\mu\text{g}/\text{m}^3$, in sieve mesh sizes of 1.0 mm – 57.4 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 20.9 $\mu\text{g}/\text{m}^3$. As can be seen from Figure 3, MP was not detected in the Yelovka River and in sieve mesh sizes of 10 mm and 5.0 mm.

Concentrations of MP in the surface water layer of the lake, detected during 15-minute trawling at distances from 438 m to 841 m are found in sieve mesh sizes 1.0 mm – 316.7 $\mu\text{g}/\text{m}^3$ and 0.315 mm – 520.8 $\mu\text{g}/\text{m}^3$ with a total concentration of MP over the water area of 837.4 $\mu\text{g}/\text{m}^3$.

High concentrations of MP are registered in the northern part of the lake up to 200.2 $\mu\text{g}/\text{m}^3$, in the northeastern part up to 286.8 $\mu\text{g}/\text{m}^3$ and in the southern part up to 151.6-157.3 $\mu\text{g}/\text{m}^3$ in the zones of the Topolevka, Urunhaika and Matabai Rivers confluence, where MP in high concentrations is also detected. MP was detected in sieve mesh sizes of 1.0 and 0.315 mm.

During the study, MP was not detected in the Kalzhyr River, which originates from Markakol Lake, which indicates the accumulation and sedimentation of micro- and macroplastics in the water and bottom sediments of Markakol Lake.

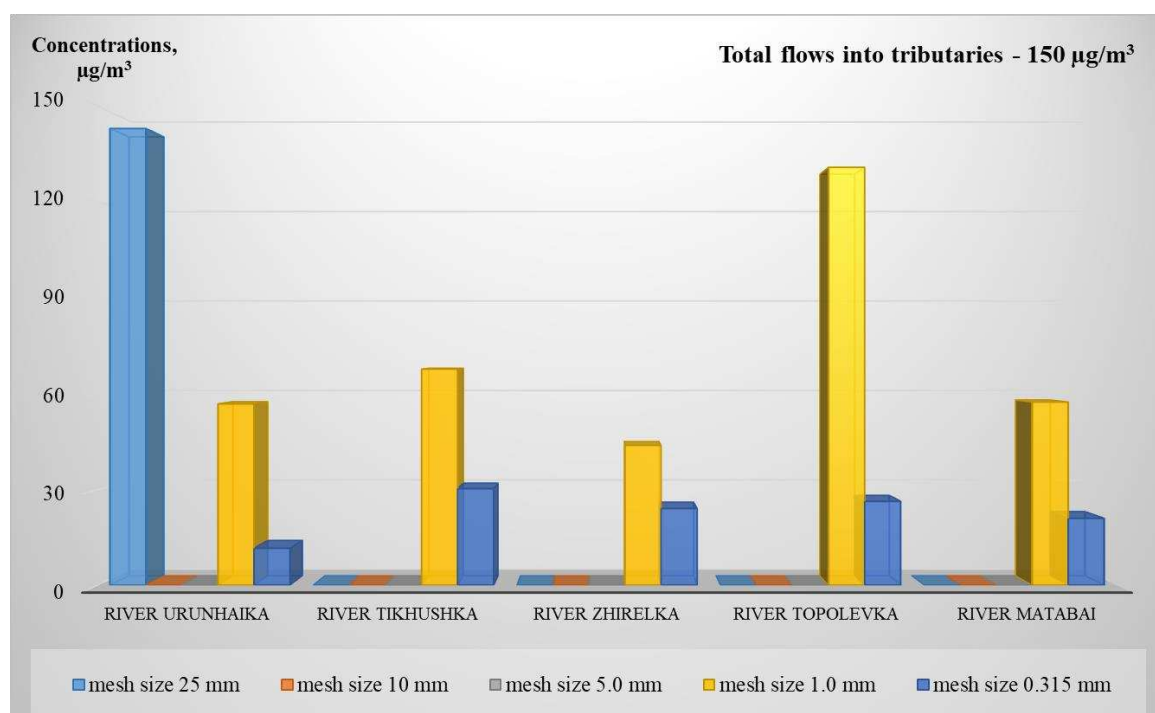


Figure 3. Concentrations of micro- and macroplastics detected in the water of major tributaries.

