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Spatial Analysis of Hydro-chemical And Toxicological Variables of the Balkhash Lake, Kazakhstan.

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ABSTRACT

The distribution of hydrophysical, hydrochemical and toxicological parameters across the Balkhash Lake waters (Kazakhstan) was studied in summer 2004. The total dissolved solids reached 1080.3–3436.8 mg/dm^3. The NH_4 content in the water was 0.103–0.102 mg/dm^3, NO_3 – 0.492–1.379, NO_2 – 0.024–0.060, P-PO_4 – 0.011–0.023, P_{tot} – 0.021–0.106, Fe – 0.010–0.056, Si – 5.20–5.76 mg/dm^3. The average concentration of zinc in the water reached 0.017–0.039, copper – 0.013–0.022, cadmium – 0.0028–0.0044, lead – 0.021–0.047, nickel – 0.037–0.042, cobalt – 0.010–0.017 mg/dm^3. It was concluded that zinc, copper, total phosphorus, iron, nitrites and nitrates enter the Western Balkhash with the Ili River waters. The contribution of copper with the river runoff to the overall level of pollution of the lake is higher than its flow from other sources. The local increase in nickel concentrations in the Western Balkhash is associated with a washoff from the tailings dam. Contamination of the Eastern Balkhash with cobalt, nickel, lead and cadmium predominantly occurs due to the waters of the Karatal River. The constant flow of water in the lake in the direction from west to east together with wind currents have a significant effect on the distribution of pollutants across the water area.
Keywords: Balkhash Lake, biogenic elements, heavy metals, statistical maps.

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INTRODUCTION

The Balkhash Lake is one of the largest drainless lakes in Kazakhstan. It is third in its lake surface area after the Caspian and Aral Seas in the large arid climatic zone of Central Asia. The Balkhash Lake peculiarity is pronounced amplitude of fluctuations in its hydrochemical conditions [1, 2]. The Balkhash Lake's unique feature is the spatial gradient of TDS of water [3]. Depending on climatic conditions of the year, the total dissolved solids (TDS) in water range from 0.6-1.2 g/dm^3 in the most extreme west to 4.0-5.6 g/dm^3 in the eastern part of the water area [4]. Large deposits of polymetallic ores in the region [5], along with the discharge of industrial and agricultural effluents into the lake or of the rivers that flow into it [6], account for increased content of heavy metals [4] and pesticides [7] in the Balkhash Lake's water.

Only the content of sulphates, magnesium, calcium, biogenic elements, copper, and pH-values are taken into account [8, 9] in monitoring of ecological state of the Balkhash Lake, or, alternatively, the average values of the parameters for the whole lake are given [4]. The mean annual content of zinc in the Balkhash water reached 0.037–0.040, of chromium – 0.025–0.034, nickel – 0.008–0.011, copper – 0.032–0.035, lead – 0.022–0.028 mg/dm^3 according to the data of the above-mentioned author [4].

The distribution of incoming pollutants is determined by a complex of natural and anthropogenic factors and causes significant heterogeneity of ecological conditions across the water area of the Balkhash Lake. One of the effective methods for assessing the ecological state of water bodies, applied by us earlier [10], is mapping of the spatial distribution of environmental variables. Data visualization (mapping) is justified if there are many variables and they are diverse, which is especially important for such large lakes as the Balkhash.

The aim of this study was to identify the potential sources of pollution and assess the ecological status of various parts of the Balkhash Lake on the basis of the statistical maps of spatial distribution of chemical and toxicological parameters of water across the lake surface.

DESCRIPTION OF THE STUDY SITE

The Balkhash Lake is drainless and located in the southeast of Kazakhstan in the arid climate zone of Central Asia. The region is characterized by sharp changes in air temperature in different seasons and during the day [6]. The average temperature in January is about -14°C. The air is warmed up to 30°C and above in July. The average annual amount of precipitation is 129.8 mm.

The lake is elongated from the southwest to the northeast (Fig. 1). At the time when water level is 342 m, its length makes up to 614 km, and the area is approximately 16.4 thousand sq. km. Width of the lake reaches 9-19 km in the eastern part and up to 74 km in western part [4]. The Uzynaral Strait divides it into two different parts: western, which is shallow and wide (the Western Balkhash), and eastern, which is narrow and deep (the Eastern Balkhash). The coastline has a length of about 2385 km and is dissected with numerous bays. The lake is fed by the rivers Ili, Karatal, Lepsy and Aksu, originating in the Tien Shan Mountains and flowing into the lake from the south.

There are two types of currents in the Balkhash Lake: a constant flow and temporal flows that occur due to the winds [11, 12]. Constant flow originates at the confluence of the Ili River and Western Balkhash. The water masses move from the river mouth to the west, then hit the opposite shore and are directed to the northeast, then moving along the shore, in the east they reach the Uzynaral Strait that divides the Western and Eastern Balkhash (Fig. 1). Further movement of the fresh Ili water is hindered due to the shallow water of the strait, and the flow breaks into a number of swirling branches. The Ili waters come into the Eastern Balkhash because of the difference in levels between the western and eastern parts, given that the Karatal, Lepsy, and Aksu rivers do not completely compensate for the evaporation from the water surface of the Eastern Balkhash. The predominance of northeasterly winds (Fig.1, H) causes western and southwestern directions of the wind currents (from Eastern to Western Balkhash) [12]. The wind currents change the direction to the opposite (from west to east) with strong west and southwestern winds and can overlap with the drain flow. As the water moves to the east, it becomes salty and changes its chemical composition due to the metamorphic processes as a result of deposition of some salts on the bottom and relative enrichment with other salts. The water area of the lake is divided into 8 hydrochemical regions (Fig. 1) due to the increase in TDS along the longitudinal axis [3].

