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Issyk-Kul Lake, Kyrgyzstan

Broder Merkel (Editor)

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Content

1. Investigation of the natural uranium content in the Issyk-Kul Lake, Kyrgyzstan

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1.1. Abstract

Work presented is related to investigations of the Issyk-Kul Lake that is located in the northern part of Kyrgyzstan. Issyk-Kul Lake is a mountainous, moderate salty terminal lake which contains an anomalous concentration of natural uranium. According to hydrochemical analyses the concentration of natural uranium is in the range of 62 to 65 µg/l. Aim of this study was to propose a hypothesis for the reason of the anomalous natural uranium occurrence in the Issyk-Kul Lake by means of investigating hydrogeochemical properties of the lake, rivers and sediments surrounding the Issyk-Kul Lake. All information including those who are published in Russian language and in particular about geological dating of the Issyk-Kul basin was reviewed. Moreover, hydrological modeling for the catchment of the Issyk-Kul water basin was done in order to calculate surface runoff of the main rivers which are feeding the Issyk-Kul Lake. This allows calculating an approximate accumulation of natural uranium in the lake over years. The today´s accumulation of uranium concentration in the lake is reached after about 350 years based on certain assumptions. However, the concentration of natural uranium in the groundwater around Issyk-Kul Lake is not investigated so far. Thus, there is a need to perform further investigation of the discharge to the lake and their hydrogeochemistry as well.

Keywords: Issyk-Kul Lake, uranium content, hydrgeoochemistry, surface runoff, accumulation, assumption

1.2. Introduction

The Issyk-Kul Basin is the most protuberant intermountain basin in the modern Kyrgyz Tien Shan orogeny (De Grave et al., 2012). Issyk-Kul Lake is located in the northern part of the Tien-Shan Mountains of the Kyrgyz Republic, Central Asia, and is one of the deepest and largest mountain lakes in the world. In recent decades of the 20th century, the Issyk-Kul Lake drew more consideration due to continuous water level decrease and contamination as well as human activity such as recreational facilities, constructions, irrigational land use and cattle breeding (Karmanchuk, 1999). However, the rather high uranium concentration is another aspect to be investigated. Considering the fact that the Issyk-Kul lake has an approximate volume of 1,730 km^3 (Romanovsky, 1990) and an uranium content of 62 ppb, the total amount of uranium in the lake water is about $1.08 \cdot 10^8$ kg (Gavshin et al, 2004). In comparison the range of the uranium in modern ocean water is small varying from about 0.1 to 5.9 µg/L (Koczy, Tomic, and Hecht, 1957). In previous studies only facts about concentrations of natural uranium in the Issyk-Kul Lake are represented while attempts to suggest reasons of the anomalous concentration of uranium in the Issyk-Kul Lake are missing so far. This paper is thus is the first attempt to advance such kind of hypothesis. Moreover, the objectives were to study the distribution of uranium along the surroundings of the Issyk-Kul Lake and in the sub-water basins. As well background and anomalous natural radioactivity of some lake shore points are examined: The lake itself, spring water as well as the determination of uranium content of the sediments and soils around the Issyk-Kul lake are addressed.

A GIS based hydrological model for the Issyk-Kul water basin was developed to calculate the surface runoff of the main rivers surrounding the Issyk-Kul Lake. This is necessary for a further calculation of the natural uranium concentration in the Issyk-Kul Lake. For the development of a hydrological model a MapWindow SWAT (Soil Water Assessment Tool) plugin was used. MapWindow is lightweight open source desktop GIS which can easily be run even in small and portable notebooks. MapWindow does not require much computational power and processing is much faster than ESRI ArcGIS. Its popularity is growing and some agencies already accept its benefits. For example, the United States Environmental Protection Agency (US EPA) decided to use it as the GIS platform for its Better Assessment Science Integrating point and Nonpoint Sources (BASINS) which is a multipurpose environmental analysis system (MapWindow, 2011).

1.2.1. Historical description of the study area

At present, the water level of the Issyk-Kul Lake is 1,606 masl. The catchment area is surrounded by high mountain ridges of 4,000-5,200 masl on both the northern and the southern side. The terminal lake is supplied by a discharge of about 48·109 m^3 annually from 834 glaciers on the alpine slopes of the basin (Revyakin and Edelstein, 1990). Based on the bathymetric map made by (Kodyaev, 1973) in 1968 it features a lengths of 178 km, a width of 60.1 km, a coast line of 688 km, an average depth of 278.4 m, a maximum depth of 668 m, a water surface area of 6,236 km^2 and a volume of water of 1,738 km^3. The maximum depth of Issyk-Kul Lake is 109 m deeper than the maximum depth of the Baltic Sea and 328 m deeper than that of the White Sea. The average depth of Issyk-Kul Lake is three times deeper than the average depth of the Baltic Sea. Geographical coordinates of the location of the Issyk-Kul region, Kyrgyzstan, are 42^{o}30-43^{o}20 N, 76^{o}10-78^{o}20 E. Its maximum level was 1,680 masl (Trofimov, 1990). However, these are absolute numbers not considering that tectonically up-and down-lift may have a certain impact as well. This aspect is not considered in detail as well in the following.

The highest possible today lake level, before water would flow through the Boom Gorge to the northwest towards the Chu valley is 1,620 masl (Figure 1.1).

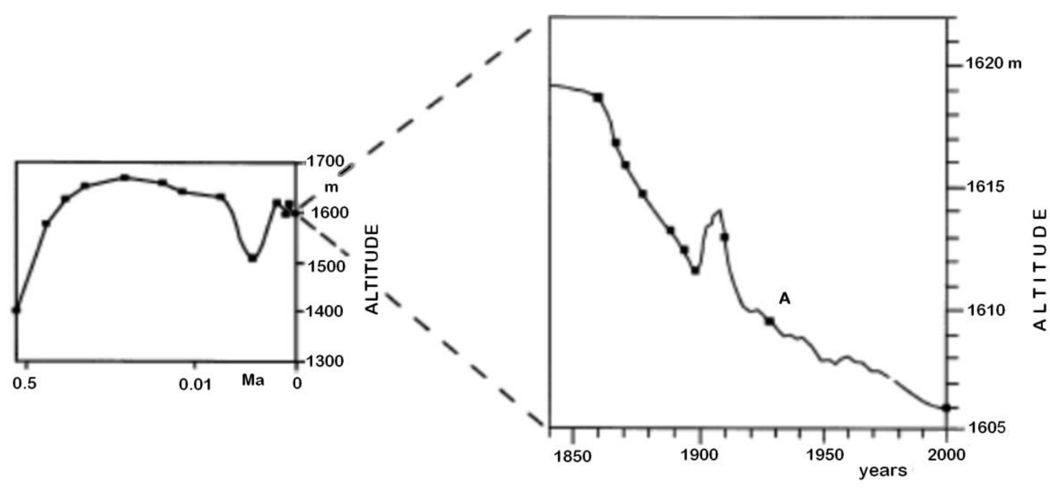

Figure 1.1 *The Issyk-Kul lake level fluctuations from Mid-Pleistocene and for the period 1860–2000 in detail, (Trofimov, 1975). The period 1860–1910 is based on reports of various researches and on cartographic sources. From A onward, there was regular monitoring. The*

period 1975–2000 had been linearly reconstructed to the recent 1,606 masl lake level

