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Assessment of the Level of Pollution of the Aquatic Ecosystem of Lake Markakol with Mobile Forms of Copper and Zinc

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Abstract: The purpose of the study is to conduct toxicological analysis to assess the degree of accumulation of heavy metals and micro- and macroplastic particles in the aquatic environment of the lake in the system "water-bottom sediments". The method of spectrometric atomic absorption analysis was used during the study. Detection of high concentrations of copper (Cu) and zinc (Zn) in the surface layer up to 1.5 and 1.3 times, in the bottom layer up to 1.3 and 1.4 times, respectively, indicated exceeding the norms of maximum permissible concentrations for fishery purposes. High values of metals in the surface water layer were registered in deep-water areas of the lake Markakol, and in the bottom layer, high values are concentrated in shallow areas and in the river confluence zones. High Cu concentrations were recorded in shallow areas of the lake, at depths from 2.7 m – 10.2 mg/kg to 4.7 m – 8.9 mg/kg, 7.9 m – 12.3 mg/kg. Cu values in deep water bottom sediments were much lower, at 20.4 m – 2.8 mg/kg, 21.1 m – 2.6 mg/kg, 21.6 m – 6.6 mg/kg. A similar distribution pattern in bottom sediments was observed for Zn. High concentrations of Zn were recorded in shallow areas, from 154 mg/kg at 2.7 m depth, to 439 mg/kg – 4.6 m, this may be due to an increase in the proportion of their bioavailable forms in the water column, which would be harmful to all hydrobionts. The results of the study can be used in practice by ecologists in order to develop and implement measures to improve the ecological state of the ecosystem of Lake Markakol.

Keywords: heavy metals; microplastics; macroplastics; concentration; anthropogenic load; migration

1. Introduction

The topic of the study requires research, as one of the main environmental problems of the present time is the deterioration of the state of the aquatic environment[1),2),3)]. The problem of the study is that in the basin of Lake Markakol the ecological situation was formed mainly under the influence of the deposit, which produced polymetallic ores containing elevated concentrations of toxic elements, among which are heavy metals such as copper (Cu) and zinc (Zn). At the same time, the high level of Zn content is due to the fact that in the basin of the Lake Markakol there is the Elovskoe nickel deposit. The study of the Lake Markakol ecosystem requires a comprehensive approach, similar to the study led by A.S. Madibekov et al. [4)]. Their work highlights aspects of assessment of pollution of the aquatic ecosystem by plastic particles, heavy metals, and polychlorinated biphenyls (PCBs). Standardized protocols, advanced analytical techniques, and rigorous data analysis used in their research contribute to the high accuracy of these methods, ensuring that the findings are both scientifically valud and practically relevant. The application of such methods can provide valuable information on the status of water in Markakol and possible threats to the local ecosystem.

In the analysis by Zh.M. Kadyrkhanova, measures to address environmental problems were presented, including improvement of the regulatory framework in the field of environmental management and environmental monitoring system[5)]. These approaches can also be

effective when applied to Lake Markakol, contributing to the reduction of pollution, and increasing the level of environmental protection. The research of M.T. Baimukanov and Zh.M. Baimukanova, M. Miloslavić et al. on the impact of plastic pollution of the Caspian and Adriatic Sea water shore can serve as an example in developing a strategy for the disposal of rubbish and fishing nets in Markakol[6),7)]. The expansion of special collection points on the sea coast and in nearby cities and towns could be a key element in preventing waste from entering the water body.

A similar approach to the study of water bodies that was presented in the work of G. Onerkhan and Sh.N. Durmekbaeva, can be applied to better understand the ecological state of Lake Markakol [8)]. According to the test results, it was determined that the studied water body – Lake Bolshoye Chebachye, corresponds to the 3rd class of pollution. Analysis of seasonal taxonomy of species composition and ecological state of Lake Bolshoye Chebachye using microalgae can become a tool for classifying the level of pollution and developing specific measures to reduce it. This method offers valuable insights into the ecological dynamics and health of a lake ecosystem. When appropriate techniques and quality control procedures are used, the accuracy of such analysis using microalgae is high. The study by D.S. Akhmetzhanova et al. on the analysis of radionuclide content in the groundwater of the Azgir landfill and research by T.P. Fedoniuk et al. on the landscape structure of the Chornobyl Radiation and Ecological Biosphere Reserve can contribute to the study of the toxicity of Lake Markakol water[9),10)]. Accuracy of the used methods in their research, such as ion chromatography and mass spectrometry, relies on high-purity reagents, careful sample handling, and calibration. Precise quantification of pollutants that could affect the radiation-ecological state is ensured by these methods. The methods used in their work can be adapted to assess the content of heavy metals in the water of this lake.

The work of A. Kartbaev, which provides data confirming the effectiveness of the project on the regulation of the Syr Darya River channel and preservation of the northern part of the Aral Sea, emphasizes the importance of integrated projects for the restoration of the natural environment [11)]. The revival of lakes in the Aral Sea area, as well as the restoration of fish species that had previously disappeared from the sea, was noted. In addition, the volume of fish catch was increased from 400 to 7 thousand tonnes. This experience can be valuable in forming a strategy to improve the environmental situation in Markakol, given the unique features of this water body.