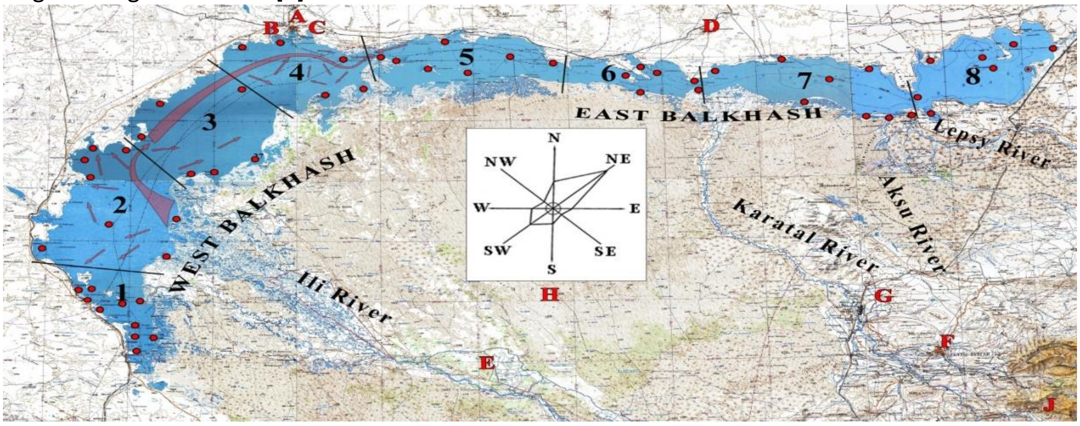

Fig. 1: Schematic map of sampling stations (red dots), scheme of constant flow (pink arrows), wind rose (H), and potential sources of pollution of the Balkhash Lake (A-J), 2004

Hydrochemical regions: 1–4 – Western Balkhash, 5–8 – Eastern Balkhash.
Sources of pollution: A – Balkhash industrial complex and Konyrat field, B – tailing dump of Balkhash mining and smelting complex and central heating and power plant (TPP), C – "Balkhashfishprom" LLP and mining company "ABS-Balkhash", D – Sayak field, E – an Akdala array of rice cultivation, F –Taldykorgan city, G – town of Ushtobe, J – town of Tekeli

SOURCES OF POLLUTION

The Balkhash Lake is located in the zone of large deposits of polymetallic ores [5]. Copper deposits are being developed in the Konyrat, 14 km north of the lake (Fig. 1, A), and Sayak, 40 km north of the lake and 170 km east of the Balkhash town (Fig. 1, D). The Balkhash town is the largest populated center in the area, with 80 thousand inhabitants, located on the shore of the Bertys Bay that is up to 14 m deep. The bay connects with the lake by a narrow shallow strait. The town-forming enterprise is the Balkhash mining and smelting complex (BMSC) (Fig. 1, A). The sewage of the city's enterprises is discharged into the Bertys Bay. On the shore of the Torangalyk Bay at 2.5–3.0 km to the south-west of Balkhash town, there is a tailings dam of the BMSC and Thermal Power Plant (TPP) (Fig. 1, B). Small dust particles are blown out of the tailings dam and enter the waters of the bay during strong winds. Spreading of pollutants emitted from BMSC chimney-stalk is mainly determined by the frequency and direction of the wind (Fig. 1, H). The smoke is carried to a distance of up to 10 km in low-wind and clear weather, and pollutants precipitate outside the town. When precipitation or fog occurs, settlement of pollutants sharply increases near the source of emission. The sewage water from the "Balkhashfishprom" manufacturing company and "ABS-Balkhash" mining company are discharged into the Little Sary-Shagan Bay (Fig. 1, C), In the catchment area of the Karatal River which flows into the Eastern Balkhash, there are known reserves of minerals such as brown coal, sodium chloride, sodium sulfate, quartz, construction sand and clay. In the Taldykorgan city (Fig. 1, F), there are 24 industrial enterprises. The light industry enterprises are located downstream the Karatal River in town of Ushtobe (Fig.1, G). A lead-zinc plant [6] and tailings dam covering 69 hectares operates in the upper reaches of the river in the Tekeli town (Fig. 1, J). Industrial waste, passing through the ponds of biological treatment, is discharged into the Karatal River [13].

The territory of the Southern Balkhash region is used in agriculture. There is the Akdalin array of rice cultivation on the bank of the Ili River (Fig.1, E). About 1.2 km^3 of water per year is spent on its irrigation whereas only 0.3 km^3/year is returns to the river [4]. The drainage water carries a large amount of foam and differs from the river water in color and lower transparency. The clear water of the Ili River becomes cloudy, milky-green when it mixed with the waste canal water.

MATERIALS AND METHODS

The research of the content of biogenic elements and heavy metals in the water in the Balkhash Lake was carried out by means of a grid of 58 stations (Fig. 1) in June and July of 2004. The measures of the temperature and pH values of the surface water layers were taken in the field environment. Water transparency was measured with Secchi disk. Coordinate referencing of the stations was done by Garmin eTrex GPS-navigator. The samples for heavy metals were fixed in the site by adding nitric acid; samples for biogenic elements were fixed with chloroform. All collected samples were transported to the lab in an icebox.

Conventional methods of chemical analysis of water were used [14, 15]. Water samples were analyzed in three-four repetitions. The error of estimate for major ions in the water was 0.5-5.0%, depending on the analyte. Concentrations of heavy metals were determined by the atomic absorption method using an AAS-1N spectrophotometer (Germany). The device allows for the detection of the various chemical elements in complex matrices, including those in the sea and grey water and in the biological objects in micro-trace quantities. Test-sensitivity of AAS-1N spectrophotometer is 0.001–0.0025% Mass.

The innovative approach with Surface plots' construction was applied using the Statistica 12.0 program for analysis of biological and environmental variables' relationship. Nonparametric correlation analysis and spatial statistical mapping in wafer plots was done with Statistica 12.0 program.

RESULTS

The Western and Eastern Balkhash differ significantly in all parameters (Table 1). The lower water temperature in the Western Balkhash is associated with inflowing less-heated water of the Ili River, which accounts for about 75% of the total volume of river flow into the lake [4]. The western part of the lake is characterized by lesser average depths, lower transparency and pH-value of water, by prevalence of soft macrophytes and lesser presence of hard macrophytes. Hard macrophytes are represented by *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L.) Palla; soft marcophytes – by *Potamogeton crispus* L., *Stuckenia pectinata* (L.) Böerner, *Nymphaea* sp., *Nuphar sp.*, *Myriophyllum spicatum* L., *Ceratophyllum* sp. as well as maroalgae *Chara tomentosa* Linnaeus and *Nitellopsis obtusa* (Desvaux A. N.) Groves J.

Table 1: Averaged hydrophysical and morphometric variables of the Balkhash Lake with standard deviation, summer 2004

Variable	Whole Balkhash	Western Balkhash	Eastern Balkhash
Temperature, °C	24.14±0.14	23.49±0.16	24.77±0.14
Depth, m	5.58±0.49	4.34±0.28	6.86±0.81
Transparency, m	1.13±0.15	0.53±0.02	1.74±0.25
Macrophytes Hard, %	20.05±3.03	18.03±3.00	22.14±5.36
Macrophytes Soft, %	25.18±2.68	28.28±3.29	22.00±4.24
pH	8.63±0.04	8.52±0.02	8.74±0.09

Total Dissolved Solids (TDS) content and other hydrochemical variables in the Western Balkhash are statistically significantly lower than in the eastern part (Table 2). According to the average values, there are higher concentrations of nitrates, nitrites, total phosphorus, iron, zinc, and copper in the Western Balkhash. Phosphates, readily oxidizable organic matter, cadmium, lead, nickel and cobalt were present in large quantities in the eastern part of the water area. The content of ammonium and silicon ions did not differ in these parts of the lake.