During the Holocene, the water level of Issyk-Kul Lake dropped to 110 m below the present level, as indicated by underwater shore terraces, submerged canyons, a network of river channels and submerged human settlements (Bondarev, 1983). Subsequently, in the first half of the 19^{th} century, the lake level rose to 1,622 masl. Since then the lake level has gradually dropped towards its current 1,606 masl level. The fluctuations of the lake level are related to climatic changes superimposed upon tectonic movements (Grigina and Fortuna, 1981). In this period (AD 1681 - 1833) the lake reached its maximum primary productivity, which is reflected by pigments but also by the total organic content. Moreover, the water level rose, reaching its highest level at the beginning of the 19^{th} century, mainly because of the higher values of the regional moisture (maximum values of the moisture climate index and the increase of monohydrocalcite percentages). Historical data also demonstrate the existence of this lake level maximum (Romanovsky, 2002). The grazing activities were maximal. In fact, the incidence of wildfires seems to decrease favoring forest regeneration.

1.2.2. Catchment basin

The Issyk-Kul is situated in an arid-zone: From west to east, desert is followed by semi-desert and then steppe. Xerophytes dominate except where more water is available. Mesophytic or wetland vegetation occurs as well (Sevastyanov and Smirnova, 1986).The catchment basin is a tectonic depression surrounded by mountain ranges. These largely determine processes within the basin. In the south the Terskey Ala-Too Range is located where the rivers Karakol and Djety-Oguz originate. The range reaches 5,200 masl but drops to 3,500 m in the west and 4,500 m in the east. The Kungey Ala-Too Range where the Chok-Tal River rises is situated in the north of the catchment basin and reaches 4,770 masl that drops by 300 m in the west and east. The Issyk-Kul basin opens westwards through the narrow Boom canyon, and eastwards through the mountain pass of Santash. In the west, the Chu River, formerly connected to the Issyk-Kul Lake, is now separated by dry land. The Chu River was connected through the Balykchy channel for some 25 years at the beginning of the 19^{th} century. The area of Issyk-Kul basin covers 22,080 km^2 with an elongated east-west extension of 252 km and a north-south length of 146 km. The lake area is 6,236 km^2 and the area of piedmont plain is 3,092 km^2. The rest of the basin is 12,752 km^2 that is occupied by mountains which form the area of river flow (Romanovsky, 1990). The area of the catchment basin is only 2.5 times larger than the Issyk-Kul Lake.

1.2.3. Main rivers feeding Issyk-Kul Lake

Formerly, 102 streams and rivers reached the lake, but 29 have discharges <1 m^3/s. Several are now diverted for irrigation. The total annual river runoff into the lake is 3.72 km^3 (Zabirov and Korotaev, 1978). For the period 1946-1965, (Kaplinsky and Timchenko, 1977) gave the following water budget: surface water discharge 40.9 m^3/s; precipitation 56.7 m^3/s; groundwater discharge 64.8 m^3/s; evaporation from lake 161 m^3/s. In 1979 according to the calculation of Romanovsky the average evaporation of the Issyk-Kul Lake was 154.7 m^3/s (Romanovsky et al, 2004), i.e. in comparison for the period 1946 - 1965 the evaporation slightly decreased in 1979. The reason that 2.06 km^3/yr discharges to the lake as groundwater is that many streams seep into the alluvial ground and disappear before they reach the lake. Rivers are fed predominantly by melt water from glaciers and snow above 3,300 masl. There are 834 glaciers, with an area of 650.4 km^2 and a volume of 48 km^3 (more than 15 times the annual runoff into the lake) (Zabirov, 1978). All the larger rivers of the basin, including the two largest, the Dzhergalan and Tuip, arise from glaciers and are fed by glacial and snow melt water. Patterns of precipitation and glacial cover determine the extent to which different regions of the basin contribute water to the lake. In this context, the basin can be divided into three regions: western, northern and eastern.

The western region, ending eastwards at Choktal on the northern shore of the lake and Tossor on the southern shore, is bordered to the north by the Kungey Ala-Too Range with very few glaciers. Only a small number of rivers drain it; they have low discharges, and in summer most or all of their water is diverted for irrigation or seeps underground. Southern rivers (Ulakhol, Aksai, Akterek, Ton) have more water as they are fed by melt water from the Terskey Ala-Too Range. This range has 80 per cent of all glaciers in the basin, and it also has a relatively high precipitation with 800-900 mm/yr (Sevastyanov and Smirnova, 1986). Only part of the water in rivers from the Terskey Ala-Too is used for agriculture and wetlands along the rivers are common. The second, northern region extends between the Choktal and Shaty rivers in the north. It is characterized by higher precipitation and more rivers. Most water is used for irrigation and only the Chon-Aksu and Kichi-Aksu rivers reach the lake throughout the year. The region is rich in groundwater and groundwater level rises to the surface along the shores of the lake. The third, eastern region extends around the eastern shores between the River Shaty in the north and River Tossor in the south. There are several rivers with relatively high discharges: Dzhergalan, Tuip, Aksu, Arasan, Karakol, Irdyk, Dzety-Oguz, Dzhuuku and Chon Kyzylsu. These are fed by glaciers and permanent snows. The rivers have the highest discharges in April-August, the lowest in December-February (Kaplinsky and Timchenko, 1977). The total surface water discharge from all rivers entering Dzhergalan Bay is 28.4 m^3/s. The Dzhergalan and Tuip rivers contribute more than half of the total surface discharge into the lake, about 70 m^3/s (Romanovsky, 1990).

