Twelve-Year Monitoring Results of Radioactive Pollution in the Kazakh Part of the Syrdarya River Basin

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ABSTRACT

Assessment of radioactive pollution of the Syrdarya river was carried out. A large number of water samples were collected over a twelve-year period from three zones: upstream of uranium mines; around uranium mines; and downstream of the mines. Samples were analyzed for gross α-, β-activity and radionuclide concentrations. Gross α-activity exceeded the permissible level in almost every water sample. Both gross α- and β-activity in Baigekum village and PV-1 mine significantly exceeded safe levels throughout entire monitoring period. Concentrations of ^{230}Th and ^{210}Pb surpassed the national intervention levels in almost all water samples. In a number of samples from Baigekum village excessive concentration of ^{226}Ra was observed. Furthermore, water samples collected from Tabakbulak in the spring of 2009 had extremely high levels of radionuclides. In general, elevated levels of radionuclides had been observed around the uranium mines and down the stream of Syrdarya since 2008-2009 when industrial-level production started at Zarechnoye, Khorasan and Irkol uranium deposits. The results suggest that radioactive pollution of Syrdarya in Kazakhstan is primarily caused by uranium mining activities. It is likely that the Syrdarya waters are not only unpalatable for human, but it may also not be suitable for household and agricultural use due to radioactive pollution.

1. INTRODUCTION

Syrdarya is the longest river in Central Asia and its basin spreads across Tajikistan, Kyrgyzstan, Uzbekistan and Kazakhstan. It flows to the northern remnants of the Aral Sea through South Kazakhstan and Kyzylorda regions of Kazakhstan and plays a crucial role for regional economies. Heavy metal contamination of Syrdarya is of greatest emerging concern as contaminations in surface and groundwater exceed World Health Organization (WHO) drinking water guidelines (Kawabata et al., 2008; Friedrich, 2009). It was also determined that the Syrdarya waters could not be used for agriculture and household purposes (Besterekov, 2013). Furthermore, it was identified that health hazards are significantly higher in downstream surface waters in Central Asia (Törnqvist et al., 2011; Bekturganov et al., 2016). Particularly, water contamination caused by uranium mining poses health risks to the population around Syrdarya. The issue of surface water contamination by radionuclides is particularly important given notable cancer incidences and high maternal and child morbidity and mortality in South Kazakhstan and Kyzylorda regions (Igissinov et al., 2011; Zetterström, 1998; Turdybekova et al., 2015).

Currently, Kazakhstan is the world`s top uranium producer, with almost 40% of global production and as a result of a national program to become a world leader, production surged by more than 1000% during 2001-2013 (Kazatomprom, 2018). The share of uranium in total export increased from 1.6% in 2000 till 3.1% in 2012 and it was the 5th largest export commodity (Akhmetov, 2017). Kaztomprom is a national operator of the uranium market in Kazakhstan and it has subsoil use rights on uranium deposits (IAEA, 2016). The race to become the world's top uranium producer led to the environmental pollution (Arnoldy, 2013). Regional offices of the State Committee for Industrial and Mining Safety Supervision and the regional governments overlook adherence to the safety of the uranium mines (Conway, 2013; IAEA, 2016).

However, widespread corruption and rent-seeking undermine the integrity of environmental monitoring process (Conway, 2013).

Uranium mining in Kazakhstan is performed by in-situ leach (ISL), which is believed to be environmentally safe and cost effective method (Kazatomprom, 2018). However, it is known that ISL releases uranium, thorium, radium, radon and their respective progeny (Tweeton and Peterson, 1981; Kasper et al., 1979). The method also alters groundwater, causes spills of dangerous pollutants, contaminates aquifers and creates solid waste from excavations, injection and production wells (Fettus and McKinzie, 2012). Furthermore, surface pollution could be minimal, but underground impacts are significant (Mudd, 1998). ISL is employed in locations with different hydrochemical properties of groundwater. It has different effects on uranium compounds and they are not always advantageous for technological process.

Shu-Syrdarya uranium region, consisting of 15 deposits of commercial interest, has been the most important in Kazakhstan due to significant reserves (Fyodorov, 2000). Total reserves of Syrdarya uranium province consist of around 250 tons of uranium with the depth of uranium ore between 100-800 meters (World Nuclear Association, 2018; Fyodorov, 1997). The deposits are hosted by sandstones and characterized by high concentrations of rare and dispersed elements (Jaireth et al., 2008). It is possible that the ISL process could cause migration of radionuclides to the stem of Syrdarya (Kadyrzhanov et al., 2005).

It was identified that radioactivity levels in ground and wastewaters at the production sites exceed the national standards (Kayukov, 2008). Furthermore, it is likely that the uranium mining may have negative health effects on the nearby population (Bersimbaev and Bulgakova, 2015). Arnoldy (2013) and Conway (2013) suggested that Kazatomprom neglects environmental concerns related to ISL mining and considers investments in safety of operations as unnecessary capital costs and the operator also claims that nature will self-restore itself at the mining sites. Moreover, due to significant costs and low population density around mines, the need for treatment of contaminated waters has been considered unnecessary in the past (Fyodorov, 2000). Nevertheless, population density around Syrdarya is notable (CIESIN, 2016). On top of that, the river is the major source of irrigation in South Kazakhstan and Kyzylorda regions.