Table 2: Averaged values of Total Dissolved Solids (TDS), hydrochemical variables and toxicants of Balkhash Lake with standard deviation, summer 2004

*Variable	Whole Balkhash	Western Balkhash	Eastern Balkhash
Ca	40.4±2.5	48.8±4.4	32.4±1.3
Mg	67.4±6.6	35.0±2.2	98.4±8.4
Na+K	454.8±53.8	202.6±22.9	695.6±71.8
HCO_3	415.1±31.6	254.3±11.0	568.6±38.6
SO_4	834.9±93.1	369.1±344	1279.5±116.2
Cl	473.3±58.9	170.5±18.6	762.4±71.3
TDS	2286.0±236.0	1080.3±83.4	3436.8±286.7

Na	448.9±51.1	193.8±2.2	692.4±63.3
K	30.4±4.1	8.8±1.0	51.0±4.9
K/Na	0.063±0.004	0.046±0.0009	0.080±0.005
K/Ca	0.978±0.161	0.196±0.022	1.725±0.215
Mg/Ca	2.021±0.256	0.749±0.039	3.235±0.331
NH_4	0.102±0.017	0.103±0.013	0.102±0.033
NO_3	0.945±0.244	1.379±0.410	0.492±0.226
NO_2	0.042±0.011	0.060±0.013	0.024±0.016
P-PO_4	0.017±0.004	0.011±0.003	0.023±0.007
P_{tot}	0.064±0.001	0.106±0.012	0.021±0.007
Fe	0.032±0.005	0.056±0.006	0.010±0.0006
Si	5.49±0.15	5.20±0.22	5.76±0.20
oxidability	7.39±0.46	5.07±0.40	9.13±0.45
Zn	0.028±0.009	0.039±0.018	0.017±0.002
Cu	0.018±0.003	0.022±0.005	0.013±0.002
Cd	0.0036±0.0002	0.0028±0.0002	0.0044±0.0002
Pb	0.034±0.003	0.021±0.002	0.047±0.004
Ni	0.039±0.001	0.037±0.002	0.042±0.002
Co	0.013±0.001	0.010±0.0005	0.017±0.001
*Note. All Variable – mg dm^{-3}, oxidability – mgO dm^{-3}.			

The highest heating-up of water is recorded in the Eastern Balkhash with the exception of area under influence of the Karatal River mouth as well as the southeastern part of the Western Balkhash as illustrated in Fig. 2a. The maximum depths are typical for the eastern extremity of the lake (Fig. 2, b). The transparency of the water increases simultaneously with the depth from 0.25 m in the west to 5.50 m in the east (Fig. 2, c). The minimum pH-values were recorded in the areas affected by the runoff of the Ili River in the west, and of the Karatal, Aksu and Lepsy rivers in the east (Fig.2, d), whereas the highest values more than 8.6 were characteristic of the most part of the Eastern Balkhash water.

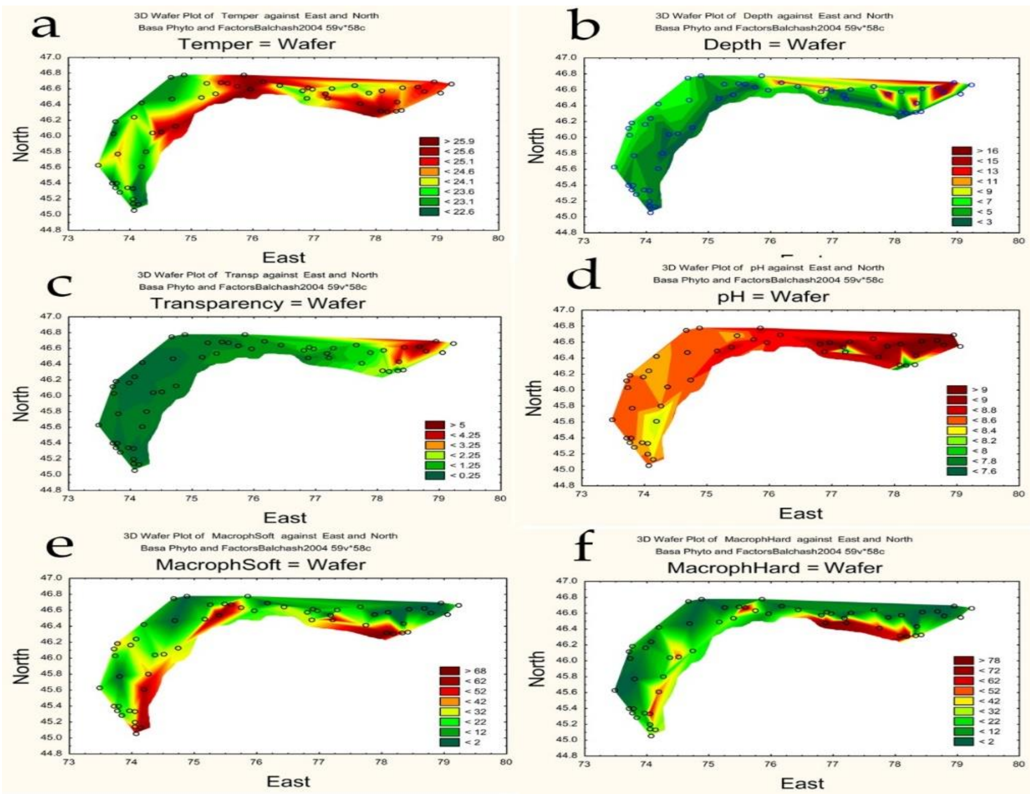

Fig. 2: Spatial distribution of hydrophysical variables and the presence of macrophytes in the Balkhash Lake, summer 2004.

Macrophytes developed near the southern coast as well as in the shallow waters of the 5th hydrochemical region (Fig. 2, e, f) in the eastern saline part of the lake. In the Western Balkhash, reeds and cattails grew in a narrow strip along the southeastern and eastern coasts. Here was recorded the greatest number of soft macrophytes forming a wider and longer belt.