Today in the East Kazakhstan Oblast, not enough attention is paid to the development of a strategy to manage pollution in the aquatic ecosystem of Lake Markakol. The purpose of the study is to assess the level of pollution of water and bottom sediments of the aquatic ecosystem of Lake Markakol.

2. Materials and Methods

The study used flame atomic absorption spectrometric method for determination of Cu and Zn in water samples and bottom sediments, the use of which is regulated by the standards of the Republic of Kazakhstan ST RK ISO 8288-2005[12)]; GD 52.18.289-90[13)]. The remarkable accuracy and precision of this method in measuring the concentration of different elements in a sample is one of its main benefits. It is a trustworthy tool in elemental analysis because of its sophisticated technology and calibration capabilities, which guarantee accurate and repeatable findings. At spectrometric determination of metals for construction of calibration graphs with correlation coefficients r=0.99 State Standard Reference Materials (SSM) were used: composition of aqueous solution of Cu ions (3K-1) SSO 7998-93 (C_{Cu}=0.0125; 0.025; 0.05; 0.1 mg/l); composition of aqueous solution of Zn ions SSO 7837-2000 (C_{Zn}=0.0125; 0.025; 0.05; 0.1 mg/l). State standard samples and calibration charts are necessary for the reliability of heavy metal content in water and bottom sediment samples.

Lake Markakol is one of the fresh, flowing water bodies located in the intra-mountain, asymmetrical depressions of Eastern Kazakhstan, but traces of pre-existing lakes can still be found at various sites in the mountains. The lake is located in a depression, probably related to the depression of the Kara-Kaba River to the east. The Kalzhyr River once flowed in the depression, but then it was dammed up, resulting in Lake Markakol. This was due to tectonic uplift of the block, which acted as a sill. Field studies conducted in the natural environment represent an integral and important aspect of integrated geo-environmental research[14)]. In this context, they aim to analyse micro- and macroplastics and to make measurements of hydrophysical, hydrochemical and toxicological parameters. These studies provide valuable data for a better understanding of environmental and ecosystem conditions and help to develop strategies and measures for conservation and sustainable management of natural resources[15),16)].

During the in-situ studies from 03 July to 13 August 2023, water and sediment samples were collected for toxicological analysis. Water samples were collected in the surface layer (0.5 m), benthic layer using a bottle bathometer, and bottom sediments using a Petersen dredge at established points along the lake water area, river water samples were collected at the river inflows and at the lake outlet (Fig. 1 and 2).

Fig. 1: Location of Markakol Lake in the Republic of Kazakhstan.
Source: compiled by the authors.

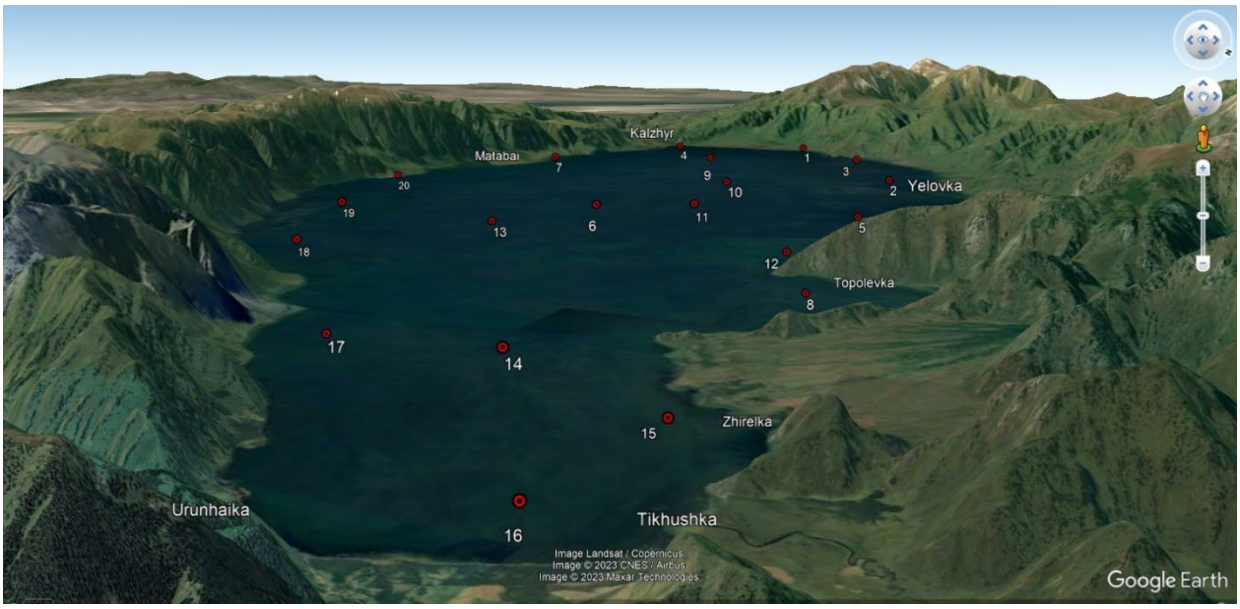

Fig. 2: Points for sampling water and bottom sediments to determine toxicological indicators.
Source: compiled by the authors.

