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Water Elemental Composition and Toxicity in Kazakhstan's Transboundary Rivers

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ABSTRACT

The article describes the monitoring results of the content of chemical elements (As, Cr, B, Ba, Li, Mo, Pb, Sb, Sr, U, and Cr) in the water of transboundary rivers of Kazakhstan (Shagan, Ural (kaz. Zhayik), Ilek, Tobol, Ayat, Irtysh (kaz. Yertys), Emel, Ili (kaz. Ile), Tekes, Shu, Kara-Balta, Talas, and Syr Darya) conducted in 2020. The toxic element concentrations underwent comparison with background levels (Clark[e] numbers) and maximum permissible concentrations (MPC), with sub-sequent calculation of the total toxicity index (KHL). The study showed that practically all the inves-tigated rivers were subject to contamination, with uranium and lithium as the greatest contributors to surface water toxicity. The rivers in Southern and South-Eastern Kazakhstan - namely, the Kara-Balta, Syr Darya and Shu - were found to be most exposed. For instance, the KHL of the Kara-Balta River water exceeded the permissible threshold by over 5.9 times. The lowest KHL value (<1) corre-sponded to the Yertys and Ile Rivers. The research made it possible to identify the toxicity of trans-boundary waters flowing into the territory of Kazakhstan, as well as provided basis for further in-vestigation to identify pollution sources.

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1. Introduction

Fresh water is not only the source of life but likewise the main strategic resource on the planet. Possession of a sufficient amount of water represents the most important economic driver. Amidst the changing climate, industrial development and growing role of anthropogenic factors, sustainable water supply and water quality are becoming increasingly challenging for multiple countries around the world. The looming water crisis that such countries are facing is significantly aggravated by their geographical location, i.e. when the available water resources are shared by two or several neighboring (riparian) countries and, thus, possess the transboundary status.

This is true for Central Asia and the Republic of Kazakhstan (RK), in particular. Almost half of its water resources come from the countries with growing economies like Russia, Kyrgyzstan, China, and Uzbekistan. Lacking (domestic) water resources (Zhupankhan et al., 2018), Kazakhstan depends on the quantity and quality of water coming from its neighbors. Perhaps the only way to provide clean water to the sectors of the national economy (including agriculture) is to control the quality of transboundary water resources via a properly functioning monitoring system.

To ensure that, the national hydrometeorological service operator – Kazhydromet – has been regularly monitoring Kazakhstan's transboundary water courses. Since 2007, the national Institute of Nuclear Physics (INP) has been involved in these efforts performing radiation, specifically water elemental composition, and environmental testing and monitoring of water streams crossing the national border. Transboundary water quality monitoring is carried out at the state level. This article presents the outcomes of the water elemental composition monitoring of transboundary rivers executed in 2020.

2. Research methodology

The quality monitoring of Kazakhstan's transboundary water courses is carried out at 15 (fifteen) border river sections (control points, CP) (see Fig. 1.). The 2020 survey and monitoring system was based on the methodology developed by the team of Central Asia (Kyrgyzstan, Uzbekistan, Tajikistan, Kazakhstan) and United States scientists under the international Navruz Project aimed at examining the transboundary Syr Darya and Amu Darya Rivers (Passell et al., 2008).