The concentrations of all cations except for Ca increased in the direction from west to east reaching the maximum values in the 7th and 8th hydrochemical regions of the lake (Fig. 3). Calcium content in water decreased in this direction by 3-4 times (Fig.3a). These tendencies were broken locally in the areas affected by inflow of the Karatal, Lepsy and Aksu rivers. The values of K/Ca and Mg/Ca ratios increased from west to east (Fig.3, f, h) when the concentration of calcium decreased and the content of magnesium and potassium increased in the water of the lake. The spatial distribution of K/Na values showed similar dynamics (Fig. 3, g) reaching its maximum along the southeastern shore of the Eastern Balkhash.

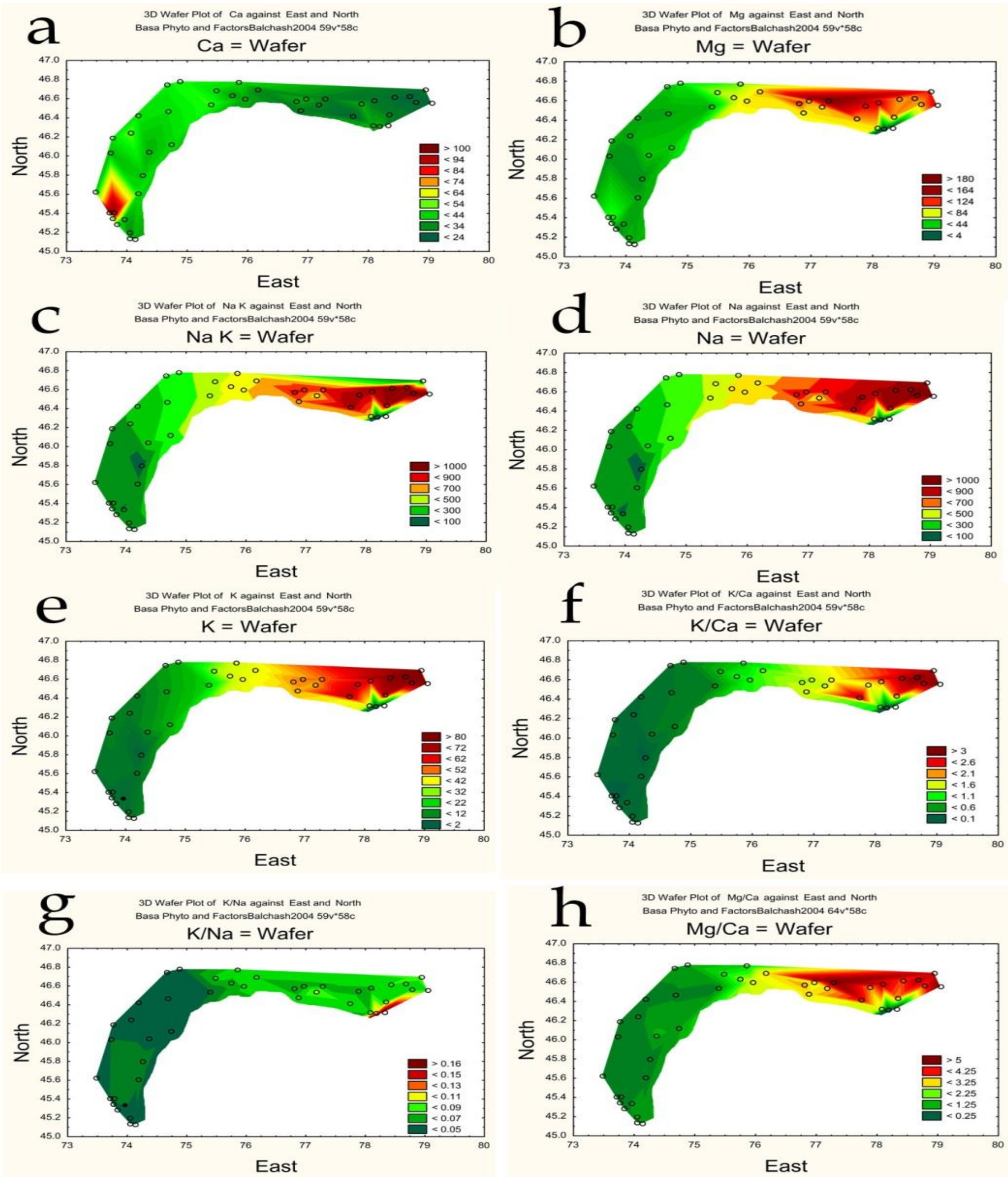

Fig. 3: Spatial distribution of cations and their ratios across the water area of the Balkhash Lake, summer 2004

TDS and anion content in the water increased in the direction from west to east (Fig.4) following the general patterns of spatial dynamics of hydrochemical variables and decreased again to the minimal values in the areas affected by inflow of the Karatal, Lepsy and Aksu rivers.