The sediment samples were dried until moisture was removed and then treated with an ammonium acetate buffer solution at pH 4.8. Atomic absorption analysis was then carried out to determine the metal content of the resulting solution. The method of atomic absorption analysis utilizes the property of metal atoms in the ground state to absorb light of a certain wavelength (e.g. Cu – 324.7 nm; Zn – 213.9 nm), which they emit when in the excited state[17]. To detect the content of Cu and Zn in the samples the equipment was used: atomic absorption spectrophotometer AA-7000 with a hollow cathode lamp and with a nozzle titanium burner, the principle of operation of which is based on the use of acetylene-air mixture.

3. Results

Lake Markakol is one of the most beautiful lakes in Kazakhstan, located at an altitude of 1447 m above sea level in the Altai Mountains far from industrial sources of anthropogenic pollution. It is in the proximity of 20 km to the closest settlement, Uryl village. The dimensions of this

lake are 38 km long by 19 km broad, with an average depth of 14 m and a maximum depth reaching 27 m. The water volume of the lake is approximately 6.61 km^3. The average yearly inflow rate is believed to be between 40 and 50 m^3/s during peak snowmelt seasons, however exact statistics can vary. In dry seasons, this can drop to about 10-15 m^3/s. The Kalzhir River serves as the main outflow. The lake's water level is mostly stable since the outflow and inflow rates are often balanced. The outflow rate can be 40-50 m^3/s in moments of maximum inflow and may drop to about 10-15 m^3/s during dry times.

Bottom sediments, as natural sorbents, have a significant impact on the formation of the ecological state of water bodies[18]. They are able to retain and accumulate a variety of organic and inorganic compounds, including toxic pollutants, which contributes to the purification of the aquatic environment[19),20]. However, in some situations, there may be conditions under which these toxic pollutants can recirculate, re-entering the aquatic environment and provoking re-pollution. Bottom sediments may have higher levels of heavy metals than water, making them potential sources of secondary contamination of aquatic ecosystems. The process by which heavy metals are transferred from sediments to water is often through desorption. Desorption plays an important role as it is associated with the biogenic transport of trace elements and their integration into the food chains of aquatic organisms.

The results of atomic absorption spectrophotometry revealed the presence of high concentrations of Cu in the water column of the lake, exceeding the maximum permissible values by 2.7-10.5 times in the surface layer and by 7.9-24.4 times in the bottom layer. The average content in the lake water area was 5.9 µg/l (surface layer) and 12.7 µg/l (bottom layer). Low values of Cu in the surface water layer were recorded at points 10 and 14, i.e. in the central part of the lake, averaging 4.7 µg/litre. High concentrations were found in the coastal zones, with values ranging from 4.4 to 8.8 µg/l and in the confluence zones of the Tikhushka River – 10.5 µg/l and Matabay River – 9.6 µg/l.

As can be seen from Fig. 3, the Cu concentration in the bottom layer water is 1.8 times higher than in the surface layer. Relatively low values – 7.9 µg/l were recorded at 4 points in the outlet zone of the Kalzhyr River. Throughout the lake water area, Cu concentration in high values, especially from 15.7 to 24.4 µg/l in the central, deep-water zone. In the Cu content in the water column, it is possible to observe an increase in the concentration in the bottom water layers and deep-water areas of the lake, which depends on the degree of prevalence of this metal in the lithosphere, its active migration ability, as well as on anthropogenic pollution of the water body.

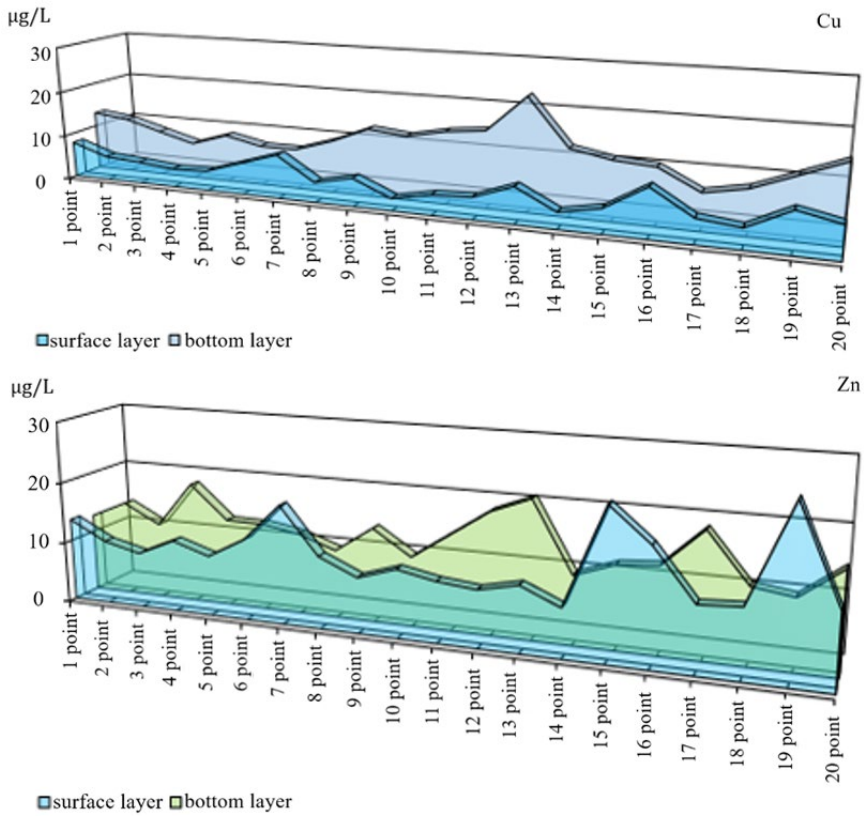

Fig. 3: Concentration of Cu and Zn in the water column over the lake area.
Source: compiled by the authors.