The River Chu flowed into the lake without hindrance until 1,200 years ago (Savvaitova and Petr, 1992). After that, it was connected only for certain times through the Kutemaldy Channel. Thus, the recent drop in level (over the last century) cannot be related to the loss of the inflow from the River Chu (Romanovsky, 1990). The same appears to be true for climatic events. Although less precipitation has fallen, a warmer climate led to increased runoff as a result of the higher melting rate of glaciers. It is the uptake of water for irrigation in the lower courses of rivers and streams that seems to be the major factor responsible for recent (last decades) and currently declining water-levels. Of 118 rivers and streams in the basin, only 30 now reach the lake throughout the year, and almost all of them have higher discharge rates when entering the plains that when entering the lake (Table 1.1). Thus, it is river diversions for irrigation which are mainly responsible for these losses. The uptake of water from inflowing rivers for irrigated agriculture is one of the major reasons for the gradual decline in the lake water-level (Savvaitova and Petr., 1992).

There are about 20 different calculations of the water balance for the Issyk-Kul Lake, proposed by different authors. Atmospheric precipitations on the surface of the lake vary in the range from 230 to 350 mm/y. According to various authors the surface runoff varies from 184 to 567 mm/y. Changing of groundwater inflow range varies from 241 to 330 mm/y. Evaporation from the surface of the lake in the water balance varies from 700 to 878 mm/y (Romanovsky et al, 2004).

Table 1.1 *Water uptake for irrigation (Romanovksy, 1990).*

	Discharge (m^3/s) upstream of irrigation uptake	**Discharge (m^3/s) into the lake**
Karakol	6.6	3.7
Djuuka	6.3	2.7
Djeti-Oguz	5.6	2.5
Chon-Aksu	5.1	0.8
Chon-Kyzylsu	4.7	1.4
Chon-Sai-Ton	5.9	4.0
Ak-Terek	4.5	2.3
Turasu	3.1	0.3
Aksu	2.9	0.5

1.2.4. Geological setting

Issyk-Kul Lake was filled for the first time with water when an isolated intermountain depression was formed by intensive tectonic movements in the early Miocene period. The Issyk-Kul Lake in Pliocene age was containing fresh water and was larger than the present lake. With respect to geology, outcrops which are giving rise to the Cenozoic sediments of the Issyk-Kul region are located in the peripheral parts of the basin and are mainly composed of alluvial-proluvial facies. Lakeside sedimentation occurred in most parts along the depression, in particular, the sedimentation on the peninsula of Suhoi ridge in the axial part of the basin. In the Suhoi ridge the Cenozoic sediments overlie limestones and shales of indigenous carbon, where 3,890 m of sediments have accumulated including 3,000 m of lake faces. Historically, there is no generally accepted point of view about the age of the Issyk-Kul Lake. Information about stages of the ancient lake sediment is limited. According to (Voskresenskaya, 1983) the Issyk-Kul intermountain basin has been occupied by lakes since the early Neogene. According to that study and its 3,000 m thick lake deposits the Issyk-Kul Lake was born 20 million years ago in the Early Miocene, when an isolated intermountain depression was formed by intensive tectonic movements and filled with water. According to (Trofimov, 1990) the present lake exists since the Mid-Pleistocene, about 700,000 years ago. The study of sediment in wells made it possible to confirm the ancient origin of the lake, to characterize the main stages of sedimentation, and to trace the evolution of the lake basin in the Cenozoic epoch. Proven with certainty by lacustrine sediments of the Sogutinsk-Dzhuukinsk suites (thickness of respectively 1,100 m and 775 m), a large and deep Issyk-Kul lake depression existed during most of the Miocene and the Pliocene period. The fine structure of sediments, dominated by silts, silty and marly clay of hydromorphic greenish-gray color, and the abundance of authigenic iron sulfides reflect the formation of precipitation during slow terrigenous erosion from the land in a broad and deep body of water.

Relief of Issyk-Kul region has a distinct geologic stage character. The geologic stage of modern and ancient glacial-nival mountain terrain in the watershed ranges at elevations of 3,250-3,000 masl and covers parts of folded Paleozoic rocks. These rocks replaced the geologic stage of erosion-denudation of the mountain relief without traces of ancient glaciation. The stage of erosion and the denudation-accumulative relief is confined to the foothills below the altitude of 2,500-2,600 masl and tends to unconsolidated zone of Paleogene-Neogene rocks by which "bad lands" were formed during erosion of the relief. The geologic stage of accumulative relief of the basin bottom is located at elevations of 1,900-2,100 m till the edge of the lake which is formed by alluvial fans and cones of proluvial lacustrine terraces, i.e. the geologic stage thickness were within elevations of 1,620 m in Holocene, Late Pleistocene (1,640 m) and Middle Pleistocene (1,660-1,680 m). They were formed during repeated transgressions and regressions of the lake (Aleshinskaya et al., 1969).

The size of the hydrogeological system of the Issyk-Kul water basin refers to its significant elements. Its linear boundaries coincide with the watershed of surface and subsurface runoff of the Terskey (southern) and Kungei (northern) ridge. The catchment area crosses the mountain pass Santash in the east as well as Karatash threshold in the west. The flat of two-dimensional boundary converges to the Terskey and Kungei ridges, where the zone is determined by exogenous and deep tectonic fractures which form an aquifer. The material of the fractured subsystems mainly consists of rocks of Paleozoic age. The subsystem of rock fracture has Mesozoic-Cenozoic age, which is the basis of the younger sedimentary cover of the Issyk-Kul basin. This sedimentary cover is characterized by gravel, sand, clay, and semi-rock cemented by clastic rocks such as conglomerates, sandstones, mudstones, and siltstones. The sedimentary cover takes up most of the Issyk-Kul basin (Mandychev, 2002b). Moreover, the Tien-Shan range is one of the most seismically active regions of the world and is known for major earthquakes (Figure 1.2) (Dzhanuzakov et al., 1980; Kondorskaya and Shebalin, 1982).