The regional economy of South Kazakhstan is primarily based on agriculture. Regional agricultural output contributes to 12% of the national agricultural production (Akhmetov, 2017). Almost 90% of rice in Kazakhstan is grown in Kyzylorda region. Hence, the quality of produced rice depends on pollution level of Syrdarya as the main source of water for rice farming. Moreover, acute and long-term health effects may occur due to water use for household purpose, drinking, boating, swimming, consumption of contaminated fish, etc.

The presence of radionuclides in Central Asian Rivers drew attention of scientists due to the history of radioecological problems in the former USSR. The three-year Navruz project was designed to bring together Kazakh, Uzbek, Tajik and Kyrgyz scientists to perform radioecological monitoring of Syrdarya and Amudarya rivers (Yuldashev et al., 2002; Yuldashev et al., 2005). The analysis of transboundary radionuclide contamination of Syrdarya was based on water samples from 60 monitoring sites (15 in each country) and analyzed for radiation readings, 71 radionuclides and heavy metals (Barber et al., 2005). The project concluded that radionuclide contamination of Syrdarya in Kazakhstan was caused by inflows from Uzbekistan, Keles and Arys river tributaries. Furthermore, the highest radionuclide concentrations were observed near Shieli uranium deposit in Kyzylorda region (Kadyrzhanov et al., 2005; Solodukhin et al., 2004).

Kawabata et al. (2008) investigated surface and drinking water at 21 sites in the Aral-Syrdarya area for uranium concentration during August, 2003. The results indicated that uranium concentration in drinking water samples from two sites with shallow wells exceeded WHO guidelines significantly (WHO, 2011), while the samples from deeper wells showed lower concentration of uranium. It was suggested that phosphate fertilizers and uranium mining were the sources of contamination.

Satybaldiyev et al. (2015) analyzed concentrations of ^{238}U, ^{234}U and ^{226}Ra radionuclides from 12 surface water samples collected along Syrdarya between the cities of Turkestan and Kyzylorda in May, 2013. Although all but one sample indicated uranium concentrations exceeding the WHO guideline level, it was concluded that they were within the level accepted for drinking water. It was also suggested that the uranium mining does not affect the quality of Syrdarya waters.

Unfortunately, after management change at the national operator, independent research organizations were barred from collecting water and soil samples for investigation around active mines. Hence, no radioecological assessment studies after 2015 were carried out.

2. METHODOLOGY

Unlike previous studies, this analysis is based on longer period of sampling (2000-2012). Unfortunately, due to limited research budget, continual sampling could not be achieved and no samples were collected in 2010. The period after 2008-2009 is of particular interest due to commencement of production at Zarechnoye, Khorasan and Irkol uranium deposits. The objectives of this analysis are to assess the radioecological situation of Syrdarya, understand the migration and areas of accumulation of radionuclides. The samples are also analyzed for concentrations of 11 radionuclides. The research compares concentration of radionuclides and α- and β-radioactivity in samples with national norms of radiation safety. Given the national plans of uranium mining expansion, it is particularly important to understand the possible contribution of the existing uranium mines on radioactive pollution of Syradrya.

2.1 Study area

Zoning method in river water sampling is used to identify radionuclide contamination hazard prone areas (Salishev, 1987; Buksa and Myach, 1990). Following the stream of Syrdarya and location of uranium mines, three zones are defined:

1) Upstream of uranium producing mines (Chinaz and Shardara);

2) Near the mines (Tabakbulak, Shaulder, Tomenaryk, Rudoupravlenie-6 (RU-6) and Baigekum);

3) Settlements located after the mines, downstream of Syrdarya (Kyzylorda, Amangeldy and Amanotkel).

A total of 43 surface water samples were collected from Syrdarya at the following 13 sites from south to north-west: Chinaz, Shardara, Tabakbulak, Shaulder, Tomenaryk, Shieli, RU-6, PV-1, PV-2, Baigekum, Kyzylorda, Amangeldy, Amanotkel as seen in Figure 1.