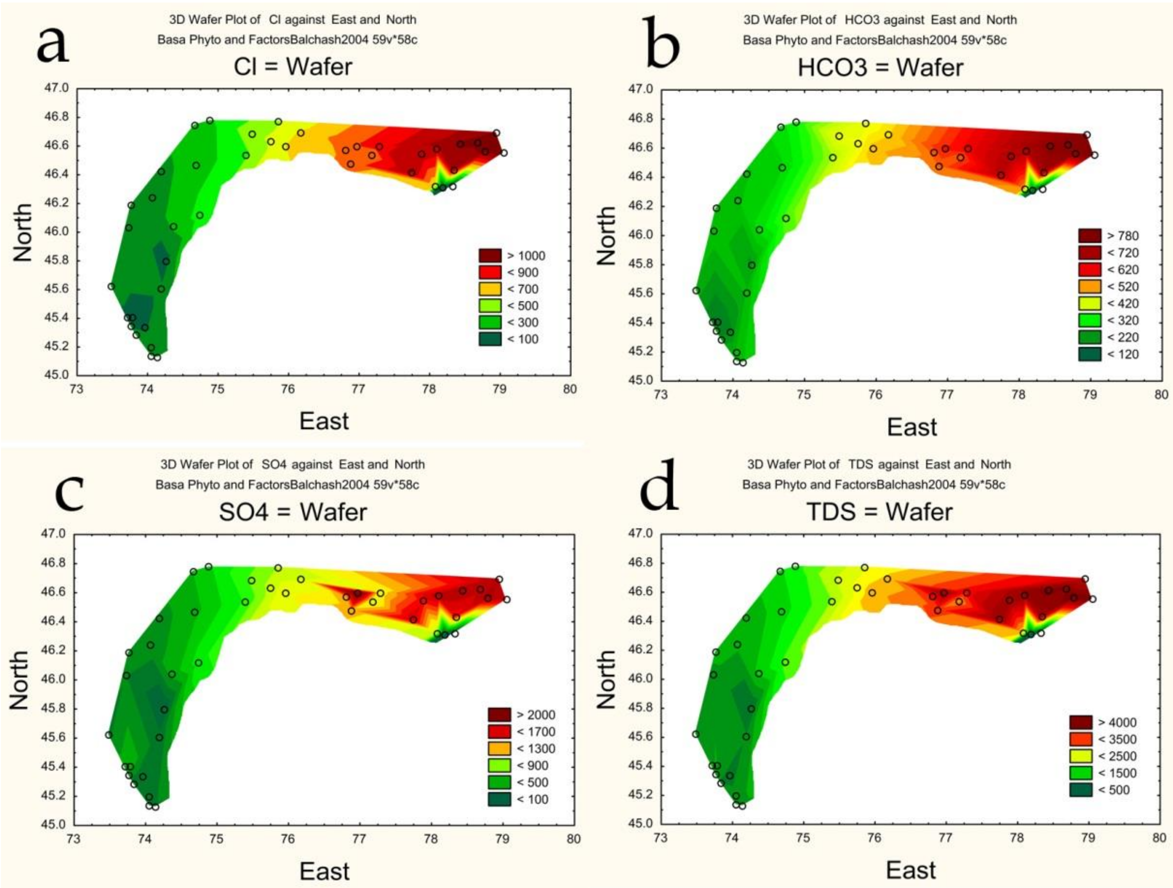

Fig. 4: Spatial distribution of anions and TDS across the water area of the Balkhash lake, summer 2004

The content of biogenic elements was often at a low level (Table 2). The maximum concentrations of nitrites, nitrates, and phosphates were recorded along the northwestern coast of the Western Balkhash and the northern coast of the Eastern Balkhash (Fig. 5 a, b, d). A high concentration of total phosphorus was recorded here and for the most part of the Western Balkhash (Fig. 5, e). The Uzynaral Strait exhibited elevated concentrations of ammonium (Fig. 5, c). The content of readily oxidizable organic matter in the water increased along the longitudinal axis of the lake with the maximum values of the variable in the east (Fig. 5, f). The distribution of silicon across the water area was relatively even with minimal in the Uzynaral Strait waters (Fig. 5, g). The content of total iron decreased in the direction from west to east with slightly increasing in the areas affected by the eastern rivers inflow (Fig. 5, h).

The content of cobalt, lead, and cadmium increased from west to east along the longitudinal axis of the lake by an order of magnitude (Fig. 6, a, c, d). Two peaks of nickel concentrations were recorded in the area where the eastern rivers Karatal, Aksu, Lepsy enter the lake and less pronounced in the 4th hydrochemical region of the Western Balkhash (Fig.6, b).

The highest concentrations of zinc were recorded in the western part of the lake at a less pronounced maximum near the northern shore of the Eastern Balkhash (Fig. 6, f). The last section of the water area was also characterized by elevated copper concentrations; however its maximum content was also recorded in the Western Balkhash (Fig. 6, e).

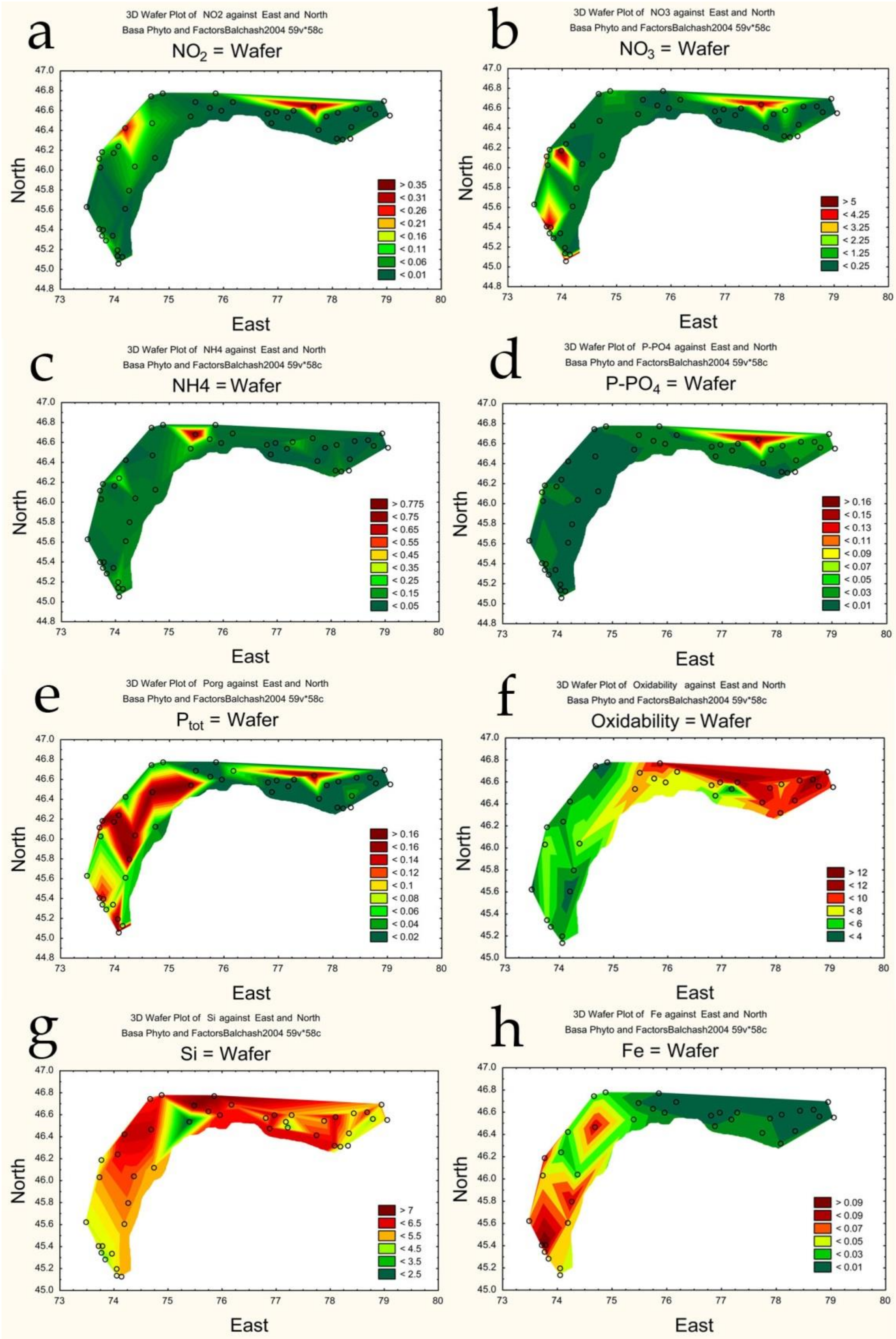

Fig. 5: Spatial distribution of nutrient elements across the water area of Balkhash Lake, summer 2004