Table 1. Concentration and size of micro- and macroplastics found in lake water.

Selection site	Trawling time 15 min/m	Concentration, $\mu\text{g}/\text{m}^3$		Total, $\mu\text{g}/\text{m}^3$
		mesh size 1.0 mm	mesh size 0.315 mm	
Zone 1	438 m	6.1	151.2	157.3
Zone 2	841 m	38.2	113.4	151.6
Zone 3	593 m	147.2	53.0	200.2
Zone 4	512 m	4.0	37.6	41.5
Zone 5	736 m	121.3	165.5	286.8
Total for the lake water area				837.4

Thus, the total concentration of detected micro- and macroplastics in the tributaries was $150 \mu\text{g}/\text{m}^3$, in the lake water area – $837.4 \mu\text{g}/\text{m}^3$.

The sizes of plastic debris detected both in river waters and in the lake water area ranged from mesoplastic debris (fragments of fishing line nets, foam balls, plastic bags, plastic bottles, wrappers, labels and food packaging, etc.) to microplastic particles detected using a microscope with 40X magnification in size ranges of 25 mm, 1.0 mm and 0.315 mm.

The plastic particles detected both in the tributaries and along the lake water area were of different sizes and colors such as green, black, red, white, transparent, etc. (Figures 4–6).



Figure 4. Results of visual inspection of selected samples. Particles of plastic products of different sizes (photos by A.A. Madibekova).

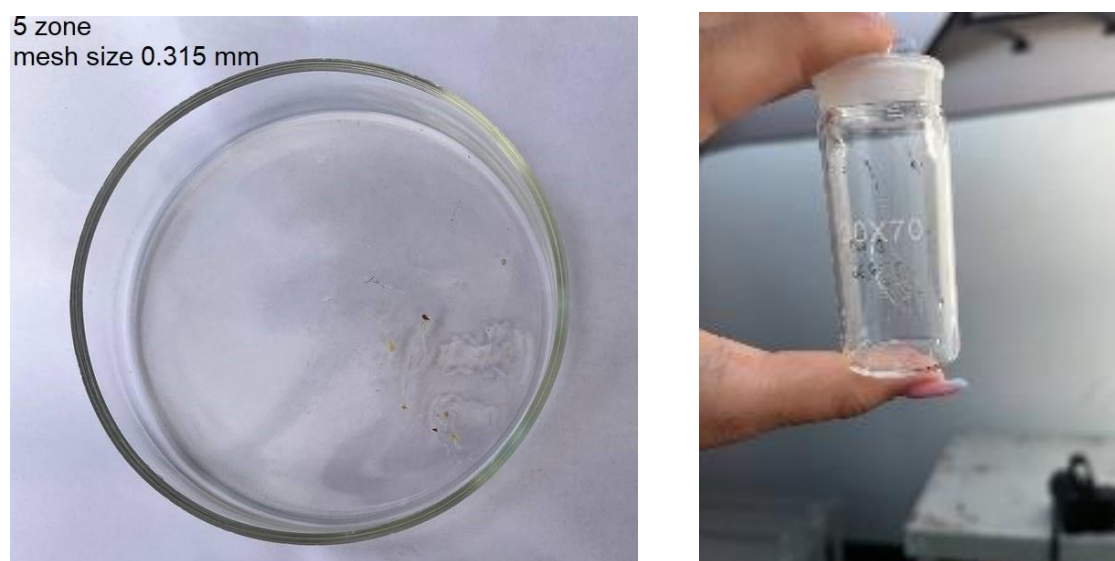


Figure 5. Results of visual inspection of the selected samples. MP particles (photos by A.A. Madibekova).