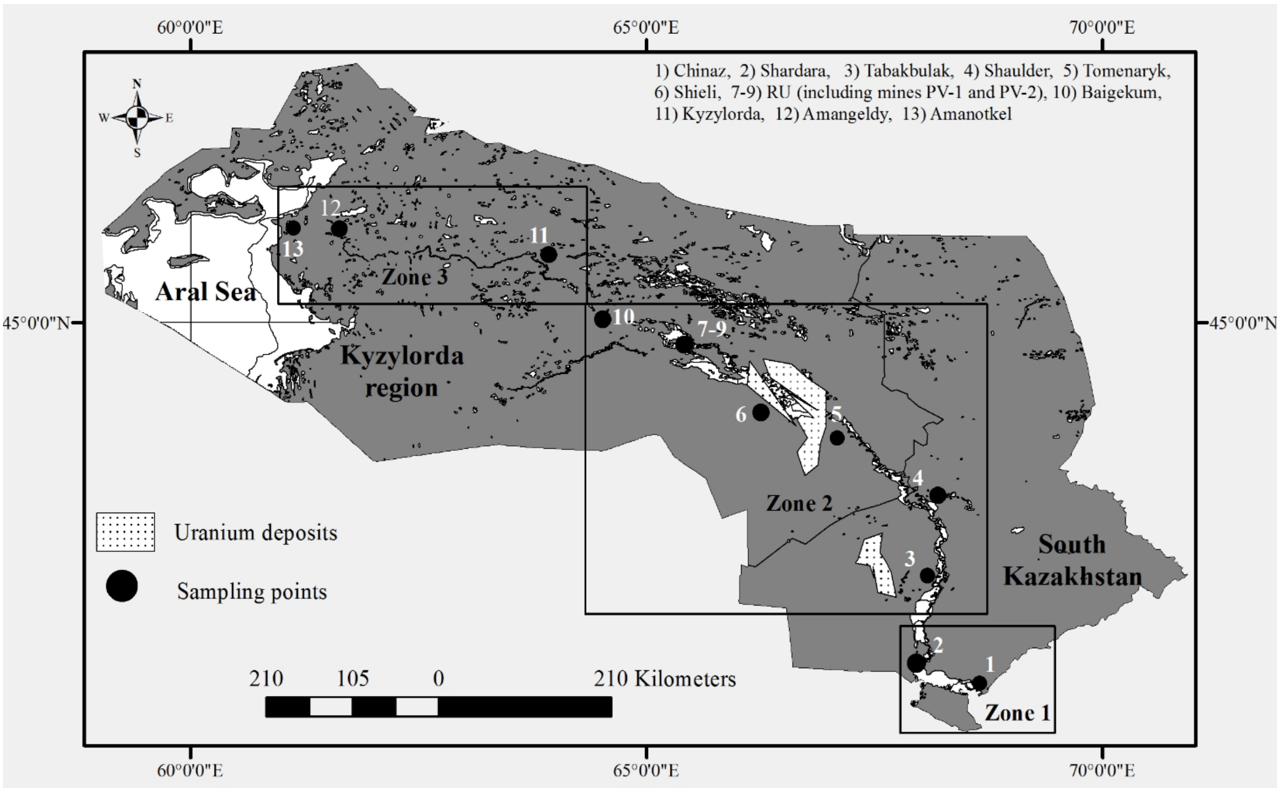

Figure 1. Idealized map of water sampling sites, location of zones and active uranium producing deposits

Chinaz is a town in Tashkent region of Uzbekistan, located on the confluence of Chirchiq and Syrdarya rivers. The reason for selecting this site is to analyze the Syrdarya water quality before the Shardara dam, while the samples from Shardara town in South Kazakhstan region aim to analyze water discharged from the reservoir. Shardara dam was constructed in the 1960s with the primary purpose of irrigation and hydropower production.

There are six main uranium producing deposits in the area. One is located in South Kazakhstan region, while others are in Kyzylorda region (World Nuclear Association, 2018). Zarechnoye uranium deposit is located in Otrar district of South Kazakhstan near Tabakbulak village, west of Syrdarya. Shaulder village is located 50 km east from the deposit on the banks of Syrdarya. Zarechnoye was prepared for industrial production in 1991. However, following the collapse of the USSR it was conserved. Preparation works to restart production started in 2006 and production reached 500 tons of uranium in 2009.

Northern and Southern Khorasan uranium deposits are located in Zhanakorgan district of Kyzylorda region, on the left bank of Syrdarya. Northern Khorasan is the largest uranium deposit in Kazakhstan, where test mining began in 2008 and commercial in 2013 Tomenaryk village is located north-east from this deposit on the banks of Syrdarya.

Irkol and Karamuryn uranium deposits are located in Shieli district of Kyzylorda region. RU-6, located in Shieli village, administers uranium production from Northern and Southern Karamuryn deposits. RU-6 is expected to sustain production of yellow cake at 1,000 tons/year for another 25 years. It is the oldest mine group of the uranium province, where production started in the 1980s, while mining at Irkol commenced in 2008. Baigekum village is located north-west from Shieli.

Kyzylorda city, Amangeldy and Amanotkel villages are located downstream of Syrdarya. Kyzylorda is a capital of Kyzylorda region with population of almost 200,000. Amangeldy and Amanotkel are the villages in Syrdarya district and Aral district respectively. Analysis in this area could help to understand the level of pollution downstream from uranium mines.