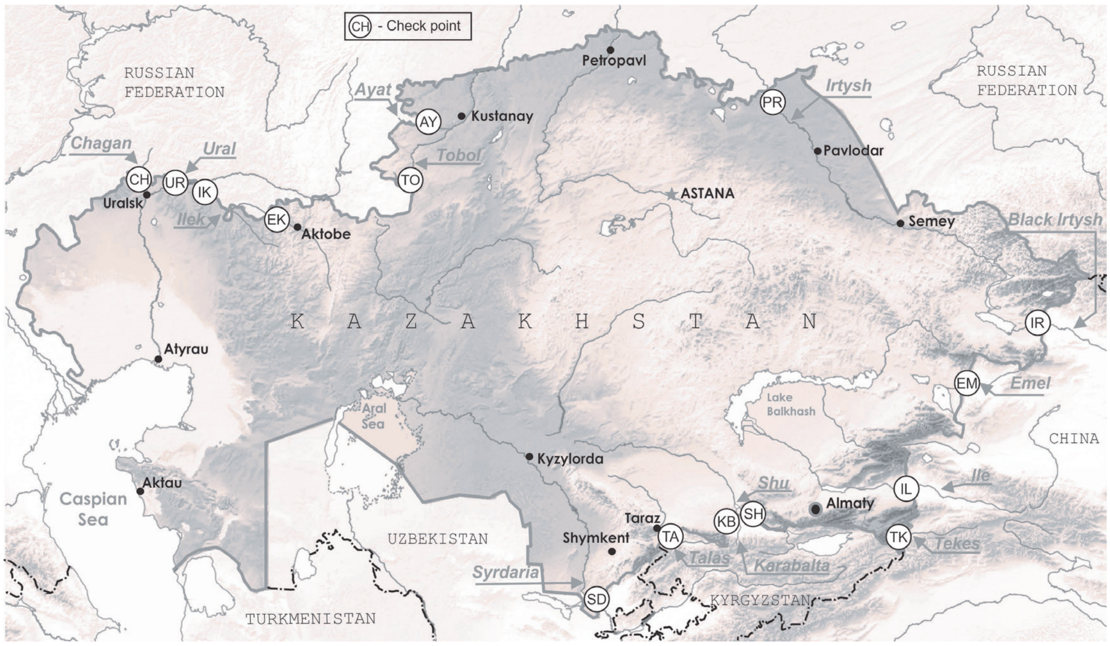

Figure 1. Layout of control points (CPs) on Kazakhstan's transboundary rivers.

In accordance with this methodology, water samples were collected annually in spring and autumn at the designated control points (CPs) (see Fig. 1.). The list of CPs included the border sections of the following transboundary rivers: Shagan (SH), Ural (kaz. Zhaiyk) (UR), Ilek (IK, EK), Tobol (TO), Ayat (AY), Irtysh (kaz. Yertys) (PR, IR), Emel (EM), Ili (kaz. Ile) (IL), Tekes (TK), Shu (SH), Kara-Balta (KB), Talas (TA), and Syr Darya (SD). Whereas the sampling and sample delivery were done by Kazhydromet, the laboratory tests were conducted by the Center for Integrated Environmental Studies of the Institute of Nuclear Physics (ISO/IEC 17025-2019 accredited). The examination of trace elements in water samples was executed by inductively coupled plasma mass spectrometry.

The list of detectable concentrations includes more than 30 (thirty) chemical elements. All monitoring results, including the INP outputs, are published in the annual bulletin (Kazhydromet, 2020). This research focused on the following elements: As, Cr, B, Ba, Li, Mo, Pb, Sb, Sr, and U; and comprised the comparison of the obtained concentration values with the corresponding river water Clarkes (Savenko, 1997) and maximum permissible concentrations (MPC). The Clarke comparison was done for the purpose of general water composition assessment against the regional average. The acceptable concentration comparison is usually carried out to assess water toxicity in terms of human health.

To ensure a comprehensive water quality analysis, the total toxicity index – KHL (Limiting Harmfulness Indicator) recommended as per Kazakhstan's sanitary standards – was applied. In accordance with the sanitary rules (MNE, 2015), in case of presence in the water of a water body of two or more substances of Hazard Classes 1 and 2 (As, B, Ba, Li, Mo, Pb, Sb, Sr, and U) characterized by a unidirectional toxic action mechanism, the cumulative concentration ratio for each of them to the corresponding MPC should not exceed 1.0, i.e. in case of KHL>1, the water is assumed contaminated. The calculations were carried out based on the formula below:

$$K_{HL} = \sum_{i=1}^{N} \frac{C_i}{MPC_i} \quad , \qquad (1)$$

where

K_{HL} is the Total Toxicity Index (Limiting Harmfulness Indicator);

C_i is the concentration value of an i-th toxic element;

MPC_i is the maximum permissible concentration of an i-th element.

The authors used the MPCi values recommended by the World Health Organization (MPCWHO) (WHO, 2017) and Ministry of National Economy of the RK (MPCKZ) (MNE, 2015).

3. Results

The diagrams in Fig. 2. compare the concentrations of studied elements in river water at all target CPs (spring and autumn period).