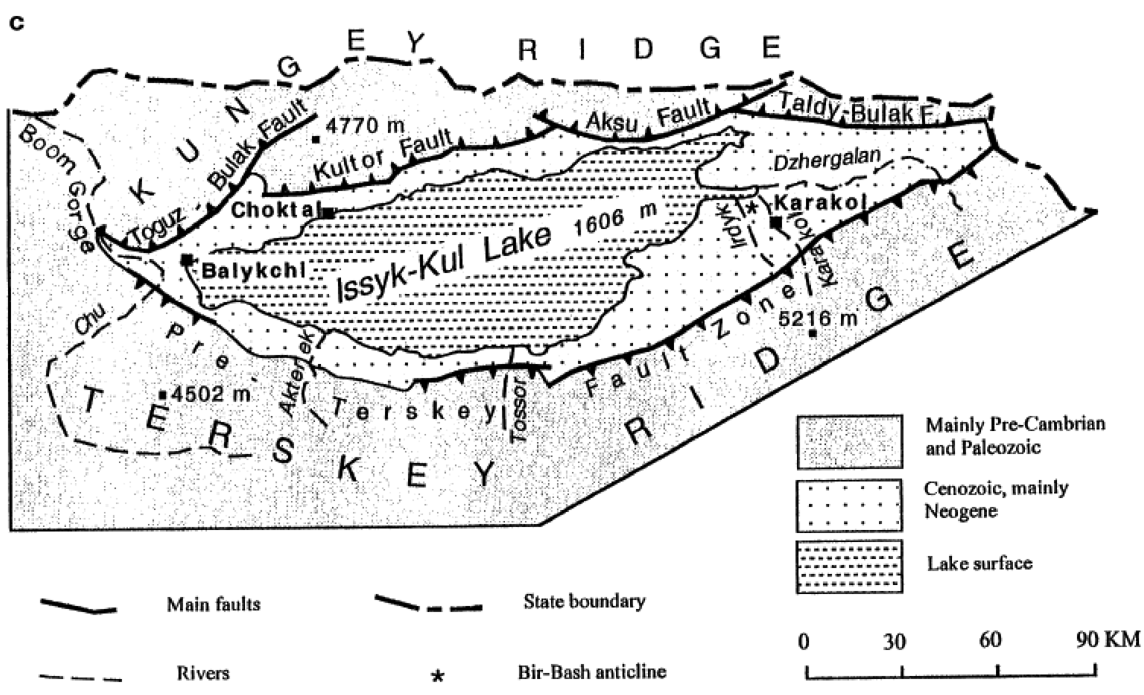

Figure 1.2 *Tectonic map of the northern Tien-Shan range (Dzhanuzakov et al., 1980; Kondorskaya and Shebalin, 1982)*

1.2.5. The salt concentration in the Issyk-Kul Lake

According to the findings of (Matveev, 1935) the average value of 34 determinations of the salinity of water of the Issyk-Kul was 5,823 mg/l. In the 1960th, according to the results of (Kadyrov, 1986), the average salinity increased to 5,968 mg/l. In the mid of 1980th, according to the results of the (Kyrgyz Agency for Hydrometeorology, 1980), it increased up to 6,100 mg/l. In 2010, according to the analysis of (Kulenbekov and Merkel, 2012a), the lake salinity content was 5,880 mg/l. The salt balance of the Issyk-Kul Lake is composed of salts entering from river runoff, precipitation, groundwater and the resulting loss of salts in the sediment. A salt balance of the Issyk-Kul Lake was determined by the Novocherkassk Hydrochemical Institute (Romanovsky et al., 2004). According to their calculations the dominant amount of salt in the lake originates from groundwater i.e.

- subterranean flow contributes 959 tons of dissolved salts annually, which represents 72% of their total input into the lake
- annual flow of the major ions by river waters with respect to irrecoverable loss of water for irrigation is 296 thousand tons or 22% of the total amount of incoming part of the lake water balance
- salt from rainfall accounts for 75 tons per year or 6% of the total amount of salt input into the lake

The total intake of salt per year is estimated at 1,330,000 tons of salt to replenish the stock of the lake. With 49.8% it is half of the incoming salt. The remaining part of 50.2% precipitates. The annual completion of the salt stock in the lake water column is calculated by the ratio of incoming and outgoing parts of the balance. It amounts to 662,000 tons, providing an annual increase in the salinity of lake water of 0.4 mg/l. The value of the accumulation of salts in the lake is determined to change the salt storage for the period from 1928-1978. That is equal to 1,110,000 tons and corresponds to an increase in salinity of 0.6 mg/l (Kuzseva, 1980).

According to other estimates, the groundwater discharge to the Issyk-Kul lake amounts to 1.5 km^3/year (Table 1.2). This groundwater carries 755,000 tons/year of dissolved salts into the lake. As for the contribution of groundwater outflow to the salt composition of Issyk-Kul lake based on these estimates, groundwater delivers 60 % of the total supply of chloride, 62 % of sulphate, 44 % of bicarbonate, 70 % of sodium and potassium, 49 % of calcium, and 79 % of magnesium (Zekster, 1996).

Table 1.2. *The groundwater discharge and content of major ions in the groundwater entering the Issyk-Kul Lake*

Region	**m^3/sec**	**mg/l**						
	***GW discharge**	**HCO_3**	**SO_4**	**Cl**	**Ca**	**Mg**	**Na+K**	**Total ions**
I	31.7	184.23	49.52	18.61	59.62	15.46	24.29	351.73
II	8.1	90.12	49.38	17.28	30.86	11.11	16.05	214.8
III	5.9	454.24	186.44	147.46	237.29	261.02	159.32	1445.77
IV	1.6	106.25	38.75	17.50	31.25	6.25	35.63	235.63
Total	47.3	834.84	324.10	200.85	359.02	293.84	235.29	2247.94

**GW discharge – groundwater discharge (47.3 m^3/sec = 1.5 km^3/year)*

1.2.6. Hydrochemical parameters of rivers feeding the Issyk-Kul Lake

The river waters belong to the class of calcium-hydrogencarbonate waters with salinity from 100 to 400 mg/l. The change of mineralization is illustrated by the example of the Chon-Kyzyl-Suu. In the upper zone (at 3500-3000 masl), the chemical composition is formed mainly from precipitation and weathering products of crystalline rocks. The value of mineralization here is 30-60 mg/l.

It increases up to 100-150 mg/l in the midlands area (at 3000-2500 m) while mineralization ranges from 160 to 200 mg/l in the lowlands zone (at 2500-2000 m). Finally, it reaches 250-300 mg/l under the influence of irrigation return flow of and seepage of groundwater on lakeside plain area (Romanovsky et al., 2004).

Rivers entering the lake contain 100 to 300 mg/l of dissolved salts, with Ca^{2+} and CO_3^{2-} ions were dominant (Kadyrov, 1971). During floods as a result of ice-melt and snow-melt inputs, river salinities vary between 42.6 and 250 mg/l (long-term average) (Zekster et al., 1988). In winter, rivers are fed predominantly by groundwater and salinities are then between 81.6 and 359 mg/l. On both occasions, Ca^{2+} and CO_3^{2-} ions dominate, except in the River Djety-Oguz in winter.