2.2 Sampling and analysis

Surface water samples were collected in accordance with the existing river water sampling method in Kazakhstan (VSEGINGEO, 1990). Samples were taken from the surface water layer (0.5-1 meter) of the river. The total volume of one sample comprised 20 liters. The samples were packed in polyethylene bottles and transported for analysis within 1-2 days to the certified laboratory at the Central Experience Methodical Expedition (CEME, 2018), where Total Dissolved Solids (TDS) in milligrams/liter (mg/L), gross α-, β-radioactivity and radionuclide concentrations were measured by UMF-2000 radiometer.

Then, the samples were evaporated to dryness and muffed for 1 hour at 350 ºC. Ethyl alcohol was added into porcelain dish as a solvent, residuals were removed from the walls of the cup and the solution was poured into a cuvette. The mixture was then dried under a lamp until homogeneous layer. An Ortec DSPEC LF spectrometer was used in accordance with the technique of measuring at the γ-spectrometer MI 2143-91 to determine radionuclide concentrations in the sample (VNNIIFTRI, 1991). Analyzed radionuclides are ^{226}Ra, ^{234Th}, ^{235}U, ^{227}Th, ^{223}Ra, ^{228}Th, ^{228}Ra, ^{40}K (Potassium-40), ^{210}Pb, ^{230}Th and ^{137}Cs. Gross α- and β-activity and radionuclide concentrations are compared with radiation safety norms in Kazakhstan presented in Table 1.

Table 1. Kazakh national intervention levels of radionuclides and permissible levels of gross α- and β-activity in water samples (Ministry of National Economy of Kazakhstan, 2015)

	Becquerel/liter (Bq/L)
^{226}Ra (Radium-226)	0.49
^{234}Th (Thorium-234)	40
^{235}U (Uranium-235)	2.9
^{227}Th (Thorium-227)	16
^{223}Ra (Radium-223)	1.4
^{228}Th (Thorium-228)	1.9
^{228}Ra (Radium-228)	0.2
^{210}Pb (Lead-210)	0.11
^{230}Th (Thorium-230)	0.65
^{137}Cs (Caesium-137)	11
Gross α-activity	0.2
Gross β-activity	1.0

3. RESULTS AND DISCUSSION

Results of this analysis indicate that TDS, gross α- and β-activity values are significantly high almost at every site as seen in Table 2. TDS tends to increase during ISL. Data indicates that average TDS is higher in spring and fall than in winter. It is lower upstream of the Shardara dam, increases when water is discharged from the reservoir, significantly higher around the mines and declines downstream. Extremely high values were observed at PV-1 and Tabakbulak in W2007 and S2009.

Overall gross α-radioactivity has declined over the years, but remained higher than the permissible level. Gross α-activity exceeds the permissible level in almost every sample, while gross β-activity exceeds in Baigekum (S2001, F2001, S2002), Kyzylorda (W2003), PV-1 (W2007) and Tabakbulak (S2009). Gross α- and β-activity is significantly high in the Baigekum and PV-1 mines throughout the entire observation period. The sample from Tabakbulak in S2009 exceeds safety norms for gross α- and β-activity 790 and 408 times respectively. Unlike TDS, gross α- and β-radioactivity do not follow seasonal variations. They have declined in Shardara, Tomenaryk, Shieli, RU-6, Baigekum and Kyzylorda, while the values have increased in Tabakbulak and PV-1 during the observation period. Moreover, in Shaulder gross α-activity has declined, while gross β-activity has increased.

Table 2. Gross α- and β-activity measurements (W-winter, S-spring and F-fall; samples exceeding intervention level are highlighted)

Season/year	Sample point	TDS (mg/L)	Gross α-activity (Bq/L)	Gross β-activity (Bq/L)
W2000	Shardara	1422	1.18±0.37	0.76±0.17
S2001	Chinaz	870	0.21±0.13	0.24±0.11
	Shardara	850	1.33±0.29	0.51±0.19
	Baigekum	1200	24.77	3.96
F2001	Baigekum	1600	20.59	3.51
W2002	PV-1	950	0.38	0.33
	RU-6	1740	0.76	0.68
S2002	Baigekum	2090	29.52	8.68
	Tomenaryk	420	1.58	0.52
	Kyzylorda	700	2.30	0.59
W2003	Kyzylorda	960	3.12	1.52
	PV-1	950	0.38	0.33
	RU-6	1740	0.76	0.68
S2003	Amanotkel	840	0.61	0.33
	Kyzylorda	950	0.46	0.33
W2004	PV-1	1950	0.39	0.45
	RU-6	950	0.20	0.54
S2005	Kyzylorda	940	0.17	0.38
	PV-1	1810	0.24	0.26
	PV-2	1770	0.31	0.26
W2006	Baigekum	590	0.08	0.25
S2006	Kyzylorda	910	0.29	0.57
	Tomenaryk	860	0.244	0.39
F2006	Baigekum	1450	0.50	0.57
W2007	RU-6	880	0.24	0.35
	PV-1	5330	1.39	2.11
	Tomenaryk	950	0.22	0.43

Table 2. Gross α- and β-activity measurements (W-winter, S-spring and F-fall; samples exceeding intervention level are highlighted) (cont.)