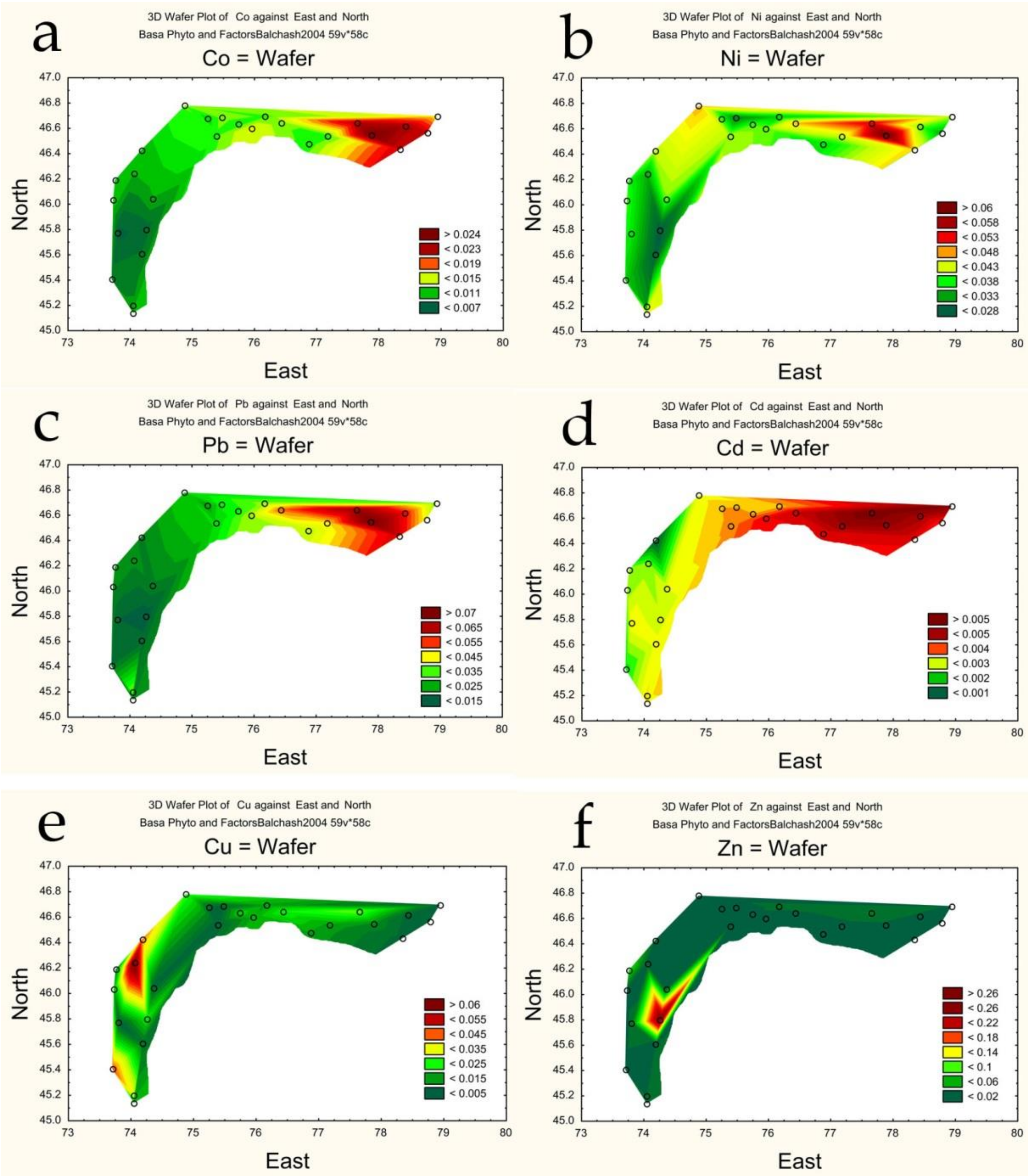

Fig. 6: Spatial distribution of heavy metals across the water area of Balkhash Lake, summer 2004

Statistical analysis evidenced that the spatial variation of the most of environmental parameters was closely correlated with the dynamics of TDS of water (Table 3). As it increased from west to east, the pH-values, K/Ca, Mg/Ca, K/Na ratios, the content of all anions and cations, except for calcium, readily oxidizable organic matter, phosphates, cadmium, lead and cobalt are increased whereas the quantity of calcium, ammonium, nitrates, and nitrites to a lesser extent, organic phosphorus, iron, and copper decreased. The relationship between these variables with TDS that varies almost linearly in the direction from west to east reflected their spatial distribution along the longitudinal axis of the lake.

Table 3: Spearman Rank Order Correlation coefficients between TDS and abiotic variables of the Balkhash Lake, summer 2004 (at p <0.05)

Dependent Variable	Spearman Rank Order Correlations	Dependent Variable	Spearman Rank Order Correlations
Temperature	0.473	K/Ca	0.956
Transparency	0.732	K/Na	0.504
Macrophytes Hard	-0.418	NH_4	-0.516
Macrophytes Soft	-0.603	NO_3	-0.619
pH	0.895	NO_2	-0.454
Ca	-0.608	$P\text{-}PO_4$	0.776
Mg	0.929	P_{tot}	-0.601
HCO_3	0.964	Fe	-0.844
SO_4	0.986	Oxidability	0.747
Cl	0.979	Cu	-0.524
Na	0.979	Cd	0.797
K	0.978	Pb	0.855
Mg/Ca	0.888	Co	0.894

The dynamics of K/Na ratio is also remarkable. The values of K/Na ratio linearly decreased from 0.056 to 0.043 averaging at 0.046 in the western, desalinated part of the lake over gradient of TDS from 490.0 to 1981.9 mg/dm^3. The trend was reversed in the Eastern Balkhash with the increase in water salinity from 2305.6 to 4981.0 mg/dm^3 the K/Na values increased from 0.062 to 0.093 averaging at 0.074. That is, with a relatively smooth change in the total dissolved solids (TDS) from west to east, the K/Na ratio changed dramatically due to more intense increase in potassium concentrations compared to sodium.