Exceedance of maximum permissible values of Zn concentration in the water column of the lake was 2.7 times in the surface layer and 2.2 times in the bottom layer. Especially high concentrations of Zn in water were registered in the zones of the Urunkhayka and Tikhushka rivers confluence, reaching 23.8 and 26.7 µg/l respectively. High values were also observed at points 6 and 7, with concentrations ranging from 13.1 to 19.2 µg/litre. In the bottom layer, high Zn values are concentrated in the shallow areas of the lakes and in the river confluence areas, where they reach 22.1 µg/l. In general, according to the definition of the intensity of water migration of Cu and Zn (concentration and dispersion) in surface waters they are referred to the average level with a coefficient from 0.05 to 1 [21]. But, considering the facts of exceeding the maximum permissible standards in the water of Lake Markakol, it is necessary to note their high concentrations, which may also be a consequence of secondary water pollution as a result of water agitation both in the bottom layers and in the surface layers due to natural and climatic changes.

The main processes controlling the forms of metal migration in waters were adsorption processes on mineral and organic particles[22]. Some difference or low content of metals in suspended particles of surface waters, may be due to its content or transfer to soil-forming rocks of Lake Markakol soil cover. Pathways of metal migration in aquatic ecosystems mainly depend on the content and form of metals in bottom sediments, which have a high capacity for absorption and are the main factors of self-purification of water bodies from metal compounds[23),24),25]. However, they can also be sources of secondary pollution, because they belong to the class of conservative substances that do not leave aquatic ecosystems, but only change the form of their presence in it.

As a result of an assessment of the level of anthropogenic pollution of bottom sediments of Lake Markakol, Cu content in all analysed samples was found within the range from 2.6 to 12.3 mg/kg, which averaged up to 7.3 mg/kg in the water area as (Fig. 4). Some regularity was observed in Cu accumulation in the bottom sediments of the lake. Thus, high concentrations of Cu were registered in shallow areas of the lake, at depths from 2.7 m – 10.2 mg/kg to 4.7 m – 8.9 mg/kg, 7.9 m – 12.3 mg/kg. Cu values in deep water bottom sediments were much lower, at 20.4 m depth – 2.8 mg/kg, 21.1 m – 2.6 mg/kg, 21.6 m – 6.6 mg/kg. A similar distribution pattern in bottom sediments was observed for Zn. Its high concentrations were recorded in shallow areas, from 154 mg/kg at 2.7 m depth to 439 mg/kg at 4.6 m depth. Such tendency of Cu and Zn distribution in bottom sediments depending on the lake depth is probably connected with the increase in the share of their bioavailable forms in the water column, which can be dangerous for all aquatic organisms. According to the standards set by the United States Environmental Protection Agency, the maximum permissible level of concentration of Cu in water is 13 µg/l. By the same guidelines, the highest permissible concentration of Zn in freshwater is 120 µg/l[26].