Season/year	Sample point	TDS (mg/L)	Gross α-activity (Bq/L)	Gross β-activity (Bq/L)
F2008	Baigekum	1910	0.222	0.104
	Shieli	1870	0.319	0.12
	Tabakbulak	2300	0.299	0.154
	Shaulder	2100	0.408	0.123
W2009	Baigekum	1620	0.63	0.249
	Shieli	1150	0.724	0.259
	Tabakbulak	2050	0.41	0.257
	Shaulder	2350	0.26	0.175
S2009	Tabakbulak	5230	158	408.1
	Baigekum	1680	1.69	0.706
	Shieli	2200	0.56	0.169
	Tomenaryk	1950	0.581	0.187
W2011	Shardara	1340	0.55	0.421
	Amangeldy	1069	0.54	0.482
W2012	Baigekum	860	0.47	0.182
	Shieli	1430	0.20	0.074

Radionuclide concentrations in samples are presented in Table 3. It is likely that the main contribution to radioactivity comes from the decay products of ^{238}U, ^{235}U and ^{232}Th. ^{226}Ra, ^{228}Ra ^{210}Pb and ^{234}Th are the decay products of the radionuclides. Decay chains of parent isotopes also contain radon gas and another contributing radionuclide is ^{40}K. Furthermore, ^{226}Ra, ^{234}Th and ^{40}K tend to migrate faster than others.

The results indicate that concentrations of ^{230}Th and ^{210}Pb significantly exceed the national intervention levels in almost all samples. Although ^{235}U concentration from Tabakbulak (S2009) was close to intervention level, concentrations of ^{235}U, ^{228}Th and ^{137}Cs have never exceeded safe levels. The concentration of ^{226}Ra significantly exceeded intervention levels in Baigekum (S2001, S2002, S2009) and Tabakbulak (S2009) by 4.7, 9.1, 1.3 and 108.6 times respectively. The latter sample also had excessive concentrations of ^{234}Th, ^{227}Th, ^{223}Ra, ^{228}Ra, ^{210}Pb and ^{230}Th. Samples from Shardara (W2011), Amangeldy (W2011), Baigekum (W2012) and Shieli (W2011) had excessive concentrations of ^{228}Ra.

In general, water inflows with elevated levels of radioactivity and radionuclide concentrations from Uzbekistan enters Shardara dam, where polluted water is accumulated and later discharged. Discharge of uranium mining effluents occurs further downstream around the mines. Polluted waters are observed downstream from the mines and eventually inflow into the Aral Sea. It should be noted that lack of continuous sampling is a major limitation of this study.

Radioecological monitoring of Syrdarya around uranium mines is currently performed by subsidiaries of the national operator, which undermines the integrity of the process. In the future, outside research organizations should be allowed to collect and analyze water and soil samples to verify independently the results of internal monitoring. Moreover, further research is needed to assess health impacts related to radiological pollution of Syrdarya.

Table 3. Radionuclide concentrations analysis (samples exceeding intervention level are highlighted)