In river mouths, where lake and river water mix, the HCO_3^-/CO_3^{2-} equilibrium is disturbed and causes precipitation of $CaCO_3$ and the formation of calcite conglomerates in shallows (Sevastyanov and Smirnova, 1986).

The major source of silicon is weathering of rocks in the lake catchment. Rivers and streams have silicon (Si) concentrations of 2.5 mg/l, groundwater, 5-6 mg/l (Kuzseva, 1980). In Issyk-Kul itself, silicon concentrations in the February-May period equal those in rivers, but deep waters have somewhat lower concentrations than inshore water, with concentrations of 2.6-2.7 mg/l. Tyup Bay has a higher concentration of silicon (4.3 mg/l) all year.

Hydrologic parameter and major elements values of rivers in the south part of Issyk-Kul Lake are represented in (Table 1.3).

Table 1.3 *Hydrologic parameter and major elements values of rivers in the south part of Issyk-Kul Lake (Matychenkov and Tynybekov, 1999)*

River (gaging station)	Date of probe	Major ions (mg/l)						
		HCO_3	SO_4	Cl	Ca	Mg	Na+K	Ions sum, (mg/l)
*Ak-Terek	September 2000	201	33	6.5	53	11	12.2	316.7

Barskon, "Sasyk"	July, 1999	98.0	32.0	4.2	34.0	3.6	5.5	177.3
Tamga mouth	July, 1999	98.0	6.0	4.4	21.0	4.8	9.4	236
Chon-Djargylchak, “Lesopunkt”	July, 1999	85.4	4.0	2.8	24.0	1.2	4.8	122.2
Tosor mouth	July, 1999	110.0	12.0	6.5	32.0	2.4	9.0	171.9
Ton, “Tuurasuu v.”	July, 1999	128.0	8.0	5.6	32.2	3.5	12.2	189.5
Djuuku, “Djuukuchak”	July, 1999	92.0	18.0	4.7	31.0	3.2	4.5	153.4
Chon-Kyzylsuu, “Lesnoi cordon”	July, 1999	73.0	18.0	4.2	24.0	3.6	4.6	127.4
*Djyrgalan	September 2000	125	22	5.7	41	4.7	8.4	206.8
*Tyup	September 2000	182	32	7.8	56	7.2	11.1	296.1

**(Vollmer et al, 2002)*

1.2.7. Mineralogical composition of the Issyk-Kul Lake sediments

The mineralogical composition of the two uppermost meters of the Issyk-Kul Lake infill is formed by two main fractions: an endogenic one (calcite, magnesium calcite, monohydro-calcite and palygorskite) and a terrigenous one (quartz, illite, clinochlorite, microcline, albite and riebeckite) (Giralt et al., 2002). Monohydro-calcite is the most abundant mineralogical species in the endogenic fraction whereas illite is the most common within the terrigenous fraction (Giralt et al., 2004). On the other hand, the grain size analysis and the electron microscope observations indicated that the mean grain size ranged between 6 and 10 μm in Issyk-Kul Lake sediments (Giralt et al., 2004). These grain sizes have also been described as belonging to loess deposits (Ding et al., 2002). Moreover, the mineralogical composition of these loess deposits is dominated by siliciclastic particles (clays and feldspars). Recent works have shown that the Asian dust storm particles have a distinctive chemical signature with predominant calcium, silica and aluminum (Ma et al., 2001), indicating that they are siliciclastic minerals (Sun, 2002). This distinctive chemical signature has also been found in the Inilchek glacier located very close to Issyk-Kul Lake (Kreutz et al., 2001).

According to the lake mineralogical composition of the core identified by (De Batist et al, 2000) ten mineral species have been identified (using XRD method): monohydro-calcite, calcite, magnesium calcite ($MgCa(CO_3)$), palygorskite, clinochlorite, quartz, illite, riebeckite, microcline and albite. Carbonates compose up to 75% of the total sediment composition, and on basis of the dominance of the carbonate specie, four main zones have been established from the bottom to the top as following:

Zone D (180 – 147 cm deep) this zone is dominated by magnesium calcite (30 – 55%), together with rough constant values of the rest of the mineral species. In this zone illite presents its highest percentages.

Zone C (147 – 97 cm deep) Calcite dominates this zone showing percentages ranging between 50 and 75% of the total weight. The other mineral species show the lowest values of the sequence.

Zone B (97 – 83 cm deep) this zone is dominated again by magnesium calcite (50 – 72% of the total weight). It is also noticeable the near constant presence of palygorskite in this zone.

Zone A (83 – 0 cm deep) Monohydrocalcite is the main carbonate of this zone, together with a continuous presence of calcite. While the percentages of monohydro-calcite fluctuates (25 – 48% of the total weight), the percentages of calcite remain roughly constant (15%). Palygorskite is present in discrete levels and quartz shows the highest percentages of the sequence.

The presence of phosphorous in the water (as sodium hexametaphoshate or triphosphate) inhibites the spontaneous precipitation of anhydrous carbonates, even they are supersaturated, and stabilizes the hydrated forms such as the monohydro-calcite (Stoffers and Fischbeck, 1974). Thus, (De Batist et al, 2000) concluded that the presence of monohydro-calcite in Issyk-Kul Lake can be interpreted as an increase of phosphorous in the lake water. This increase could be related to the closure of the output of the lake. This closure could be caused due to both tectonic activity and to increasing dryness. (Bondarev and Sevastyanov, 1991) suggest that the tectonic activity led to changes in the flow of the Chu river and its separation of the lake. This activity seemed to be important during the end of the Late Pleistocene, but not during the Holocene. These authors also suggest that during the last 10,000 years the lake level oscillations seemed to be mainly triggered by changes in moisture. In any case, both processes imply a reduction of the lake water volume, increasing the phosphorous concentration present in the water. This lake level decrease is visible in the western and southern part of the lake, where recent lacustrine sediments outcrop. A third factor that could let an increase of phosphorous in the water of the lake is the anthropogenic activity in the shores of the lake. In fact, the beginning of the monohydro-calcite formation broadly coincides with the first signals of anthropic management of the territory (clearly pointed out by the presence of crop taxa such as Plantago sp. and the first important expansion of Papaver). According to the preliminary chronological framework this change took place around the 1100 A.D. Since then, this anthropic activity has become progressively more important towards the present-day.