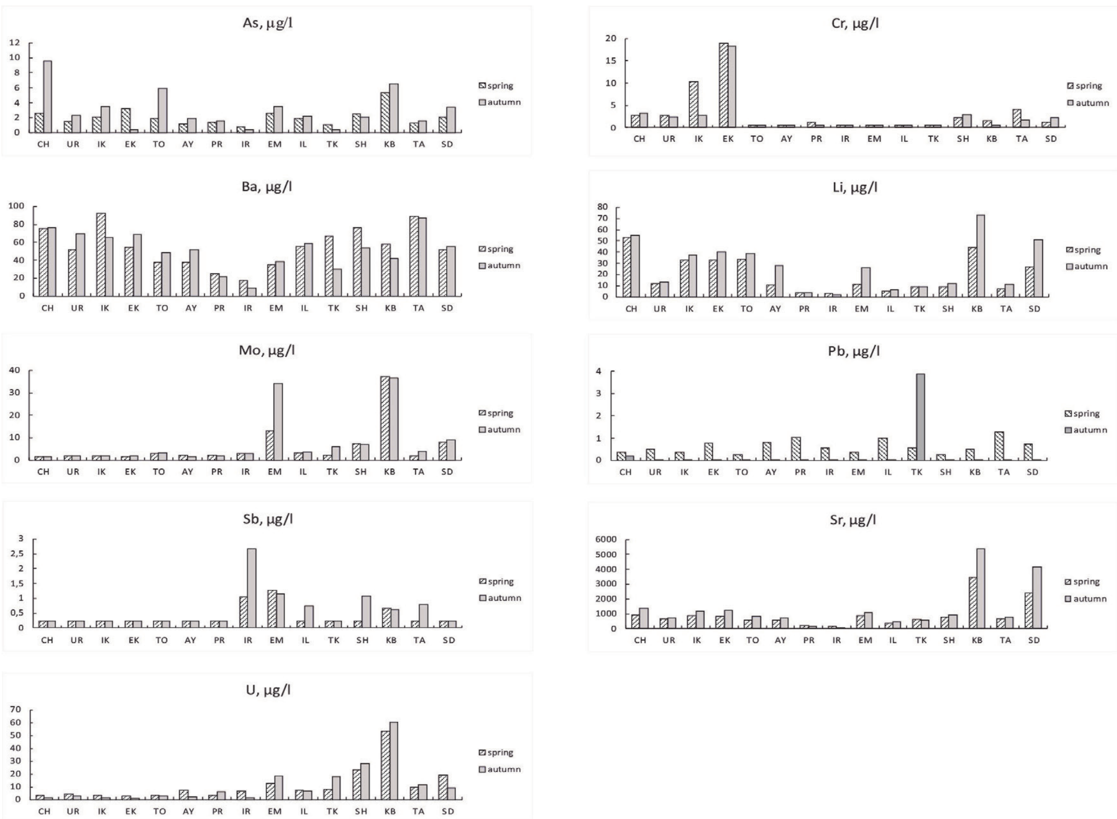

Figure 2. Distribution of chemical element concentrations at CPs (spring and autumn, 2020).

As the diagrams show, the distribution of chemical element concentrations in water at different CPs is uneven. The highest concentrations of Mo were recorded in the water at the EM, SH, SD and especially KB control points. Also, the water samples collected at these CPs contained elevated concentrations of Sb, U, and Li. In addition, increased concentrations of Sb compared to other rivers were noted at the IR and EM CPs, and of Li – at the CH, IL, TO and AY CPs. The highest Cr content was detected at the IL as well as CH and UR control points. The concentration of As did not show any significant difference among the target CPs, with a slight exception at the CH, TO, EM, KB and SD control points. It was mostly the same for Ba, however it was clear that the element was present in the smallest amount in the water at the IR CP. The diagram also demonstrates that the Sb and Cr concentrations were quite different between the two control points located on the same river: IR-PR and IK-EK.

Slight differences in element concentrations in spring and autumn were detected as well, specifically, for Mo at the EM, Sb at the IR, Li at the EM, KB and SD CPs; and for Pb at the TK, Sr at the KB and SD CPs. Whereas the concentrations of As, Mo, Li, Sb, U, and Sr were predominantly higher in autumn, this of Pb (except for the TK control point) was higher in the spring.

The content of studied chemical elements in water (2020 mean) at target transboundary river CPs compared to the regional river water Clarkes is presented in Table 1. below.

Table I. Correlation (ratio) between chemical element concentrations (2020 annual means) and river water Clarke values.

Control Point (Sampling Site)	Ci / Clarke										
	As	Ba	Co	Cr	Fe	Li	Mo	Pb	Sb	Sr	U
CH	2.4	1.3	2.0	3.0	1.3	21.5	2.9	2.8	0.2	19.2	9.9
UR	0.7	1.0	1.3	2.6	0.9	5.1	4.0	2.7	0.2	11.4	14.6
IK	1.1	1.3	1.7	6.6	0.7	14.1	3.7	2.0	0.2	17.1	9.9
EK	0.7	1.0	2.2	18.6	0.2	14.6	3.5	4.0	0.2	17.0	8.3
TO	1.6	0.7	1.9	0.6	0.6	14.5	6.2	1.5	0.2	11.9	12.6
AY	0.6	0.7	1.5	0.6	1.7	7.8	3.8	4.2	0.2	10.7	19.7
PR	0.6	0.4	0.8	0.9	2.5	1.5	4.0	5.3	0.2	3.0	19.1
IR	0.2	0.2	0.7	0.6	0.2	1.0	5.7	3.0	1.9	2.2	17.4
EM	1.2	0.6	1.2	0.6	0.2	7.4	47.4	2.0	1.2	16.3	65.4
IL	0.8	0.9	1.1	0.6	1.9	2.4	6.6	5.3	0.5	6.8	29.3
TK	0.3	0.8	0.9	0.6	6.9	3.7	8.2	22.2	0.2	9.8	53.8
SH	0.9	1.1	1.0	2.6	0.3	4.3	14.2	1.4	0.7	14.3	107.1
KB	2.4	0.8	2.0	1.0	2.0	23.6	74.0	2.7	0.6	73.5	237.7
TA	0.6	1.5	1.2	2.9	7.2	3.6	5.9	6.6	0.5	12.1	43.9
SD	1.1	0.9	1.8	1.8	0.1	15.5	17.0	3.9	0.2	54.7	60.2
Clarke	**2.5**	**60**	**0.2**	**1.0**	**40**	**2.5**	**0.5**	**0.1**	**1**	**60**	**0.2**
Min	**0.2**	**0.2**	**0.7**	**0.6**	**0.1**	**1.0**	**2.9**	**1.4**	**0.2**	**2.2**	**8.3**
Max	**2.4**	**1.5**	**2.2**	**18.6**	**7.2**	**23.6**	**74.0**	**22.2**	**1.9**	**73.5**	**237.7**