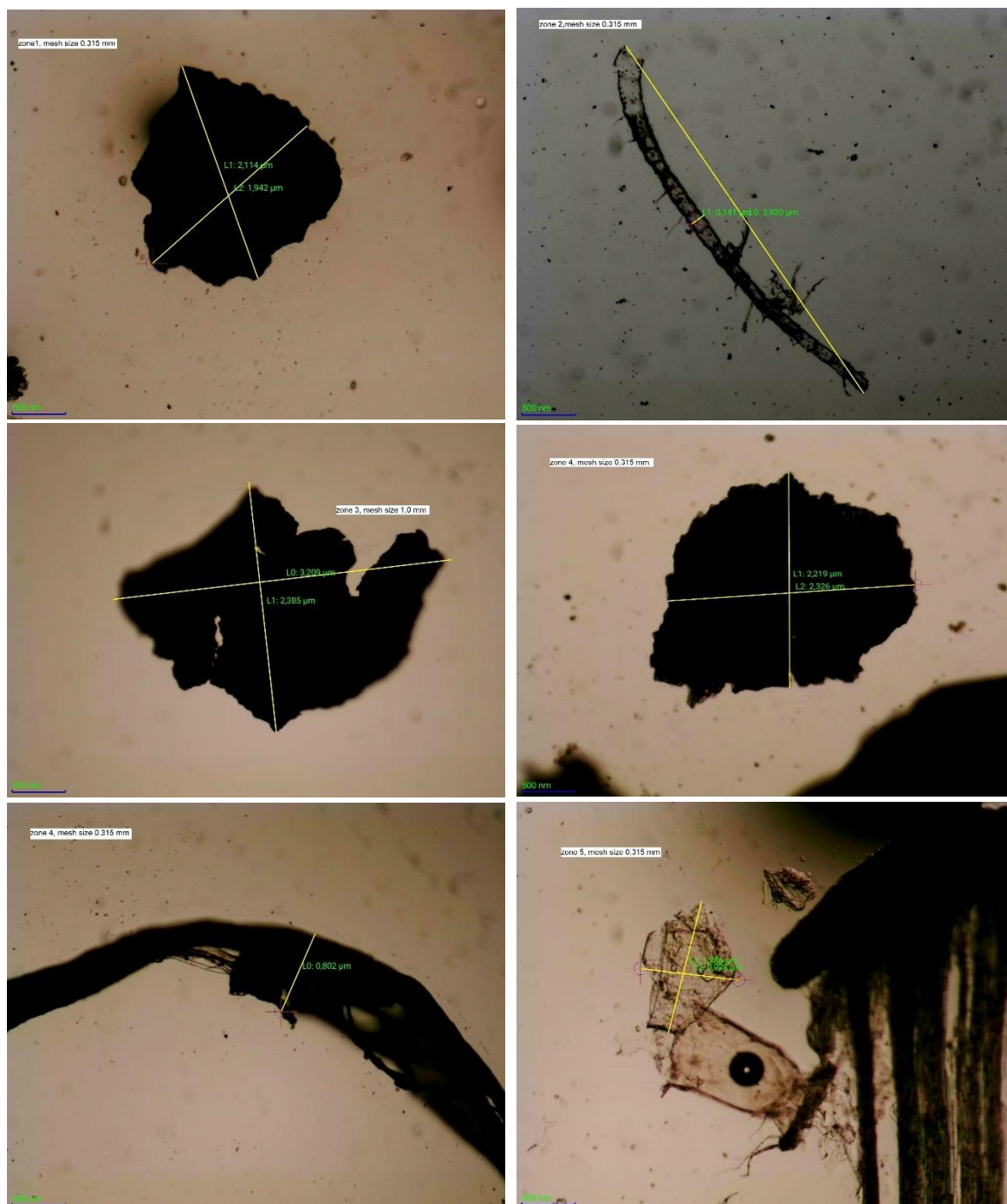


Figure 6. MP (size) detected in water samples, under a microscope with 40X magnification (photos by A.A. Madibekova).