There are no clear evidences in order to decipher which factor provoked the increase of phosphorous in the lake waters, but the increase of values of aquatic taxa during this moment seems to indicate that the phosphorous increase was due to natural causes (climatic and /or tectonic) rather than due to human activities. These last ones, if they have affected the lake, seems that they only have had acted amplifying this phenomena. Although the lake level has changed during this last period, the phosphorous concentration in the water has remained high enough for favoring the precipitation of monohydro-calcite until the present-day (De Batist et al, 2000).

1.2.8. Transported organic, nutrient and pollutant substances with river flow into Issyk-Kul

Employees Novocherkassk Hydrochemical Institute calculated the annual runoff of organic nutrients and specific pollutants using data on the flow and accumulation of the major components of the chemical composition of the lake for the period of 1926-1978 years: organic matter by bichromate oxidizability - 7300 tons; organic matter by permanganate oxidation - 4600 tons; Silicon (Si) - 5400 tons; Phosphorus - 20 tons; total iron - 90 tons; Nitrate -1820 tons; copper -2 tons; zinc - 9 tons; oil products - 470 tons (Romanovsky, 1990).

The largest river Dzhyrgalan supplies to Issyk-Kul Lake in the average 64 tons of sediment per year. According to the calculations a total mass of suspended sediment entered the lake from all rivers is 224 tons per year (Saposhnikov and Veselkina, 1960).

Nutrient concentrations depend on the ratio of river discharge to total lake water mass. In the Aral Sea, the ratio is 5.3 % in the Azov, 20 % in Caspian Sea and 13.4 % in Lake Balkhash. In Issyk-Kul it is only 0.2 % (Kadyrov, 1986). This indicates the poor supply of nutrients to Issyk-Kul and explains its low biological productivity. Issyk-Kul Lake has phosphorus load and the high water transparency, and mixing type of the lake is warm monomictic.

1.2.9. Uranium content in sedimentary rocks

Clastic sediments are formed in different tectonic environments revealing the dependence of the uranium content from the grain-size composition of the rocks: The uranium content increases gradually in the series of conglomerates-sandstones-siltstones-mudstones. This tendency is expressed in different levels of accumulation of radioactive elements in sediments. The concentration of uranium in soils depends on their content in the bedrock. This phenomenon is well known. It is based on geochemical methods of prospecting for deposits with dispersion halos (Dispersion halos are abnormal levels of the metals that develop around deposits). The radioactive inheritance of soil-forming rocks can be traced by different types of weathering and soil formation in different climatic zones. There is also information about the uranium content in soils of Great Britain (2.86 ppm), Canada (1.32 ppm), Poland (0.87 ppm) and India (12.1 ppm). The average uranium content in soils of the former USSR is 1.65 ppm (Grigoriev, 2003) (Table 1.4). According to (Kowalski, 1968), the uranium content in soils of uranium provinces is higher than in non-uranium-bearing areas. For example, in the Issyk-Kul (Kyrgyzstan) graben depression it was from 6.4 to 11.8 ppm, whereas in the Kursk (Russia) syncline, only from 0.55 to 0.88 ppm was found.

Table 1.4 *The average content of natural uranium in sedimentary rocks of the upper continental crust*

Mountains rocks	Uranium content, (ppm)	
	[a]Former USSR, 2003	[b]USA, 1994
Sand and sandstones	2.53	3
Clay and argillaceous shales	4.96	2.8
Carbonate rocks	2.31	2
Siliceous rocks	5.51	1-3
Sedimentary rocks as whole	3.75	2.54

[a]*Grigoriev N. A.*

[b]*NCRP 94*

With respect to 2009 and 2010 gamma spectrometry results, the uranium content in the sand of the southern coastal zone of the Issyk-Kul is 3.55 ppm in Djiluu-Bulak valley sediments, 4.43 ppm in Issyk-Kul Lake shore sediments as well as 5 ppm in clay of cover material of tailing dump sediments (Kulenbekov and Merkel, 2011a). According to (Djenbaev, 2008) the average content of uranium in sedimentary rocks is 3.75 ppm (Table 1.5).

Table 1.5 *Natural uranium content of sediments and soils around the Issyk-Kul Lake*

Sampling point	Uranium content, (ppm) (2009-2010)	Sampling point	Uranium content, (ppm) (2008)
Kadji-Sai tailing dump	5	Kara-Oi (soil)	5.7*

cover material (clay)			
Djiluu-Bulak valley (sand)	3.55	Kichi-Aksuu (soil)	5.7*
Issyk-Kul lake shore (sand)	4.43	Ak-Terek	21*

**Djenbaev, 2008*

In contrast to the Clark value for the upper continental crust are enriched in natural uranium. According to (Vinogradov, 1953) natural uranium in sedimentary rocks contains 3.53 ppm, whereas the Clark value is 2.75 ppm for the earth's crust. The reason for this imbalance could be found in the different mobility of elements in the supergene zone.

1.3. Methodology

1.3.1. Methods

Hydrochemical investigations were implemented in 2009 and 2010. In-situ measurements were performed and surface, ground water samples for major, minor and trace elements including uranium were taken. Specific activity of some spring water was measured as well using alpha spectrometry. Gamma spectrometry and electron microscopy coupled with Energy-Dispersive X-ray Spectroscopy (SEM/EDX) were used to investigate sediment samples and coal ashes from Kadji-Sai uranium tailing site, Kyrgyzstan. Also calculation of mobility factor of toxic trace elements in solid samples was fulfilled from the result of sequential extraction analyses. More details for the investigation of hydrochemical parameters and uranium content of the Issyk-Kul lake and spring, stream water as well as the uranium content of soil and sediments in the vicinity of the tailing site and other places of that region are published (Kulenbekov and Merkel, 2011a, 2012b).

The MapWindow program provides the "Watershed delineation" plugin to delineate watersheds. This plugin is part of the Terrain Analysis Using Digital Elevation Models (TauDEM) by David Tarboton and his collaborators (Maidment, 1992 and MAPWINDOW, 2005). The delineation process may be performed by simple steps or automatically. In this study the automated watershed delineation option was chosen. The digital elevation map (DEM) is selected at the start of the interface. It can be any resolution, but (a) it must be projected to UTM or another “equal area” projection (and one may use MapWindow’s GIS Tools plugin to do any reprojection) and (b) the elevation must be in meter.