The data presented point to toxic element concentrations in the water of most transboundary rivers exceeding the corresponding Clarke values within the following limits:

As – from 0.2 (at the IR control point) to 2.4 (at the CH and KB CPs);
Ba – from 0.2 (at the IR CP) to 1.5 (at the TA CP);
Co – from 0.7 (at the IR CP) to 2.2 (at the EK CP);
Cr – from 0.6 (at the TO, AY, IR, EM, IL, and TK CPs) to 18.6 (at the EK CP);
Fe – from 0.1 (at the SD CP) to 7.2 (at the TA CP);
Li – from 1.0 (at the IR CP) to 23.6 (at the KB CP);
Mo – from 2.9 (at the CH CP) to 74.0 (at the KB CP);
Pb – from 1.4 (at the SH CP) to 22.2 (at the TK CP);
Sb – from 0.2 (for most CPs) to 1.9 (at the IR CP);
Sr – from 2.2 (at the IR CP) to 73.5 (at the KB CP);
U – from 8.3 (at the IL CP) to 237.7 (at the KB CP).

Thus, almost all toxic elements presented at the KB CP exceeded the regional background levels, with the largest excess of (Ci/Clarke) at this control point registered for Li, Sr, Mo and U (by 23.6, 73.5, 74.0 and 237.7 times, respectively). In addition, the highest Clarke excesses (over 15 times) corresponded to the SD and EM CPs for Mo (by 17.0 and 47.4 times); to the SD CP for Sr (by 54.7 times); to the TK CP for Pb (by 22.2 times), and to the EK CP for Cr (by 18.6 times). Significantly exceeded U concentrations were detected at the IL (by 29.3 times), EM (by 65.4 times), TK (53.8 times) and especially at the SH (by 107.1 times) CPs.

The evaluation of correlations between chemical concentrations and Clarke values does not allow drawing conclusions about water toxicity. Therefore, in order to assess whether the recorded Clarke excesses were actually pollution, the concentration values of the studied toxic elements were compared to the permissible levels (MPCi) with subsequent calculation of the total toxicity index (KHL) (see Table 2.). The diagram in Fig. 3. describes the distribution of KHL mean annual (spring and autumn of 2020) values among all target CPs.

Table II. Correlations between toxic element concentrations in water at target CPs (spring and autumn of 2020) and corresponding MPCs, and calculated KHL values.

Control Point (Sampling Site)	**Ci / MPCi**									
	Season	As	B	Ba	Li	Mo	Pb	Sb	Sr	U	KHL
CH	Spring	0.26	0.09	0.11	1.76	0.02	0.036	0.012	0.13	0.11	**2.52**
	Autumn	0.96	0.13	0.11	1.83	0.02	0.020	0.012	0.20	0.05	**3.32**
UR	Spring	0.14	0.04	0.07	0.39	0.03	0.049	0.012	0.09	0.14	**0.98**
	Autumn	0.23	0.05	0.10	0.45	0.03	0.004	0.012	0.10	0.09	**1.07**