The polymer composition of the isolated plastic fragments both visually and under the microscope are represented by different types of plastic: PET, PE HD, PEBD, PP, PS, which are widely used in everyday life (Figure 7).

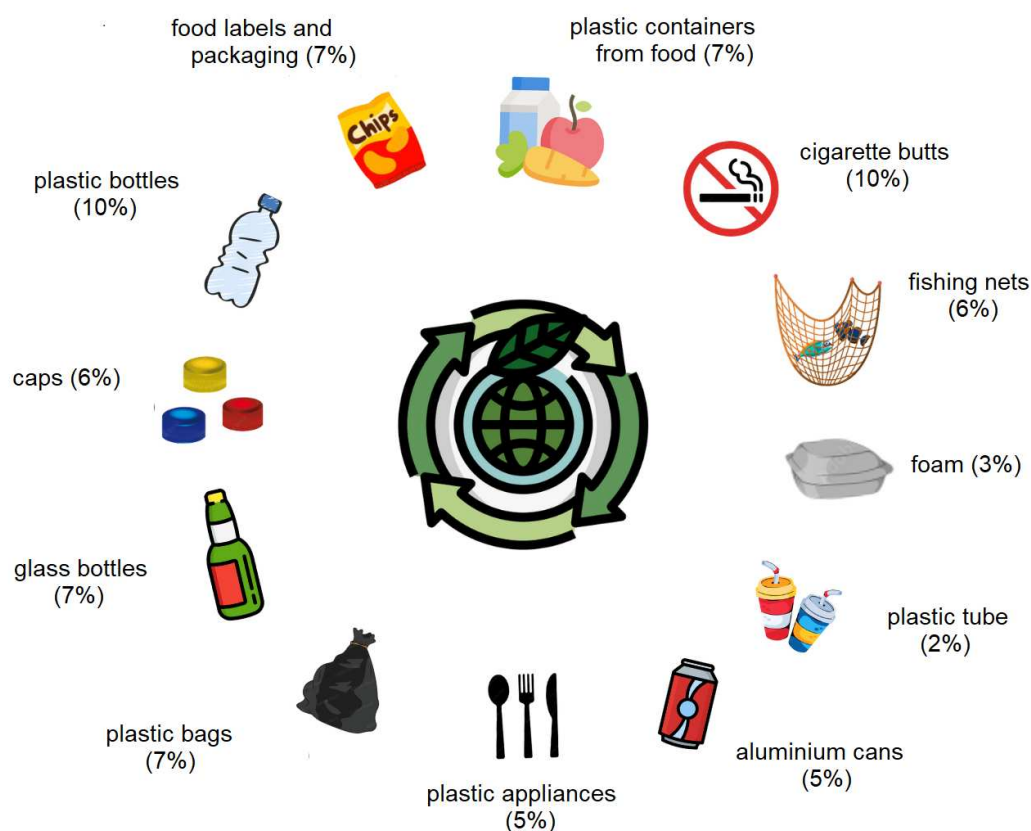


Figure 7. Types of plastic debris found (picture made by A.A. Madibekova).

The areas in the lake and river water areas where MP was detected may be related to the increase in tourism and close proximity of the population to the object of study, as the low specific density of plastic particles ensures their widespread distribution in aquatic systems. Long-range atmospheric transport of small plastic particles can also be assumed, although this issue has not been studied sufficiently yet.

4. Discussion

In the works of many authors [61–64], who conducted studies to assess the microplastic content in various aquatic environments, plastic particles were found in significant concentrations. Microplastic content up to 292 particles/m³ was found in the water of Lake Ladoga with high values at the confluence of the rivers Janisjoki and Vuoksa – 144 and 109 particles/m³, near urban areas (Priozersk) – 160 particles/m³, and near the plant in Pitkäranta – 353 particles/m³ [61].

Plastic pollution of coastal surface waters of the middle and southern Baikal plastic particle content ranged from 14912 to 75382 particles/km² with an average of 41807 particles/km², in total mass content from 0.39 to 20.77 g/km² with an average of 6.66 g/km² [62].