MapWindowSWAT (MWSWAT) uses global_soils and global_landuses by default. Those characteristics are defined in the table usersoil and userlanduse defined in mwswat.mdb and hence in a project database. In the case of a landuse map, the table should have the string landuse in its name. Then it will be offered as an option for a landuse table. It must have the same structure as the table global_landuses in mwswat.mdb. In the case of a soil map, the table should have the string soil in its name. Then it will be offered as an option for a soil table. One has to copy the structure of the table global_soils in mwswat.mdb. Main digital source data (DEM, land and soil) should be preprocessed in MapWindow, from selection of files, clipping and re-projecting.

When measured weather data is not available, SWAT uses data simulated by a weather generator program which uses parameters supplied in weather generator files. MWSWAT supports the use of a weather generator table, which can contain the parameters for a number of weather stations, each represented by one line in the table. MWSWAT allocates the nearest weather generation station from the selected table to each sub-basin. The algorithm used by MWSWAT is as follows for each of the five categories precipitation, temperature, solar radiation, relative humidity and wind speed:

1) If there are no tables in that category, the category is simulated using a weather generator.

2) Otherwise, each sub-basin will use measured data from the table whose weather station is closest, amongst those stations having tables in that category.

Methods of deriving weather data for further practical use are presented in citations such as precipitation data from APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources). APHRODITE is based on a Dense Network of Rain Gauges (Main Hydrometeorological Administration of Kyrgyzstan) (Yatagai et al, 2012). Temperature data was used from the AATSR (Advanced Along-Track Scanning Radiometer) sensor (Sobrino et al, 2003-2004), the Moderate Resolution Imaging Spectroradiometer (MODIS-MOD11A2) and the Land-Surface Temperature (LST) (Soria and Sobrino, 2007). Relative humidity, wind speed and solar radiation data was used from the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL).

Collected data from 25 hydrological gauge stations around the Issyk-Kul Lake were used for validation of the model output such as the surface river runoff.

1.3.2. Data sources

The meteorological data provided here are based on data of the World Meteorological Organization (WMO) World Weather Watch Program according to WMO Resolution 40 (Cg-XII). Over 9,000 worldwide stations' data are typically available and intended for free and unrestricted use in research, education, and other non-commercial activities (NCDC, 2006). Historical data of the worldwide stations are generally available for 1973 to the present. Global summary of day contains a subset of the stations listed in this station history. In deriving the summary of day data, a minimum of 4 observations for the day must be present (allows for stations which report 4 synoptic observations/day). As for quality control (QC), the input data undergo extensive automated QC to correctly 'decode' as much of the synoptic data as possible, and to eliminate many of the random errors found in the original data. Then, these data are quality controlled further as the summary of day data are derived. Four weather stations' data of the Issyk-Kul water basin is available in the global surface summary of day data produced by the National Climatic Data Center (NCDC) in Asheville, NC. The input data used to build these daily summaries are Integrated Surface Data (ISD) which includes global data obtained from the United Nations Air Force (USAF) Climatology Center (Federal Climate Complex of the NCDC). The latest daily summary data is normally available 1-2 days after the time of observations. Data files are available online at the Version 7 of the compression and uncompression software level.

The input weather data for the 24 points in the Issyk-Kul water basin were derived from different sources such as APHRODITE (precipitation data), ATSR (temperature data) and NOAA-ESRL (relative humidity, wind speed and solar radiation data).

Data from 25 hydrological gauge stations (for 1996-1997-1998) are available around the Issyk-Kul Lake and were obtained from the Main Hydrometeorological Administration of Kyrgyzstan.

Topographic properties have been extracted from the SRTM digital elevation model (Shuttle Radar Topography Mission) with a resolution of 90 by 90 m. SRTM data version 4 represents a significant improvement from previous versions using new interpolation algorithms and better auxiliary DEM´s.

Landuse maps and soil maps for most parts of the world are available from the WaterBase site. Landuse data was constructed from the USGS Global Land Cover Characterization (GLCC) database. They are provided in the form of zip files containing one or more files for each continent.

1.3.3. Water balance equation

The hydrologic cycle for the soil compartment is based on the water balance equation (Neitsch et al., 2005):

$$\mathbf{SW}_t = SW_0 + \sum_{i=1}^{1}\left(P_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

Where

SW_t- final soil water content (mm)

t – time (days)

SW_0 – initial soil water content on day i (mm)

P_{day} – amount of precipitation per day i (mm)

Q_{surf} - amount of surface runoff on day i (mm)

E_a - amount of evapotranspiration on day i (mm)

W_{seep} - amount of percolation and bypass flow exiting the soil profile bottom on day i (mm)

Q_{gw} - amount of return flow on day i (mm)

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each hydrologic response unit (HRU) and dispersed to derive the total runoff for the watershed. It implies that accuracy is increased and a better physical description of water balance is given by above mentioned aspects.

1.3.4. Surface runoff equation

Surface runoff takes place whenever the rate of water flowing on the ground surface exceeds the rate of infiltration. To calculate surface runoff in the given study the SCS curve number method was applied. It is one of the MWSWAT methods (SCS, 1972). The model was developed to provide a consistent basis for calculating the amount of runoff under varying land use and soil types (Rallison and Miller, 1981).

The SCS curve number equation is

$$\boldsymbol{Q_{surf} = \frac{\left(P_{day} - I_a\right)^2}{\left(P_{day} - I_a + S\right)}}$$

Where

Q_{surf} - the accumulated runoff (mm)

P_{day} - the rainfall depth for the day (mm)

I_a - the initial abstractions which include surface storage, interception and infiltration prior to runoff (mm)

S – the retention parameter (mm)

The SCS curve number is a function of the soil permeability, land use and prior soil water conditions.

1.4. Results and discussion

1.4.1. Hydrological model

The main idea of this work was to suggest reasons of the anomalous concentration of uranium in the Issyk-Kul Lake. The river runoff calculation is necessary to determine the total uranium content in the lake. The river runoff was calculated using the MWSWAT program. The MWSWAT allows a number of different physical processes to be simulated in a watershed. For modeling aims, the watershed was partitioned into a number of sub-basins. The use of sub-basins in a simulation is especially beneficial when different areas of the water basin are dominated by land use or soil and when they are dissimilar enough in properties to impact the hydrology. The special relationship of the objects within the watershed is defined by the watershed configuration. There are three methods used to subdivide a watershed which are sub-watershed discretization, hill-slope discretization, and the grid-cell discretization. The sub-watershed discretization divides the watershed into sub-basins based on topographic features of the watershed. In this work the sub-watershed discretization method was used (Neitsch et al., 2005). The modeling output covered 42 sub-basins (Figure 1.3). Input information for each sub-basin is grouped into categories such as climate, hydrologic response unit (HRUs), ponds/wetlands, groundwater and the sub-basin draining main channel flow. HRUs are lumped land areas within the sub-basin that are comprised of unique land cover, soil and management combinations.