IK	Spring	0.20	0.06	0.13	1.09	0.03	0.036	0.012	0.13	0.12	**1.80**
	Autumn	0.35	0.10	0.09	1.26	0.03	0.004	0.012	0.17	0.04	**2.05**
EK	Spring	0.32	0.10	0.08	1.09	0.02	0.077	0.012	0.12	0.09	**1.91**
	Autumn	0.04	0.17	0.10	1.34	0.03	0.004	0.012	0.17	0.04	**1.91**
TO	Spring	0.19	0.07	0.05	1.11	0.04	0.027	0.012	0.08	0.10	**1.69**
	Autumn	0.60	0.09	0.07	1.30	0.05	0.004	0.012	0.12	0.10	**2.34**
AY	Spring	0.11	0.04	0.05	0.36	0.03	0.079	0.012	0.08	0.24	**1.01**
	Autumn	0.19	0.07	0.07	0.94	0.02	0.004	0.012	0.10	0.07	**1.49**
PR	Spring	0.14	0.02	0.04	0.12	0.03	0.103	0.012	0.03	0.10	**0.58**
	Autumn	0.16	0.02	0.03	0.13	0.03	0.004	0.012	0.02	0.21	**0.61**
IR	Spring	0.08	0.01	0.02	0.11	0.04	0.055	0.052	0.02	0.22	**0.61**
	Autumn	0.04	0.01	0.01	0.06	0.04	0.004	0.134	0.01	0.06	**0.37**
EM	Spring	0.26	0.08	0.05	0.37	0.19	0.036	0.064	0.13	0.43	**1.61**
	Autumn	0.35	0.16	0.06	0.86	0.49	0.004	0.058	0.15	0.61	**2.75**
IL	Spring	0.19	0.02	0.08	0.18	0.05	0.101	0.012	0.05	0.25	**0.93**
	Autumn	0.22	0.03	0.08	0.21	0.05	0.004	0.037	0.07	0.22	**0.93**
TK	Spring	0.11	0.01	0.10	0.31	0.03	0.056	0.012	0.09	0.27	**0.99**
	Autumn	0.04	0.02	0.04	0.31	0.09	0.387	0.012	0.08	0.59	**1.57**
SH	Spring	0.25	0.05	0.11	0.31	0.10	0.025	0.012	0.11	0.77	**1.74**
	Autumn	0.21	0.07	0.08	0.40	0.10	0.004	0.054	0.13	0.94	**1.98**
KB	Spring	0.53	0.11	0.08	1.48	0.53	0.050	0.034	0.49	1.78	**5.09**
	Autumn	0.66	0.16	0.06	2.45	0.52	0.004	0.031	0.77	2.03	**6.68**
TA	Spring	0.13	0.03	0.13	0.23	0.03	0.127	0.012	0.09	0.32	**1.09**
	Autumn	0.16	0.04	0.12	0.37	0.06	0.004	0.040	0.11	0.38	**1.29**
SD	Spring	0.21	0.09	0.07	0.89	0.11	0.073	0.012	0.34	0.65	**2.45**
	Autumn	0.34	0.20	0.08	1.69	0.13	0.004	0.012	0.59	0.31	**3.36**
MPCWHO ***MPCKZ (μg/l)**		**10**	**2,400**	**700**	**30***	**70**	**10**	**20**	**7,000***	**30**	

As can be seen, toxic chemical element concentrations do not exceed the MPCs. At the same time, the increased concentrations of U and Li in the water at individual CPs deserves noting. High Li content was recorded in the water samples collected at the CH, KB, IK, TO and SD control points. The concentration of this element at the KB and CH CPs was almost 2 times higher than the corresponding MPC. The U concentration was registered to exceed the norm by 2.03 times at the KB CP; yet, at the SH CP it was found close to the standard value (0.94).

Fig. 3. below maps out the calculated KHL annuals (for 2020 entirely) as well as shows seasonal means (for spring and autumn of 2020) (the graph in the figure's center).