Study in surface water of Chao Phraya River, located in Bangkok with high population density microplastics were found in total 104 particles/m³ and concentration of 805.20 mg/m³ with sizes ranging from 0.5 to 1.0 mm. The predominant MPs were particle size fragments ranging from 0.5 to 1.0 mm mainly polypropylene, polyethylene and polystyrene, which was confirmed by Fourier transform infrared spectroscopy [63].

The FanPLESStic-sea project "Baltic Sea without microplastics" [64], led by the Swedish Water Research Institute (SWR), analysed the microplastic content in different aquatic environments. Thus, in waste water of Gdansk (Poland) the content of microplastics is 184 particles/m³, which is equal to

1600 $\mu\text{g}/\text{m}^3$, river water in the city limits was found up to 3206 particles/ m^3 , 616 $\mu\text{g}/\text{m}^3$, expressed by polyester, polypropylene and polyamides.

The results of our research conducted on Markakol Lake and its main tributaries microplastics with sizes below 0.315 mm were found in concentrations up to 520.8 $\mu\text{g}/\text{m}^3$ and 113.0 $\mu\text{g}/\text{m}^3$, which is slightly lower than in urbanized and agricultural areas. However, the presence in the aquatic environment of the protected area of both microplastics, mesomass and macroplastics is a consequence of local human activities, such as fishing, tourism, improper disposal of household waste, etc. The presence of microplastics in the aquatic environment of the protected area is a consequence of local human activities.

Along with the determination of plastic content in the environment, recently there has been a special scientific and public interest in the sources from which microplastics get into water bodies. Since microplastic has the property of accumulation and transportation of harmful substances (heavy metals, persistent organic pollutants), and its particles can get into the organism of hydrobionts, further on the food chain to be transmitted to humans. Accumulation of plastic in body tissues can harm the reproductive system, lead to obesity, the emergence of various inflammatory and autoimmune processes, as well as cause developmental delays in children. And one of the main reasons for the spread of micro- and macroplastics is - improper disposal of plastic garbage.

According to the results of studies [65–67], the global output of plastic according to different estimates is from 275 to 340 million tons/year, while the scale of disposal and recycling of plastics is incommensurably smaller. In Europe, about 70% of plastic waste is sent for utilization and recycling [66], while the world average is 20% [68].

Plastic recycling is a global problem. Plastic is nearly indestructible in the wild, but is discarded on a large scale around the world. Approximately 359 million metric tons of plastic are produced globally each year. Nature cannot handle the volume of their disposal at a rate fast enough to prevent environmental damage.

There is a perception that plastics are an unsustainable material. Plastics are certainly a huge problem, but they don't have to be. The main problem stems from our linear economic model: goods are produced, consumed, and then disposed of. This model assumes infinite economic growth and fails to take into account the planet's exhaustible resources.

Most people believe that plastic recycling is strictly limited and only a few types can be recycled. This is not surprising. The percentage of plastic that is recycled is minimal.

But all polymers are technologically 100% recyclable. Some have a perfect life cycle from production to overproduction: they can be used over and over again to produce the same goods. Some plastics can be reused simply as they are, by shredding the object into flakes, melting it, and reusing it.

Such recycled plastic may have lower mechanical properties than virgin plastic because each time the plastic is melted and processed, the polymer chains are broken down. But these properties can be restored by blending with specialty additives or virgin plastic.

Examples of successful industrial recycling include PET – poly (ethylene terephthalate), which is used to make beverage bottles, and polystyrene [69].

In 2018, the UN called on all sectors of society to unite in the fight against plastic pollution. For World Environment Day, which is celebrated on June 5, the United Nations Environment Program (UNEP) published a report on plastic pollution. According to the UN, 500 billion plastic bags are used globally every year, and 1 million plastic bottles are bought every minute. Each year, 17 million barrels (2.7 billion liters) of oil are used to produce bottles [70].