DISCUSSION

Maps of spatial distribution clearly demonstrated the changes in hydrophysical and hydrochemical parameters along the longitudinal axis of the Balkhash Lake. The constant gradient of total dissolved solids (TDS) is associated with the inflow of fresh water of the Ili River from the Western to Eastern Balkhash [12]. The Eastern Balkhash is characterized not only by the maximal values of TDS but also by the peculiar chemical composition of water. This is due to the fact that an increase in the concentrations of magnesium, potassium, sodium and a decrease in the calcium content in the TDS gradient occur with different intensities which are confirmed by the correlation analysis (Table 3). The relationship between TDS and the ratio Mg/Ca (R=0.888) is weak whereas the correlation coefficient between the TDS of water and the content of magnesium, sodium, potassium, the ratio of K/Ca, sulfates, and chlorides is close to one (very strong positive correlation). The relationship between TDS and calcium content as a result of Spearman rank coefficients calculation (R= -0.608) and the ratio K/Na (R=0.504) is even less evident.

The chemical composition of water plays an essential role in the formation of the biota of every water body. For living organisms, not only the absolute content of ions is important [16-18], but also their ratios [19], since sodium, potassium, calcium and magnesium are antagonistic towards each other [20-22]. The Eastern Balkhash is characterized by an unfavorable ratio of K^+/Ca^{2+} and K^+/Na^+, especially in low-water years when the total salt saturation increases. The negative influence of the Eastern Balkhash water upon hydrobiontes was evidenced in experiments [23] and in field studies [24].

The iron content reached its maximal concentration in the confluence area of the Ili River (Fig. 5, h) decreased in the gradient of TDS (Table 3) and slightly increased in the mouths of the eastern rivers Karatal, Lepsy and Aksu. The nature of iron distribution across the water area indicates its primary entry with river waters. Iron plays an important role in the intrabasin processes including its contribution to the binding of phosphorus by bottom sediments [25, 26]. Taking into account the fact that the increase of water salinity encourages leaching of iron from the ground and the following increase of iron content in the water [25, 27], the spatial distribution of iron across the Balkhash water area can be explained not only by the effect of total saturation with salts, but, evidently, by its interaction with total phosphorus [26]. There is a strong positive correlation between the content of total phosphorus and iron in the water of the Balkhash Lake at R=0.825, p<0.05. The interaction of iron with phosphorus is one of the main mechanisms responsible for the change in iron concentrations in water due to its precipitation together with phosphorus and accumulation in sediments [28].

The spatial dynamics of phosphates compared to total phosphorus was characterized by opposite tendencies: by an increase in the concentration within the gradient of the total dissolved solids of water (Fig. 5, d) and, respectively, by a negative correlation with iron ($R = -0.646$, $p<0.05$). It can be caused by the fact that in fresh waters phosphorus precipitates due to its interaction of with metal cations [29] which leads to the increase in water salinity, followed by increase in bioavailability of phosphorus, i.e. the proportion of mineral forms (phosphates) [30].

The amount of readily oxidizable organic matter increased within TDS gradient of water (Fig. 5, f) that may reflect its accumulation in the eastern part due to the flow of water from the Western Balkhash as well as due to underutilization by the biota.

Analysis of spatial distribution maps of nutrient elements and heavy metals made it possible to identify the main ways of their entry into the Balkhash Lake. The increased concentrations of ammonia in the northern coast of the Western Balkhash indicate an influx of fresh organic pollution which can be attributed to the local impact of sewage from the Balkhashfishprom enterprise (Fig.1, C) that processes fish.

Taking into account the location of potential sources of pollution (Fig. 1, J, F, G), the main contribution to the supply of cobalt, lead, cadmium and nickel to the Balkhash Lake is being done by the Karatal River which overall pollution level is estimated as high [31]. The accumulation of heavy metals in the eastern part of the lake can also be caused by a constant flow from west to east (Fig. 1). Maximal values of nickel concentrations and increased copper concentrations near the northern shore of the Eastern Balkhash (Fig. 6, b, e) can be related to the emissions from the Sayak copper field (Fig. 1, D). Analysis of the statistical maps showed that the main contribution to the pollution of the Balkhash Lake is made not only by the exploitation of the field but also by the river runoff (Fig. 6, e). The source of the Ili River's pollution by copper is the Akdala array of rice cultivation (Fig. 1, D).

Copper serves as part of several complex fertilizers and its increased concentrations in the areas affected by the river runoff indirectly indicate the entry of other pollutants, reflecting the overall deterioration of the ecological situation in this lake region. Elevated copper concentrations in the Balkhash Lake are also associated with natural causes, since they are also recorded on background areas of the Ili River that are not exposed to anthropogenic impact [32]. A highly toxic insecticide decis enters to the Ili River from the Akdala array and goes further into the lake [7], and, as can be seen on Fig. 5e, same is true of the total phosphorus, as well as zinc (Fig. 6, f). Nickel enters the lake mainly from the BMSC tailings dump (Fig. 1, B) as evidenced by a local increase in its concentrations near the Torangalyk Bay in the Western Balkhash (Fig. 6, b).

The statistically calculated maps show that distribution of nitrates, nitrites, total phosphorus, iron, copper, and zinc across the Western Balkhash was well linked with the direction of the runoff flow (Fig. 1) that moves from the mouth of the Ili River to the opposite shore and further towards the Uzynaral Strait. The maximal concentrations of nitrites, nitrates, and copper were recorded at the opposite northwestern shore of the lake, and of zinc – directly in the area affected by the Ili River. The relationship between the movement of water masses and the spatial dynamics of total phosphorus was traced most clearly (Fig. 5, e).

The air pollution in the lake catchment basin contributes to the ecological state of the Balkhash Lake and the adjacent area. The Balkhash mining and smelting complex alone emitted from 238.1 to 403.0 thousand tons of pollutants per year into the atmosphere [31] in the period from 1997 to 1999. The analysis of the statistical maps, however, did not reveal a connection between the distribution of heavy metals in the lake area and the dominant wind directions. It can be assume therefore, heavy metals from emissions precipitate on wide areas of rivers' catchment basins, and as a results entry into the lake with river flow as evident on the maps.