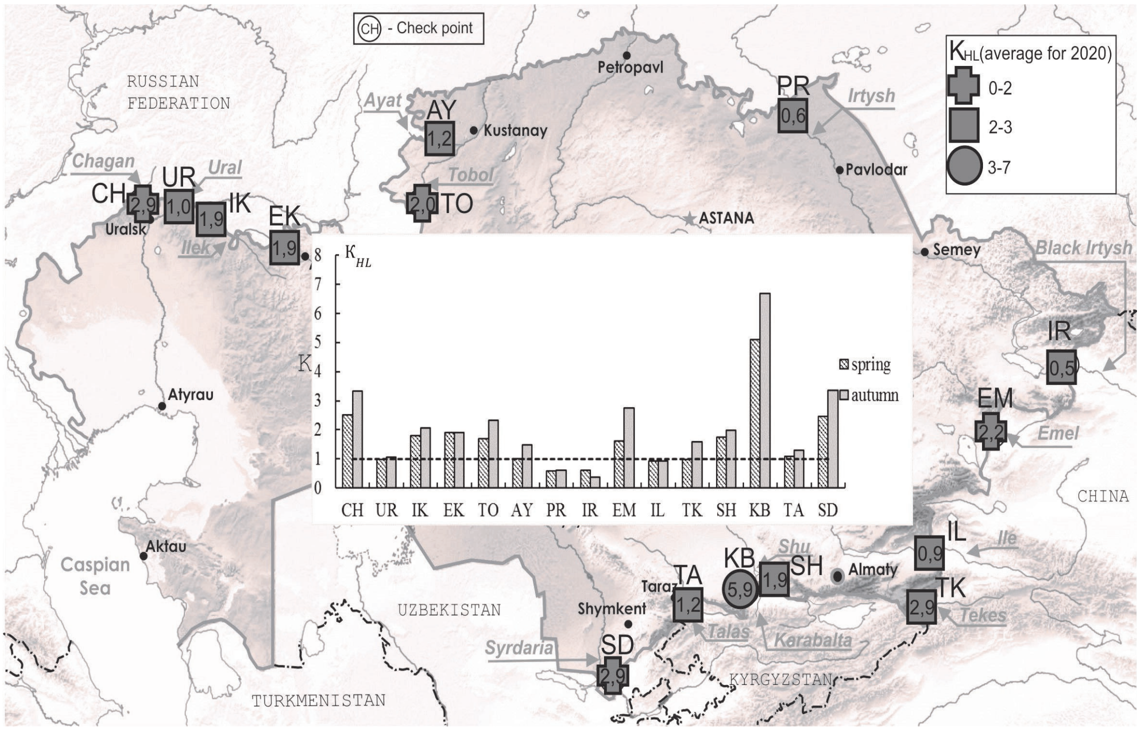

Figure 3. KHL of surface water at target transboundary river CPs in Kazakhstan.

The KHL calculations showed signs of water contamination at almost none of the target CPs (except for the PR, IR and IL) – KHL >1. The highest KHL value (5.9) corresponded to the KB CP.

The results of comparing the calculated KHL means for 2020 with the previous year (2019) and 5-year (2016-2019) means are presented in Fig. 4.

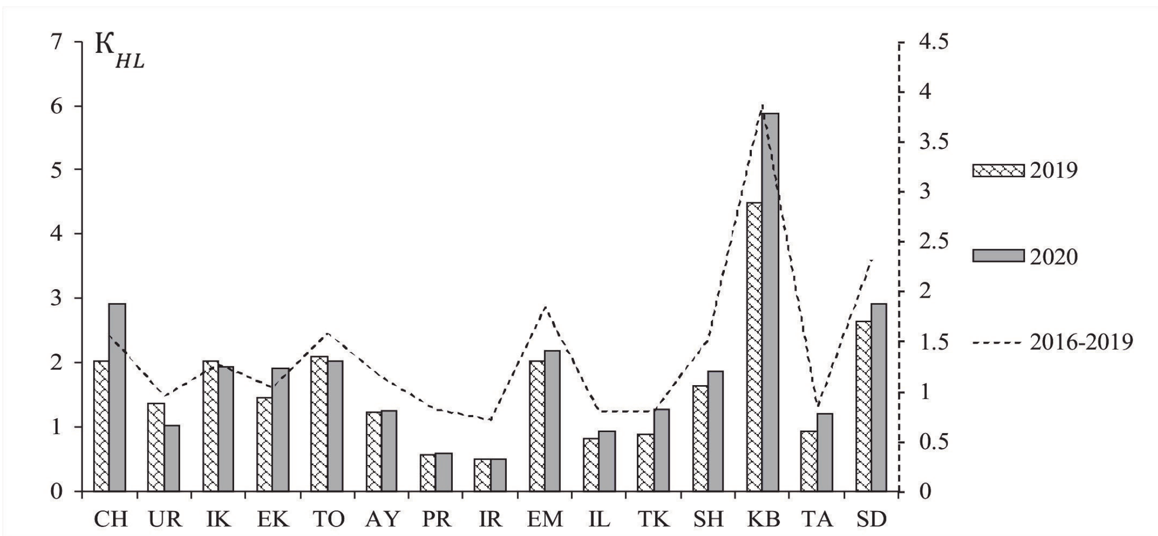

Figure 4. KHL dynamics: 2020 means compared to 2019 and 5-year (2016-2019) means.

As is evident, the results do not point to any inter-annual variability – no significant differences between water toxicity at the target CPs were detected in the course of multiple year monitoring.

4. Discussion

The study allowed obtaining a significant amount of data for discussion and further investigation. The first and main finding of this research effort was the detection of toxic contamination signs (as per the presence of the studied toxic chemical elements in water) in almost all transboundary rivers of Kazakhstan.

The comparison of concentrations for individual toxic elements at target control points along transboundary rivers (Fig. 2.) showed a rather differentiated picture – the content of studied chemical elements in water varied at different CPs, yet, the peaks of increased concentrations of individual elements could be distinguished at each of the target CPs. In particular, the highest frequency of elevated concentrations of individual elements in water compared to other control points corresponded to the Shu (SH), Syr Darya (SD) and Kara-Balta (KB) Rivers. In other cases, increased toxic element concentrations in the water of individual rivers were recorded: Pb in the Tekes River (TK) and Sb at the Yertys-1 (IR) control points. The difference in the Sb content between the two CPs located at the Yertys inflow into and outflow from Kazakhstan (IR and PR) shown in the diagram in Fig. 2. may indicate the presence of a transboundary source of river pollution and further dilution of this element downstream. At the same time, the increasing concentrations of such elements as Ba, Pb, As, Cr, Li, and Sr between these two CPs may indicate their entry into Kazakhstan's territory. The increasing concentration of Cr between the control points along the Ilek River (IK-EK) (Fig. 2.) may likewise point to its inflow into the country.