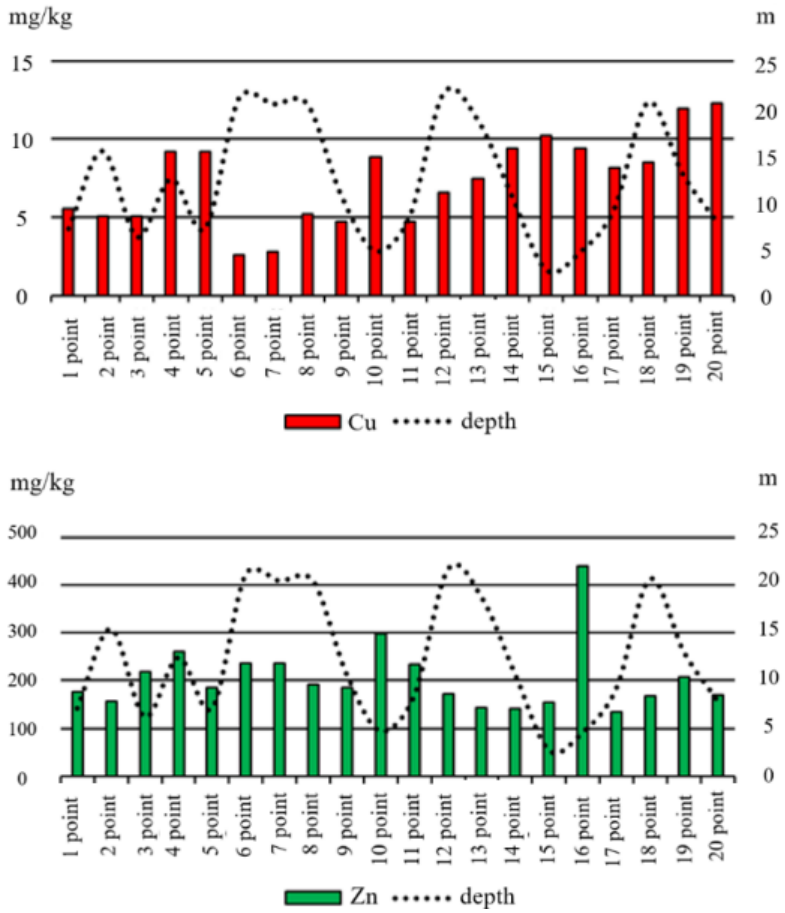

Fig. 4: Concentration of Cu and Zn in lake bottom sediments.
Source: compiled by the authors.

As can be seen from Fig. 4, when comparing Cu and Zn concentrations, high concentrations of Zn can be observed in bottom sediments from 133 to 439 mg/kg, which averaged 206 mg/kg in the lake water area. High concentrations of Zn were observed in the summer-autumn period, from 267 mg/kg to 396 mg/kg, respectively, indicating the active participation of this metal in metabolic processes.

To determine the level of contamination of bottom sediments, the content of metals in rocks, the content in the lithosphere and their clarks for those rocks, to which the catchments of lakes are confined, were taken into account. Soil cover in the mountainous areas of the Kazakh part of Altai is characterized predominantly by mountain-chestnut soils. Table 1 shows several types of soils in the study area[27].

Table 1. Characteristics of types of soils in the area of Markakol Lake

Name	Location	Climate	Vegetation	Properties
Mountain-tundra	High-altitude, typically above the tree line	Cold, with short growing seasons and long winters	Sparse, primarily mosses, lichens, and low-growing shrubs	Thin, acidic, and low in organic matter. Permafrost may be present
Mountain-forest	Mountainous regions below the tree line	Cooler temperatures with significant precipitation	Forests dominated by coniferous or deciduous trees	Well-drained, rich in organic matter, slightly acidic to neutral pH
Mountain-meadow	High-altitude meadows	Cold to temperate, with adequate moisture	Grasses, herbs, and wildflowers	Rich in organic matter, fertile, good drainage
Dark grey weakly podzolic	Temperate regions with deciduous forests	Temperate, with moderate precipitation	Mixed or deciduous forests	Moderately leached, grey in color, low in nutrients, slightly acidic
Forest chernozem	Forest-steppe regions	Temperate, with sufficient moisture and	Deciduous forests, grasslands	Rich in organic matter, dark in color, highly fertile, slightly

		warmer temperatures		alkaline
Mountain forest-meadow	Mountain regions where forests transition to meadows	Cool to temperate, with ample precipitation	Mix of forest and meadow vegetation	Rich in organic matter, well-drained, fertile
Meadow-steppe	Transition zones between meadows and steppes	Temperate, with moderate to low precipitation	Grasslands with occasional shrubs	Fertile, rich in organic matter, good drainage
Mountain-steppe leached chernozem	Mountainous steppe regions	Cooler temperatures with moderate precipitation	Grasses, herbs	Dark in color, fertile, leached of some minerals, neutral to slightly alkaline pH
Meadow-chernozem	Meadow regions with rich vegetation	Temperate, with adequate moisture	Dense grasslands, occasional shrubs	High organic matter, dark in color, very fertile
Meadow	Flat or gently sloping meadow areas	Temperate, with sufficient moisture	Grasses, wildflowers, and herbs	Rich in organic matter, fertile, well-drained
Meadow-marsh	Low-lying areas with poor drainage	Temperate to cold, with high moisture	Water-tolerant plants, grasses, reeds	High organic matter, waterlogged, acidic, often rich in peat
Bog	Bogs and wetlands	Temperate to cold, with high moisture and low oxygen levels	Sphagnum moss, sedges, and other bog plants	High in organic matter, acidic, poorly drained, rich in peat

However, during field studies, it was found that the upper layer of bottom sediments on the lake bottom is characterized by the presence of sapropel, both dark and brown types, closer to the shoreline. In many water bodies, bottom sediments are represented by sand, silty sand, sandy silt, silt, and clayey silt, depending on their granulometric composition. Closer relationship was formed between metals and clay/clayey silt. However, when assessing contamination of Lake Markakol bottom sediments, it was not possible to directly compare metal concentrations with their average lithospheric content or particle size distribution, as bottom sediments consisting of sapropelic sediments differ significantly from the composition of the lithogenic base of the landscape.

All rivers showed elevated levels of heavy metals. In particular, the normative values of Cu concentration were exceeded in all the mentioned water bodies, ranging from 3.6 μg/dm^3 in the Yelovka River to 10.5 μg/dm^3 in the Tikhushka and Topolevka Rivers (Fig. 5). Similarly, Zn content in water was also recorded at high levels, especially in the Urunkhayka (12.7 μg/dm^3) and Topolevka (17.3 μg/dm^3) rivers flowing into the lake from the north. According to these values, the norms for fishing were exceeded several times both in tidal rivers and at the mouth of the Kalzhyr River.