		Radionuclide concentrations, Bq/L										
		^{226}Ra	^{234}Th	^{235}U	^{227}Th	^{223}Ra	^{228}Th	^{228}Ra	^{40}K	^{210}Pb	^{230}Th	^{137}Cs
W2000	Shardara	0.071	0.12	0.01	-	-	<0.008	<0.019	0.18	0.17	-	<0.006
	Chinaz	<0.015	<0.08	<0.008	-	-	<0.01	<0.03	0.19	-	-	<0.08
S2001	Shardara	0.13	<0.06	<0.013	-	-	<0.016	<0.05	0.18	-	-	<0.014
	Baigekum	2.29	1.49	0.014	-	-	<0.028	<0.06	0.18	-	-	0.016
F2001	Baigekum	0.021	-	-	<0.036	<0.02	0.009	0.02	0.26	-	-	<0.007
W2002	PV-1	0.047	-	-	-	-	<0.011	0.031	0.21	-	-	<0.009
	RU-6	0.062	-	-	-	-	<0.033	<0.041	<0.18	-	-	<0.02
S2002	Baigekum	4.47	0.94	0.08	0.09	0.24	0.06	0.012	0.4	1.17	<4.11	<0.031
	Tomenaryk	0.21	<0.05	<0.07	<0.06	<0.05	<0.018	<0.06	<0.23	<0.09	<1.39	<0.014
	Kyzylorda	0.19	0.168	0.016	<0.08	<0.07	0.023	<0.08	<0.20	<0.19	<2.3	<0.02
W2003	Kyzylorda	0.45	-	-	0.074	0.067	<0.032	<0.08	<0.27	-	-	<0.028
	PV-1	0.047	-	-	<0.001	<0.001	<0.011	0.031	0.21	-	-	<0.009
	RU-6	0.062	-	-	<0.002	<0.002	<0.033	<0.041	<0.18	-	-	<0.015
S2003	Amanotkel	<0.008	0.113	-	<0.032	<0.032	<0.01	0.028	0.14	<0.078	<0.83	-
	Kyzylorda	0.021	0.12	-	<0.025	<0.025	<0.008	<0.022	0.17	<0.062	<0.69	<0.006
W2004	PV-1	0.028	0.13	-	<0.047	<0.035	<0.013	0.047	0.14	<0.72	<1.8	<0.009
	RU-6	0.164	<0.09	-	<0.053	<0.04	<0.009	0.041	0.21	<0.81	<2.2	<0.01
S2005	Kyzylorda	<0.015	0.14	0.0083	-	-	<0.0101	<0.036	0.21	<0.058	<0.69	<0.008
	PV-1	<0.014	<0.058	<0.0066	-	-	<0.0071	<0.032	<0.13	<0.06	<0.73	<0.008
	PV-2	<0.014	0.065	0.0063	-	-	<0.0095	<0.024	<0.15	<0.061	<0.75	<0.008
W2006	Baigekum	0.011	0.057	<0.0085	-	-	0.013	<0.034	<0.13	<0.05	<0.58	0.008
S2006	Kyzylorda	0.019	0.109	<0.009	-	-	0.043	<0.049	0.2	<0.055	<0.87	<0.011
	Tomenaryk	0.024	0.072	0.0076	-	-	0.01	<0.049	<0.21	<0.062	<0.78	<0.013
F2006	Baigekum	<0.034	<0.14	<0.0121	-	-	<0.0265	<0.085	<0.37	<0.161	<1.7	<0.022
W2007	RU-6	0.017	0.122	0.0079	-	-	<0.0061	<0.024	<0.1	<0.038	<0.43	<0.006
	PV-1	0.062	0.191	<0.021	-	-	0.0279	<0.132	1.22	<0.228	<2.55	<0.034
	Tomenaryk	0.013	0.158	0.0013	-	-	0.009	<0.021	<0.09	<0.035	<0.39	<0.005
F2008	Baigekum	<0.06	0.17	<0.017	-	-	<0.03	<0.12	<6.0	<0.27	<2.2	<0.45
	Shieli	<0.05	0.16	0.016	-	-	<0.029	<0.11	<6.0	<0.26	<2.1	<0.4
	Tabakbulak	0.078	0.12	<0.015	-	-	<0.035	<0.13	<6.0	<0.23	<2.3	<0.4
	Shaulder	0.036	0.23	0.017	-	-	<0.023	<0.12	<5.0	<0.23	<2.3	<0.45

Table 3. Radionuclide concentrations analysis (samples exceeding intervention level are highlighted) (cont.)

		Radionuclide concentrations, Bq/L										
		^{226}Ra	^{234}Th	^{235}U	^{227}Th	^{223}Ra	^{228}Th	^{228}Ra	^{40}K	^{210}Pb	^{230}Th	^{137}Cs
W2009	Baigekum	0.039	0.25	0.0184	-	-	0.033	<0.06	<6.0	<0.14	<1.2	<0.45
	Shieli	0.05	0.23	0.019	-	-	0.021	<0.11	<6.0	<0.25	<2.1	<0.45
	Tabakbulak	0.046	0.18	<0.019	-	-	<0.024	<0.11	<6.0	<0.27	<2.3	<0.4
	Shaulder	0.054	<0.12	<0.018	-	-	<0.035	<0.11	<6.0	<0.18	<2.0	<0.45
S2009	Tabakbulak	53.2	67.9	1.19	30.6	25.3	0.93	<2.6	<7.0	124.0	372	<0.6
	Baigekum	0.638	0.27	<0.026	<0.12	<0.11	0.033	<0.12	<6.0	<0.29	<2.5	<0.4
	Shieli	0.045	0.26	0.015	<0.11	<0.1	0.033	<0.11	<6.0	<0.23	<2.2	<0.4
	Tomenaryk	<0.05	0.17	0.015	<0.11	<0.1	0.031	<0.11	<6.0	<0.26	<2.1	<0.4
W2011	Shardara	0.12	0.26	<0.04	<0.07	<0.022	-	<0.25	<6.0	<0.5	<4.0	<0.4
	Amangeldy	<0.10	0.25	<0.04	<0.06	<0.024	-	<0.24	<6.0	<0.5	<4.5	<0.4
W2012	Baigekum	<0.06	0.23	<0.023	<0.16	<0.16	<0.045	<0.25	<3.0	<0.4	<3.5	<0.19
	Shieli	0.07	0.25	<0.024	<0.06	<0.16	<0.06	<0.24	<4.0	<0.4	<3.5	<0.3

4. CONCLUSIONS

The uranium industry has become an important source of income for the resource-export oriented Kazakh economy. Expansion of production likely leads to radioactive pollution of Syrdarya. The results of this study indicate that both inflow and outflow water samples from Shardara dam contain elevated levels of radioactivity. However, it is likely that most radioactive water pollution of the Kazakh part of the Syrdarya river basin occurs around active uranium mines.