The revealed differences (Fig. 2.) in toxic element concentrations (spring and autumn, 2020) in the water of the majority of water courses is most likely due to their additional seasonal entry into surface water from irrigated farmland and/or decreased dilution of toxic substances due to annual river flow fluctuations.

Comparing the obtained results with the regional background values (Clarke numbers) (Table 1.) allowed establishing the excessive presence of target toxic elements in water.

In their turn, KHL calculations (Table 2. and Fig. 3.) showed that almost all the studied transboundary rivers demonstrated signs of pollution. According to the mutual presence in water of toxic elements of Hazard Classes 1 and 2, the Kara-Balta (KB) River turned out the most contaminated, with the KHL at the corresponding CP exceeding the permissible norm by 5.9 times (Fig. 3.). The lowest KHL values corresponded to the Yertys (0.5, IR) and (0.6, PR), Ile (0.9, IL). The study revealed that Li and U contributed the most to water pollution of individual rivers – the Shagan (SH), Ilek (IK, EK), Tobol (TO), Syr Darya (SD) and Kara-Balta (RB) water samples showed Li excess. The concentration of this element in the latter water stream was 2 times higher than the MPC (Table 2.). Also, special attention should be paid to the increased concentrations of U in the water of the Kara-Balta (KB) and Shu (SH) Rivers, up to 2 and 0.9 MPC, accordingly.

Comparing the findings of this study with the previous periods (Fig. 4.) pointed to long-term pollution with a potential permanent transboundary contamination source.

The water quality in the Shu (SH), Syr Darya (SD) and Kara-Balta (KB) Rivers in Southern and South-Eastern Kazakhstan deserves particular attention, especially in terms of content of Li and a most toxic element of U. In case of elevated concentrations in water and due to high toxicity, uranium poses a potential threat to the environment and living organisms. Getting into agricultural land with irrigation water, this element (as well as arsenic and molybdenum) easily penetrate into crops and, consequently, into food chains (Malakar et al., 2019b) causing potential human health risks.

The increased content of individual elements in the river water in Southern Kazakhstan is most likely associated with the physical and geographical characteristics of their locations. The Shu (SH) and Kara-Balta (KB) originate in Kyrgyzstan's mountains and flow through sites of geochemical anomalies, as well as through territories hosting various radiation hazard zones. A natural anomaly affecting the water quality in the Shu River's upper and middle reaches is due to the large Shu/Sary-Su Uranium Ore Province and Kamyshanovskoye Deposit inside it on the territory of Kyrgyzstan. Uranium can be washed out by rain and meltwater from the deposit's peat rock and penetrate into the Shu's runoff. Another source may be the wedging of groundwater enriched with uranium and other related elements at the deposit itself. Separate studies (Solodukhin, Djenbayev, et al., 2020) conducted along the Shu River stream flowing adjacent to the Kamyshanovskoye Deposit showed that U, Ca, Ni, Li, Sr, U, Mg, and Cr concentrations in river water in the segment located near the ore deposits exceeded these upstream.

Water contamination in the Shu (SH) River may also occur as a result of pollution of its tributary – a small river of Kichi-Kemin known for a major radiation and environmental disaster in the past. In 1964, a seismic event at the Ak-Tyuz Mine located in the river's upper part (Kyrgyzstan) resulted in the sudden destruction of Tailing Dam No. 2 and subsequent release of about 600 thous. m^3 of waste containing high concentrations of radioactive thorium and other toxic chemical elements into the river. The flow went almost 40 km down reaching the confluence of the Kichi-Kemin and Shu in Kazakhstan. Despite the efforts to clean the river course from the introduced waste, some areas remained untouched, including within certain settlements (Solodukhin et al., 2020).

The contamination of the Kara-Balta (KB) River may be due to the river flowing through the territory of Kyrgyzstan near the Kara-Balta Mining Plant's tailing dump located in the distribution zone of the large Zapadno-Shuisky Groundwater Deposit. It was established that as a result of waterproofing deterioration of the facility's bed, the infiltrate characterized by the high content of sulfates, nitrates, heavy metals and natural radionuclides enters the aquifer (Solodukhin, Lennik, et al., 2020; Torgoyev & Aleshyn, 2003). In the zone bordering Kazakhstan, these ground waters flow into the zone of their shallow occurrence and, as a result of wedging, pollution of rivers and reservoirs (including the Kara-Balta River) with toxic elements and radionuclides contained in the tailing storage may occur.