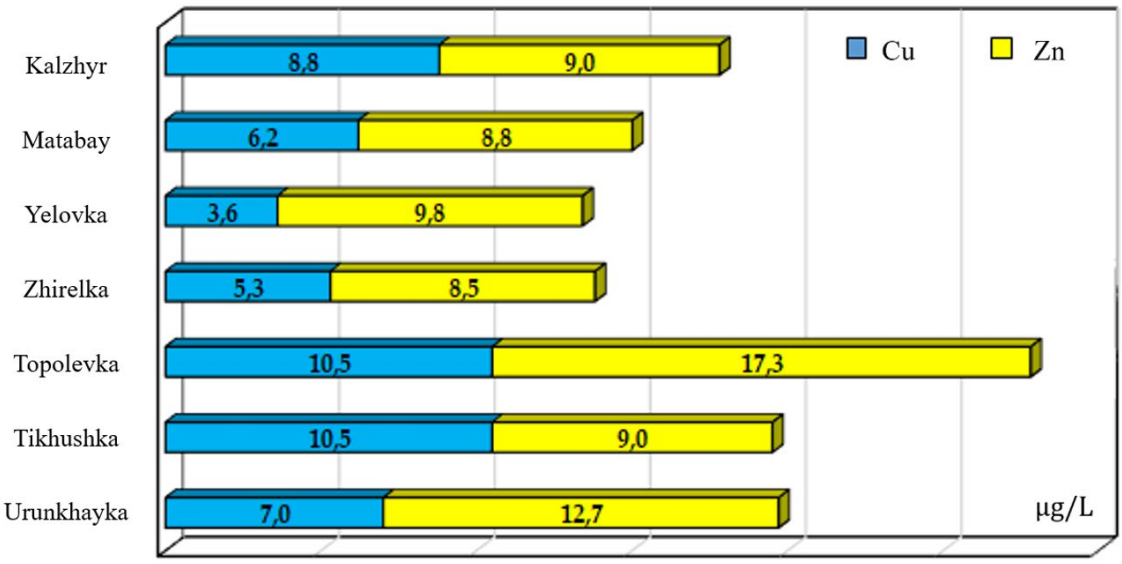

Fig. 5: Concentration of heavy metals in river waters.
Source: compiled by the authors.

Pollutants contributed by tributaries to the lake have tangible effects. The contribution of total polluted water masses entering the lake was 43 µg/litre for Cu, 66.1 µg/litre for Zn. Whereas only 8.8 µg/l for Cu and 9 µg/l for Zn were discharged from the lake by river waters of Kalzhyr. Thus, heavy metals were registered in the lake water, bottom sediments and river waters in rather high concentrations exceeding fishery standards.

When studying the movement of heavy metals in the system "water – bottom sediments" or "surface water – bottom layer of water – bottom sediments", which play an important role in assessing the ecological state of the lake, it was found that the Cu content was increased to 9.4 and 10.2 mg/kg in the bottom sediments of the Urunkhayka, Tikhushka and Zhirelka river mouths. In the same estuarine zone, Cu content was found in water up to 5.3 and 10.5 µg/litre. The deposition of Cu from the surface layers to the bottom water layer and bottom sediments was traced in shallow water areas, i.e. there was a decrease from the coastal zones of the lake to deep water areas, since the sedimentation of the bulk of the sediment brought in by rivers depends on the nature of the water mass and the activity of the metal. Migration of Cu in the water column occurred with increasing concentrations from the surface layer to the benthic layer, where it was deposited in the upper layers of bottom sediments in amounts ranging from 2.6 to 12.3 mg/kg. High Cu content was observed in the near-bottom layers and bottom sediments, where sapropel sediments were dark. The organic origin of sapropel sediments has the property of sedimentation of dissolved forms of metals, which negatively affects water quality.

Spatial distribution of Zn and its sedimentation both in the water column and bottom sediments occurs in shallow areas of the lake and in the zones of influence of tributaries. The maximum Zn content was recorded in the bottom sediments of the northern shallow part, up to 439 mg/kg. High Zn concentrations both in the bottom stratum and in sapropel sediments in general were recorded throughout the bottom surface of the lake. Vertical migration activity of Cu and Zn in the system "water – bottom sediments" has a direct dependence on their forms of presence in water. The nature of distribution and concentration of Cu and Zn in Lake Markakol indicated a high level of anthropogenic impact due to the influence of these tributaries on the ecological state of this water body.

Previous studies suggest that fish species inhabiting Lake Markakol have evolved under conditions of high levels of heavy metals in the water, including Zn, Cu, and lead (Pb)[28]. The increased Zn content may be related to the presence of polymetallic ore deposit located on the southern slopes of the Kurshim mountain range in the area of Lake Markakol. Studies conducted by the Republican State Enterprise "Kazhydromet" in 2018 indicate that exceedances of maximum permissible concentrations were found for nutrients (e.g., iron (Fe)) and heavy metals (e.g., Cu, Zn, and manganese), as well as actual concentrations of suspended solids over background values[29]. Based on the results of the study, it was concluded that the water quality of Lake Markakol was assessed as "moderate pollution level".