This twelve-year monitoring of Syrdarya indicates that gross α-activity exceeds permissible level in almost every water sample throughout the entire observation period. Gross β-activity is higher around the Karamuryn uranium deposit, while commencement of production at Zarechnoye likely caused extremely high gross α-, β-activity and radionuclide concentrations in water sample from Tabakbulak in 2009. In general, it is most likely that elevated levels of radionuclide concentrations in samples from sites around mines and downstream of the river in 2008-2009 and onwards are caused by expansion of uranium production.

Based on WHO drinking water guidelines (WHO, 2011), it could be said that water from Syradarya is unpalatable due to excessive TDS and dangerous radionuclide concentrations. Likewise, it is possible that the river water is not suitable for household and agriculture use. There is growing evidence that uranium production in the region causes radioactive pollution of Syrdarya. Hence, there is an urgent need to thoroughly assess the safety and environmental effects of ISL technology in Kazakhstan.

REFERENCES

Akhmetov A. Testing the presence of the Dutch disease in Kazakhstan. Munich Personal RePEc Archive (MPRA) Paper 77936; 2017.

All-Russian Research Institution of Physicotechnical and Radiotechnical Measurements (VNIIFTRI). Measurement procedure on gamma spectrometer. Moscow, USSR: VNNIIFTRI; 1991. (in Russian)

All-Union Research Institution of Hydrogeology and Geological Engineering (VSEGINGEO). Methodological recommendations on sampling, processing and storage of groundwater. Moscow, USSR: MinGeo USSR; 1990. (in Russian)

Arnoldy B. The cost of being the world's No. 1 uranium producer. The Christian Science Monitor [Internet]. 2013 [cited 2018 Apr]. Available from: https://www.csmonitor.com/World/Asia-South-Central/2013/0828/The-cost-of-being-the-world-s-No.1-uranium-producer.

Barber DS, Betsil JD, Mohagheghi AH, Passel HD, Yuldashev B, Salikhbaev U, Djuraev A, Vasiliev I, Solodukhin V. The Navruz experiment: cooperative monitoring for radionuclides and metals in Central Asia transboundary rivers. Journal of Radioanalytical and Nuclear Chemistry 2005;263(1):213-8.

Bekturganov Z, Tussupova K, Berndtsson R, Sharapatova N, Aryngazin K, Zhanasova M. Water related health problems in Central Asia: a review. Water 2016; 8(6):1-13.

Bersimbaev RI, Bulgakova O. The health effects of radon and uranium on the population of Kazakhstan. Genes and Environment 2015;37(18):1-10.

Besterekov U. Transboundary water pollution of the Syrdarya river by heavy metals. Proceedings of the Conference Dedicated to 70th Anniversary of South Kazakhstan State University named after M. Auezov; 2013 Oct 25-26; South Kazakhstan State University named after M. Auezov, Shymkent: Kazakhstan; 2013:190-5. (in Russian)

Buksa II, Myach, LT. Assessment of modern and future state of the environment. Moscow, USSR: Hydrometeoizdat; 1990. (in Russian)

Central Experience Methodical Expedition (CEME). Chemicoanalytical expedition [Internet]. 2018 [cited 2018 Apr]. Available from: http://www.come.kz/page/part/19. (in Russian)

Center for International Earth Science Information Network (CIESIN). Documentation for the Gridded Population of the World. Version 4 (GWP v4). Palisades, NY, USA: NASA-Socioeconomic Data and Applications Center; 2016.

Conway JE. The risk is in the relationship (not the country): political risk management in the uranium industry in Kazakhstan. Energy Policy 2013;56:201-9.

Fettus GH, McKinzie MG. Nuclear fuel's dirty beginnings: environmental damage and public health risks from uranium mining in the American West; Mar 2012; Natural Resources Defense Council; 2012.

Friedrich J. Uranium contamination of the Aral sea. Journal of Marine Systems 2009:76:322-35.

Fyodorov GV. Industrial types of uranium deposits in Kazakhstan. Proceeding of the IAEA-OECD Technical Committee Meeting on Assessment of Uranium Deposit Types and Resources - A Worldwide Perspective; 1997 Jun 10-13; IAEA-OECD, Vienna: Austria; 1997:77-83.

Fyodorov GV. Uranium production and the environment in Kazakhstan. Proceeding of the International Symposium on the Uranium Production Cycle and the Environment; 2000 Oct 2-6; IAEA-OECD, Vienna: Austria; 2000:191-8.

International Atomic Energy Agency (IAEA). In situ leach uranium mining: an overview of operations. Vienna, Austria: IAEA; 2016.

Igissinov N, Igissinov S, Moore MA, Shaidarov M, Tereshkevich D, Bilyalova Z, Igissinova G, Nuralina I, Kozhakhmetov S. Trends of prevalent cancer incidences in the Aral-Syr Darya ecological area of Kazakhstan. Asian Pacific Journal of Cancer Prevention 2011;12(9):2299-303.