There are also ecologically stressed areas near the longest river in Central Asia – the Syr Darya (SD). Jointly, the Amu Darya and Syr Darya Basins form a major water resource system in the region, i.e. the Aral Sea Basin. The latter river originates in Kyrgyzstan's highlands and flows through the territory of four riparian states, namely Afghanistan, Uzbekistan, Tajikistan, and Kazakhstan. The Syr Darya Basin is rich in minerals (gold, silver, mercury, antimony and coal). Major industrial (gold mining) centers are operating at the Muruntau Deposit in Uzbekistan and Kumtor in Kyrgyzstan. Uranium mining is also actively carried out in the Syr Darya River Basin, in the distribution zone of the Syr Darya Uranium Province. In the course of exploration, extraction and processing of minerals, the appearance of technologically disturbed territories and auxiliary industrial facilities, such as waste rock dumps, tailing dumps, etc. is inevitable. The anthropogenic activity in the river basin has spawned a complex ecological situation subject to discussion, including at the international level.

According to this study, the transboundary rivers between Russia and Kazakhstan (Ural (Zhaiyk) (UR), Tobol (TO), Ilek (IK, EK), and Ayat (AY)) demonstrate relatively low concentrations of chemical elements, however, the issue of transboundary surface water pollution is also relevant. Attention should be paid to the increased concentrations of Li in the water of the Shagan (CH), Ilek (IK, EK) and Tobol (TO) Rivers, and Cr in the Ilek River. The sources of Cr entering the water of the Ilek River include the Aktobe Ferroalloy Plant and Aktobe Plant of Chromium Compounds in Kazakhstan.

A special situation has been evolving in terms of transboundary water contamination between China and Kazakhstan (Emel (EM), Yertys (IR), and Tekes (TK) Rivers). Separate publications note the complexity of negotiations concerning water allocation and transboundary pollution of water streams flowing into Kazakhstan from China. As a result, it is currently difficult to identify the sources of chemical elements (ex.: Sb) entering these rivers, although the relevance of such studies is obvious. Simultaneously, the monitoring results show that the Yertys (IR) River (Chemagin, 2020) is also exposed to As, Ba, Cr, Zn, Fe, and Ca pollution inside

Kazakhstan, evidenced by the values between two control points – IR (at the river's entry into country) and PR (at its exit to Russia).

Based on the foregoing, contamination sources of Kazakhstan's transboundary rivers can be represented by certain industrial facilities on the territory of neighboring states. The influence of geochemical conditions on river water elemental composition cannot be factored out either. Agriculture may also be a main source of transboundary river pollution (as evidenced by the differences in concentration values for individual elements registered during spring and autumn monitoring missions (Fig. 2 and Table 2.). It is known that application of fertilizers and chemicals leads to accompanying chemicals and toxic elements entering the environment. From soil, pollutants migrate to surface and groundwater, and may facilitate severe consequences like decreased land productivity, crop loss, as well as human health hazards (Bekturganov et al., 2016; Liu et al., 2020; Malakar et al., 2019).

Kazakhstan's authorities should take all of the above facts and information into account to make proper management decisions. Since the challenge of transboundary river pollution is of international nature, interstate negotiations and research to identify pollution sources are practically the only ways to address it. The purpose of such studies should be to detect the sources of chemical elements entering surface waters, assess risks to populations and devise recommendations to reduce the environmental burden. The national Institute of Nuclear Physics is presently conducting the thematic research.

5. Conclusion

The monitoring of Kazakhstan's transboundary rivers (2020) for the content of toxic chemical elements in surface water showed that almost all of them are exposed to transboundary anthropogenic impacts, with Li and U as the greatest contaminants. The Shagan, Ilek, Tobol and Syr Darya Rivers demonstrated excessive Li concentrations. Elevated (up to 0.9 MPC) U concentrations (a most toxic element) were registered in the Shu River. Particularly high Li and U concentrations were detected in the Kara-Balta River. Based on the cumulative presence of toxic elements belonging to Hazard Classes 1 and 2, the rivers of Southern and South-Eastern Kazakhstan – Kara-Balta, Syr Darya and Shu – were found to be the most polluted. The KHL for the Kara-Balta River exceeded the permissible norm by over 5.9 times. The lowest KHL value (<1) corresponded to the Yertys and Ile Rivers. Kazakhstan's sections of the Ilek and Yertys Rivers showed signs of contamination with Cr; and Ba, Pb, As, Cr, Li, Sr, accordingly.

The study revealed no KHL inter-annual variability, meaning that pollution sources are constant. Transboundary river pollution factors may include industrial facilities on the territory of neighboring states, special geochemical conditions, as well as intensive fertilizer-based agricultural production.

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