4. Discussion

According to the results, elevated concentrations of Cu up to 1.5 and Zn 1.3 times were detected in the surface layer, and up to 1.3 and 1.4 times in the bottom layer, which indicated that the standards of maximum permissible concentrations for fishery purposes were exceeded.

J. Pandiyan et al. provided an assessment of heavy metal pollution in the Point Calimere Wildlife and Bird Sanctuary [19]. It should be noted that both studies measure concentrations of heavy metals such as Cu, Zn, chromium (Cr), but they focus on different elements and on different species of biota (polychaetes, molluscs, crustaceans, shrimps, fish). In the study above analytical techniques such as collecting benthic prey species and collecting fish and shrimp are applied. Both studies use Atomic Absorption Spectrophotometry technique to estimate heavy metal concentrations, but the latter study is more effective because of the more advanced methodological approach to study sedimentation processes.

R. Rozirwan et al. focused on the assessment of environmental risks of heavy metal (Pb and Cu) contamination of water, sediments, and polychaetes in rivers and coastal areas of South Sumatra[30]. They used atomic absorption spectrometry techniques to measure heavy metal concentrations in water, sediments, and polychaetes, and they applied and performed statistical analysis. However, the second study analysed the movement of heavy metals in the system "water-bottom sediments", which is more effective, because on the basis of the above methodology for assessing the impact of bottom sediment pollution on the quality of watercourses, potentially dangerous areas of Lake Markakol with secondary pollution were established.

I. Achoukhi et al. presented the results of a study indicating that fibres were the most common form of microplastics detected (90% detected in water and 31% fibres detected in sediment)[31]. In Al Hoceima Bay, a new digital microscopy technique and a modern infrared spectroscopy method were used to identify microplastics and measure their concentration. However, in the study of Lake Markakol, one of the most sensitive and accurate elemental analysis methods, the atomic absorption spectrophotometry method, was used to measure Cu concentration and identify other heavy elements in water and bottom sediments. The identification and measurement methods presented in the study by I. Achoukhi et al. are modern and efficient, and can be adapted and used to study microplastics in Lake Markakol. The analysis of Cu transport in the water-sediment system can be applied to better understand the pollution dynamics

of the lake.

The research by P. Sivalingam et al. was to study the physicochemical parameters, levels, and sources of heavy metals, and ecotoxicity of bottom sediments collected from five lakes in southern India[32]. Based on the results of the study, it was learnt that the sediments of Lake Ukkadam had a mercury (Hg) content of 5.08 mg/kg and Cu content of 203.32 mg/kg dry weight. The biotesting method was used while this analysis used atomic absorption spectrophotometry method and the scientific investigation conducted focused on the accumulation of heavy metals in fish and their potential impact on the hydrobiont population. It should be noted that the advantage of the biotesting method may be its sensitivity to low concentrations of substances, while atomic absorption spectrophotometry may be less sensitive to low concentrations of substances. Metal concentration analysis methods and ecotoxicity assessment methods can be applied in this study to assess the impact of contaminated samples on the lake ecosystem and more accurate measurements of heavy metal concentrations.

In a study by A.D. Gabriel and H.P. Bacosa, the presence of plastic particles in the sediments of the Cagayan de Oro River was studied in detail[33]. The results of the study revealed that the most common types of microplastics were blue coloured particles (41%), fibrous particles (41%), 0.5-1 mm particles (43%) and polyethylene particles (43%). A stereomicroscope and infrared spectroscopy method useful for analysing the structure of microplastic were used. The disadvantage of this method is that it is not suitable for analysing metallic elements. In this study, the atomic absorption spectrophotometry method is found to be more effective than infrared spectroscopy. This is because it can be used for quantitative analysis with high accuracy, while the second method cannot provide the same accuracy in all cases.

In the course of conducting the study, B. Qian et al. studied the characteristics and environmental risks of heavy metal pollution in Dongting Lake[34]. The results show that cadmium (Cd) and Hg are the main sources of pollution. The geoaccumulation index method and potential environmental risk assessment were used to evaluate the ecological risk. The study is based on atomic absorption spectrophotometry to detect Cu concentrations in the water column and assess sedimentation processes. It is worth agreeing that the analytical methods used in the work by B. Qian et al. are effective for analysing sediments and identifying pollution sources. However, atomic absorption spectrophotometry can also be useful for the determination of heavy metal concentrations in water.

Based on the research of Q. Wang et al., it was found that among all five metals (Cu, Pb, Cd, Cr, and Zn) identified in sediments in the Changli ecological monitoring area, Cd represents the main source of environmental risk[35]. The authors applied heavy metal and spatial distribution analysis methods, and used the potential environmental risk index (PERI) and secondary phase enrichment factor (K_{SPEF}) to assess the environmental risk. The conducted study showed that atomic absorption spectrophotometry method is more preferable. Its advantage is the high accuracy of metal concentration measurement. Unlike the method presented in the work by the researchers, which does not have high sensitivity and accuracy in measuring metal concentration. Risk assessment indices (e.g. PERI) can be applicable for a more comprehensive assessment of the ecological status of a lake.