Jaireth S, McKay A, Lambert I. Association of large sandstone uranium deposits with hydrocarbons: the geology of uranium deposits in Kazakhstan points to similar deposits in Australia. Australian Government Geoscience Australia 2008;89:1-6.

Kadyrzhanov KK, Barber DS, Solodukhin VP, Poznyak VL, Kazachevskiy IV, Knyazev BB, Lukashenko SN, Khazhekber S, Betsill JD, Passell HD. Radionuclide contamination in the Syrdarya river basin of Kazakhstan: results of the Navruz project. Journal of Radioanalytical and Nuclear Chemistry 2005; 263(1):197-205.

Kasper DR, Martin HW, Munsey LD, Bhappu RB, Chase CK. Environmental Assessment of In Situ Mining; Dec 1979; United States Department of the Interior Bureau of Mines; Open File Report 101-80;1979.

Kawabata Y, Aparin V, Nagai M, Yamamoto M, Shiraishi K, Katayama Y. Uranium and thorium isotopes from Kazakhstan. Journal of Radioanalytical and Nuclear Chemistry 2008;278(2):459-62.

Kayukov PG. Ecological considerations related to uranium exploration and production. In: Salbu B, Skipperud L, editors. Nuclear Risks in Central Asia. Dordrecht, Netherlands: Springer; 2008. p. 219-23.

Kazatomprom. National Atomic Company of the Republic of Kazakhstan [Internet]. 2018 [cited 2018 Apr]. Available from: http://www.kazatomprom.kz/en

Ministry of National Economy of Kazakhstan. Sanitary-epidemiological requirements for radiation safety assurance; 2015 Feb 27; Decree 155; 2015. (in Russian)

Mudd G. An environmental critique of in situ leach mining: the case against uranium solution mining; Jul 1998; A Research Report for Friends of the Earth (Fitzroy) with the Australian Conservation Foundation; 1998.

Salishev KA. Development of maps. Moscow, USSR: MGU; 1987. (in Russian)

Satybaldiyev B, Tuovinen H, Uralbekov B, Lehto J, Burkitbayev M. Heavy metals and natural radionuclides in the water of Syr Darya River, Kazakhstan. In: Merkel B, Arab A, editors. Uranium - Past and Future Challenges. Proceedings of the 7th International Conference on Uranium Mining and Hydrogeology. Cham, Germany: Springer; 2015. p. 155-60.

Solodukhin VP, Poznyak VL, Kazachevskiy IV, Knyazev BB, Lukashenko SN, Khazhekber S. Some peculiarities of the contamination with radionuclides and toxic elements of the Syrdarya river basin, Kazakhstan. Journal of Radioanalytical and Nuclear Chemistry 2004;259(2):245-50.

Törnqvist R, Jarsjö J, Karimov B. Health risks from large-scale water pollution: trends in Central Asia. Environment International 2011;37(2):435-42.

Turdybekova YG, Dosmagambetova RS, Zhanabayeva SU, Bublik GV, Kubayev AB, Ibraibekov ZG, Kopobayeva IL, Kultanov BZ. The health status of the reproductive system in women living in the Aral Sea region. Open Access Macedonian Journal of Medical Sciences 2015:3(3):474-7.

Tweeton DR, Peterson KA. Selection of lixiviants for in situ leach mining. In Situ Mining Research. Information Circular 8852. Bureau of Mines Technology Seminar; 1981 Aug 5; United States Department of the Interior, Bureau of Mines, Denver: USA; 1981.

World Health Organization (WHO). Guidelines for drinking-water quality, 4th edition. Geneva, Switzerland: WHO; 2011.

World Nuclear Association. Uranium and nuclear power in Kazakhstan (Updated February 2018) [Internet]. 2018 [cited 2018 Apr]. Available from: http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/kazakhstan.aspx

Yuldashev B, Salikhbaev U, Radyuk R, Djuraev A, Djuraev A, Vasiliev I, Tolongutov B, Alekhina V, Solodukhin V, Pozniak V, Littlefield AC. The Navruz project: Monitoring for radionuclides and metals in Central Asia transboundary rivers. End of year one reports, 2002 Sep. New Mexico, USA: Sandia National Laboratories; 2002.

Yuldashev BS, Salikhbaev US, Kist AA, Radyuk RI, Barber DS, Passell HD, Betsill JD, Matthews R, Vdovina ED, Zhuk LI, Solodukhin VP, Poznyak VL, Vasiliev IA, Alekhina VM, Djuraev AA. Radioecological monitoring of transboundary rivers of the Central Asian region. Journal of Radioanalytical and Nuclear Chemistry 2005;263(1):219-28.

Zetterström R. Food pollutants and child health with special reference to the situation in the Aral Sea region in Kazakhstan. Näringsforskning 1998;42(1):130-5.