CONCLUSION

The Balkhash Lake is characterized by a pronounced gradient of the total dissolved solids and the chemical composition of water, which is clearly demonstrated by the statistical maps of the spatial distribution of these variables. The visualization of the data made it possible to draw conclusions that zinc, copper, total phosphorus, iron, partially nitrites, and nitrates enter the Western Balkhash with waters of the Ili River, polluted by drainage flow. The total phosphorus, zinc, and copper enter the Western Balkhash in high concentrations despite the considerable distance of the Akdalin array of rice cultivation from the lake (about 180 km) and additional natural purification of river water during its movement through a vast delta that is overgrown by macrophytes. The contribution of river runoff to the overall level of pollution of the lake with copper is higher than its input from other sources including the Sayak copper field. Local increase of nickel concentrations in the Western Balkhash is associated with surface runoff from the territory of the BMSC tailing dump and TPP. Influence of fish production on the coastal zone of the Western Balkhash is evidenced by the content of ammonium in water. The Eastern Balkhash is characterized by an elevated content of cobalt, nickel, lead, and cadmium in water that predominantly enter the water body with the Karatal River waters. The sources of pollution of this river are the industrial enterprises of towns Tekeli, Taldykorgan and Ushtobe. The permanent natural water flow in the direction from west to east as well as wind currents can be defined as powerful factors that significantly influence the distribution and places of concentration of the pollutants. Data visualization is a useful addition to the generally accepted statistical methods of analysis, as it allows not only to assess the ecological state of different parts of large water bodies but also to link the distribution of the environmental parameters with potential sources of pollution and hydrodynamic characteristics such as river runoff and dominant currents within the lake.

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REFERENCES

[1] Barinova SS, Bragina TM, Nevo E. Community Ecology 2009; 10(1): 7-16.
[2] Barinova SS, Nevo E, Bragina TM. Acta Botanica Croatica 2011; 70 (2): 215–244.
[3] Tarasov MN. Hydrochemistry of the Balkhash Lake, Academy of Sciences of the USSR, Moscow, 1961; 224 p. (In Russian)
[4] Kudekov TK (ed.). Contemporary ecological state of the Balkhash Lake’s basin, Kaganat, Almaty, 2002; 386 p. (In Russian)
[5] Mazurov AK. Proceedings of Tomsk Polytechnic University 2005; 308(4):33-39. (In Russian)
[6] Samakova AB (ed.). Issues of hydro-ecological sustainability in the Balkhash Lake’s basin, Kaganat, Almaty, 2003; 584 p. (In Russian).
[7] Sadykova GD. Hydrometeorology and Ecology 2002; 3:131-140. (In Russian)
[8] Petrakov IA. The quality of surface water on the territory of the Kazakhstan Republic for the first half of 2015. Department of Environmental Monitoring, Astana, 2015; 223 p. (In Russian)
[9] Information bulletin on the environmental status of the Balkhash Lake basin. Department of Environmental Monitoring, Astana, 2010; 16 p. (In Russian)
[10] Krupa EG, Barinova SS, Amirgaliyev NA, Issenova G, Kozhabayeva G. MOJ Eco Environ Sci 2017; 2(1): 1-8.
[11] Abrosov VN. The Balkhash Lake. Science, Leningrad, 1973; 180 p. (In Russian).
[12] Semenov VA, Kurdin RD (eds). Resources of surface waters of the USSR. Volume 13. Central and Southern Kazakhstan. Issue 2. The basin of the Balkhash Lake. Hydrometeorology, Leningrad, 1970; 646 p. (In Russian)
[13] Mitrofanova AN, Kalita RSh. News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and engineering sciences 2014; 4:74-78. (In Russian)
[14] Semenova AD (ed). Guideline for chemical analysis of surface water. Gidrometeoizdat, Leningrad, 1977; 541 p. (In Russian)
[15] Fomin GS. Water. Control of chemical, bacterial and radiation safety according to international standards. NGO "Alternative", Moscow, 1995; 618 p. (In Russian)
[16] Khlebovich VV. Critical Salinity of Biological Processes. Nauka, Leningrad, 1974; 236 p. (In Russian)

[17] Borvinskaya EV, Sukhovskaya IV, Vasil'eva OB, Nazarova MA, Smirnov LP, Svetov SA, Krutskikh NV. Mine Water Environ 2017; The online version DOI 10.1007/s10230-016-0426-0

[18] Martemyanov VI. Russian Journal of Biological Invasions 2011; 2(2-3):213-222.

[19] Vinberg GG. Biological Journal, 1933; 2(6): 519-527. (In Russian)

[20] Berezina N.A. Influence of ionic composition of water on freshwater macrozoobenthos in natural and experimental conditions: thesis abstract of Cand. Biol. Sc.: 03.00.16, Borok, 2000; 23 p. (In Russian)

[21] Chekunova VI. Proceedings of the All-Union Scientific Research Institute of Fisheries and Oceanography 1960; 28: 235-243. (In Russian)

[22] Lozovik NY, Dubrovina LV, Kurinnaya AA, Fedorova NV. Determination of Toxic Properties of the Environment by Experimental and Theoretical Modeling. Modern Problems of Aquatic Toxicology, Borok: Inst. Biol. Vnutr. Vod. Ross. Akad. Nauk, 2002; 95-96. (In Russian)

[23] Birshtein YA, Belyaev GM. Zoological Journal 1946; 25(3): 225-236. (In Russian)

[24] Krupa EG, Stuge TS, Lopareva TYa, Shaukharbaeva DS. J. Inland Water Biology 2008; 1(2): 150-157.

[25] Luo M, Zeng C-Sh, Tong Ch, Huang J-F, Chen K, Liu F-Q. Estuaries and Coasts 2016; 39:1679-1693.

[26] Bakker ES, Donk EI, Anne K. Aquat Ecol 2016; 50:121-135.

[27] Pezzetta E, Lutman A, Martinuzzi I, Viola C, Bernardis G, Fuccaro V. Environ Earth Sci 2011; 62:377-391.

[28] Paludan C, Morris JT. Biogeochemistry 1999; 45:197-221.

[29] Jun M, Altor AE, Craft CB. Estuaries and Coasts 2013; 36:508-518.

[30] Hartzell JL, Jordan TE. Biogeochemistry 2012; 107:489-500.

[31] Tilekova ZhT, Oshakbaev MT, Tonkopiy MS. Bulletin of Kazakh National Technical University 2015; 2:14-20. (In Russian)

[32] Slivinsky GG, Krupa EG, Lopatin OE, Mamilov NSh, Prikhodko DE. Bulletin of Kazakh National University. Ecological series 2010; 2:73-78. (In Russian)