Much plastic is produced with the expectation of being discarded immediately after use. Consequently, plastic packaging materials account for about half of all plastic waste in the world, with most of this type of waste generated in Asia. According to a UNEP report, of the 9 billion tons of plastic produced in human history, only 9% is recycled. Unrecycled plastic ends up in landfills, landfills or the environment. If this trend continues, by 2050, about 1-2 billion tons of plastic waste will end up in landfills and the environment.

The problem of plastic waste management in Kazakhstan, as well as in most countries of the world, is quite acute. According to "Operator ROP" LLP the share of plastic packaging formation in 2016 amounted to 283387 tons, while the volume of its processing in 2017 – 6066 tons (about 2%), in 2018 – 8994 tons (about 3%) [71,72].

In 2019, the Center for Sustainable Development Assistance analyzed the industry of plastic waste management, mainly PET and HDPE. To date, there are over 80 companies in Kazakhstan for the collection and processing of such waste. As a rule, these are small and medium-sized enterprises, individual entrepreneurs, including 69 companies-collectors and 15 companies-processors of plastic, and to consolidate the efforts of stakeholders in the collection and processing of plastic waste, a network PlastNet was created in Kazakhstan [72].

Despite the development of infrastructure for plastic waste management, the country faces the problem of collection and transportation of plastic waste to processing plants. An important task for the development of the system of collection and recycling of plastic waste is public awareness of safe methods of waste management, rules of separate waste collection and existing systems of waste collection for the population.

Implementation of the mentioned activities in the future could have a great impact on the development of the system of collection, transportation and recycling of waste plastic, which will have a positive impact on the improvement of the environmental situation in Kazakhstan and will contribute to the achievement of the goals of the "green" economy.

5. Conclusion

This paper presents a preliminary assessment of micro- and macroplastic pollution in the water area of Markakol Lake and its main tributaries. The research on determination of primary microplastic pollution, determination of its quantity and size is the first work in Kazakhstan.

Markakol Lake, located on the territory of the Markakol Reserve, accepted into the UNESCO World Network of Biosphere Reserves, which is considered not subject to anthropogenic impact, also conditionally undisturbed, according to the results of the research was among those water bodies that were subjected to plastic pollution.

Higher concentrations of MP are registered in the northern part of the lake up to 200.2 $\mu\text{g}/\text{m}^3$, in the northeastern part up to 286.8 $\mu\text{g}/\text{m}^3$ and in the southern part up to 151.6-157.3 $\mu\text{g}/\text{m}^3$ in the zones of Topolevka, Urunhaika and Matabai rivers confluence, where MP in high concentrations is also detected. At the Kalzhyr River, which originates from Markakol Lake, MP was not detected, which indicates the accumulation and sedimentation of micro- and macroplastics in the water and bottom sediments of Markakol Lake. The total concentration of micro- and macroplastics in the tributaries was 150 $\mu\text{g}/\text{m}^3$, in the lake water area – 837.4 $\mu\text{g}/\text{m}^3$.

The sizes of plastic debris found both in river waters and in the lake water area ranged from mesoplastic debris (fragments of fishing line nets, foam balls, plastic bags, plastic bottles, wrappers, labels and food packaging, etc.) to microplastic particles. The polymer composition is represented by: PET, PE HD, PEBD, PP, PS. The areas along the lake and river water area, where the MP was found, can be associated with poaching, unconstructive tourism violating the protected regime, which in addition to catching and extermination of endemic fish species, litter it with plastic debris (left nets made of polyamide fiber, monofilament, etc.).

Until there are clear restrictive measures on the production and use of plastics, we need to preserve the natural heritage. For this purpose, special protection measures are implemented in the territories of UNESCO sites and other no less important natural areas, but, unfortunately, as the results of this work show, this was not enough. The main sources of pollution are recreational and poaching fishing, lack of organized collection of solid waste, as well as low level of environmental awareness of both tourists and local population. In this regard, continued monitoring of plastic in aquatic ecosystems is an important step to understand the extent of the problems and to develop effective pollution management strategies.

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