A study by M.M. Uddin et al. analysed the level of heavy metal pollution in the sediments of Lake Lunhu[36]. The excesses of average levels of Cu, Zn, Cd, and Pb over the corresponding values of class I of the Chinese soil quality standard were 2.1, 3.5, 8 and 2.5 times, respectively. The study is based on the application of atomic absorption spectrophotometry method. The methods of ecological risk assessment and metal migration analysis can be applied to analyse the ecological impact of Cu and Zn on fishery resources in Lake Markakol. Compared to the methods of M.M. Uddin et al., the atomic absorption spectrophotometry method applied in this study was more effective. This is due to the fact that this method is based on the measurement of light absorption by atoms of the analysed element.

D.H. Nhon et al. analysed the content of heavy metals on the territory of Northern Vietnam[37]. The results show that the concentrations of Cu, Pb, and arsenic (As) exceeded the interim sediment quality standards, while the levels of Cr, Zn, and Cd were below the limits of these standards. The characteristics of each sediment type were mentioned in the study, but sedimentation processes were not discussed. The method of classification of sediment types can be useful to identify areas with different levels of contamination. Atomic absorption spectrophotometry method is more effective than the method proposed by the authors as it provides high sensitivity and accuracy in determining the concentrations of certain chemical elements.

The aim of the study by L.E. Oura et al. is to assess the distribution of heavy metals in sediments of the coastal zone of Côte d'Ivoire[38]. The sediments under study were found to be contaminated with Cd, Cr, and As. The applied X-ray fluorescence spectroscopy method is more efficient, as it can be used to determine a wide range of elements simultaneously. Unlike the atomic absorption spectrophotometry method, which may be less versatile for the determination of several elements simultaneously.

In order to determine the quality of freshwater sediments of the Indus River and its tributaries, A.U. Haq and S. Muhammad made an effort to collect heavy metal concentration data for the period 1992-2021[39]. From the results, it was determined that Fe showed the highest concentration of pollution, while silver showed the lowest level of heavy metal pollution. They focused on the

geospatial distribution of contamination in different geological sections. Atomic absorption spectrophotometry would be a more effective method to apply as this study analyses the chemical compositions of the samples. Geospatial analysis can be used to identify areas with higher concentration of metals in the lake.

The work of A. Dhiman et al. deals with the distribution of heavy metals and determination of environmental risk in river water, sediments, and suspended particles in the Ganges River Basin[40]. The results of the metals index indicated that 27% of the water sites were anthropogenically influenced. In the work of the researchers as well as in this study, the method of atomic absorption spectrophotometry was used to determine the concentrations of heavy metals. However, in the study of Lake Markakol, the method was applied with a focus on analysing Cu and Zn in the lake water column and in bottom sediments. Water-sediment interactions and the role of sedimentation are important in assessing the ecological status of an aquatic system and can be applied to Markakol.

The section conducted a literature review and reviewed studies on the assessment of heavy metal pollution in water, surface sediments of coastal zones, studied the presence of plastic particles in river sediments and the distribution of heavy metals, and determined the level of environmental risk in river water.

5. Conclusions

The assessment of the level of pollution of the lake's aquatic ecosystem by heavy metals in the system "water-bottom sediments" was carried out for the first time. At the same time, the results of the study show the presence of high concentrations of Cu and Zn in the aquatic ecosystem of the lake in the surface layer up to 1.5 and 1.3 times, in the bottom layer up to 1.3 and 1.5 times, respectively. Their high concentrations are registered in bottom sediments, up to 6.6 mg/kg for Cu and up to 439 mg/kg for Zn.

According to the results of the analysis carried out during the field studies, it was revealed that the upper layer of bottom sediments at the bottom of the lake was characterized by the presence of sapropel, both of dark and brown type. This fact complicated the assessment of heavy metal contamination of bottom sediments. However, taking into account the facts of exceeding the maximum permissible standards in the water of Lake Markakol, it is necessary to note their high concentrations, which may also be a consequence of secondary water pollution as a result of water agitation both in the bottom layers and in the surface layers due to natural and climatic changes. Another difficult factor in assessing the level of contamination of bottom sediments was the lack of historical or archival data for comparative analyses. It was noted that the heavy metals registered in the lake water in rather high concentrations, exceed the fishery standards, which will inevitably lead to their accumulation in the ichthyofauna (grayling, uskuch), reducing their vital activity. It is known that even a moderate content of heavy metals in water and bottom sediments inevitably leads to their accumulation in fish, depriving them of their economic and nutritional value.

Consequently, anthropogenic load, to which the whole ecosystem of the lake is exposed, has a very close relationship in the conditional systems "water-bottom sediments-water organisms". It is worth taking into account the fact of long-term preservation of toxic substances in water, bottom sediments and their migration along the trophic chain. Accordingly, it is not possible to exclude the accumulation of toxicants in fish in the future, which in turn has an important role in providing the population with ecologically clean fish products.

The directions of further research may include introduction of clear coordination of monitoring programmes between the main actors at the regional (local) level, unification of the regulatory framework and measurement techniques, scientifically justified correction of the programme and observation sites depending on specific local conditions.

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