According to the result of this modeling, the area of Issyk-Kul basin is 21944 km^2. Before, an area of 22080 km^2 had been reported (Romanovsky, 1990). This implies in a difference of 136 km^2.

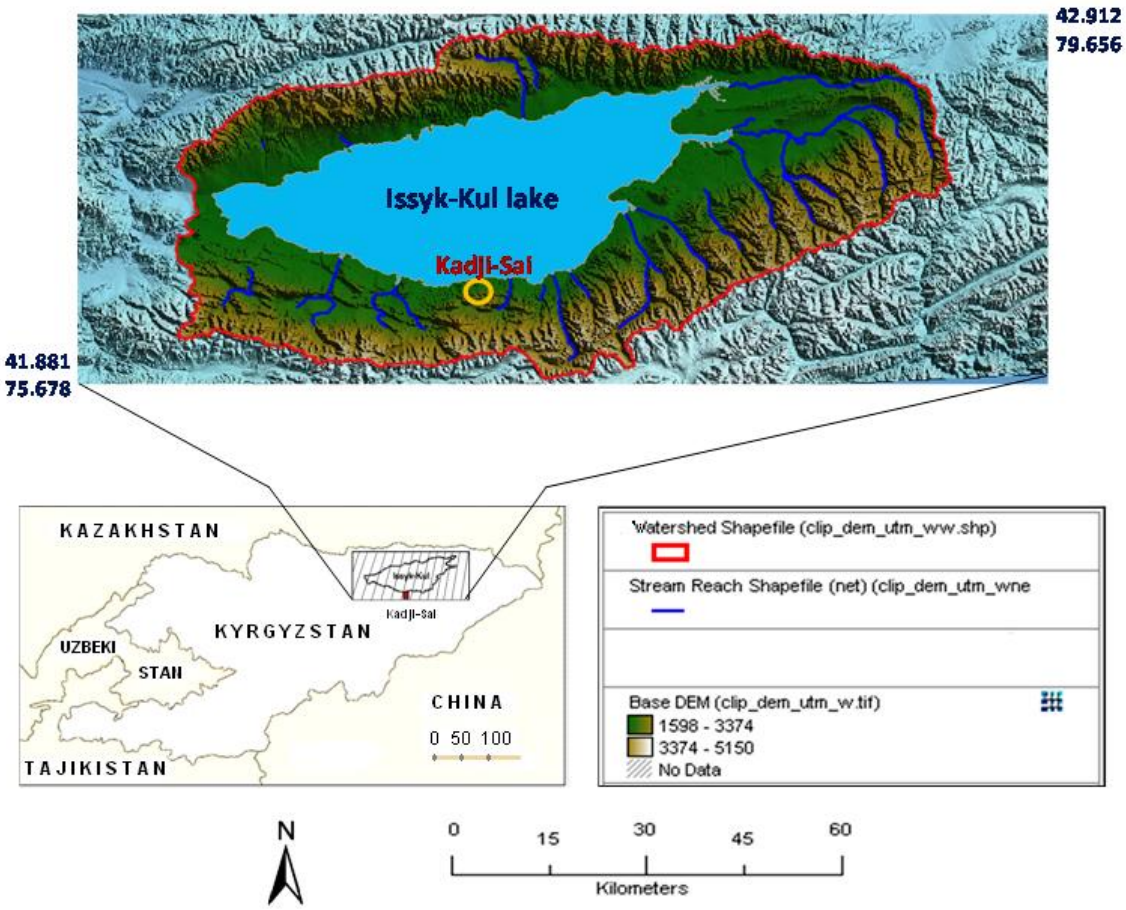

Figure 1.3 *Map of the hydrological model (sub-watersheds, stream flow and hydrological response units). Area of the Issyk-Kul water basin is 21944 km^2 based on the hydrological modeling result (using SRTM DEM). (Datum: WGS 1984)*

1.4.2. Land use map

The Issyk-Kul region´s ecology typified by vegetation cover, soil characteristics, plant and anthropogenic densities affects the infiltration characteristics and influences the storage coefficient and runoff behavior. Landuse data was built from the USGS Global Land Cover Characterization (GLCC) database. They are provided in a mesh of approximately 400 meters (at the equator). Landuse map has a spatial resolution of 1 km and 24 landuse classes (Figure 1.4). The parameterization of the landuse classes (e.g. leaf area index, maximum stomatal conductance and maximum root depth, optimal and minimum temperature for plant growth) is based on the available SWAT landuse classes and literature research. The landuse map allows the categorization of land use in the Issyk-Kul basin into 16 classes (Figure 1.4).

However, due to similar types (such as deciduous forest or grass land) they were combined into 10 classes by the model itself (Table 1.6). Much of the upstream land in the Issyk-Kul (15.8% of the total area) is of largely wooded tundra while grass land, irrigated land, shrub land, dry land and settlements typify the downstream surface cover.

The soil map was produced by the Food and Agriculture Organization of the United Nations (FAO, 1995). Almost 5,000 soil types are differentiated at a spatial resolution of 10 km. Some soil properties are provided for two layers (0-30 cm and 30-100 cm depth). Further soil properties (e.g. particle-size distribution, bulk density, organic carbon content, available water capacity and saturated hydraulic conductivity) were obtained from (Reynolds et al, 1999) or by using pedo-transfer functions fulfilled in the model Rosetta.

Table 1.6 *Land use features for the Issyk-Kul basin derived from the USGS Global Land Cover Characterization (GLCC) database.*

Land use	code	Area (ha)	Watershed (%)
Wooded tundra	TUWO	142345.14	15.81
Barren or sparsely vegetated	BSVG	56191.99	6.24
Mixed forest	FOMI	4861.51	0.54
Shrub land	SHRB	96941.26	10.77
Grass land	GRAS	414415.65	46.03
Crop land/wood land mozaik	CRWO	12984.39	1.44
Crop land/grass land mozaik	CRGR	100261.45	11.14

Irrigated crop land and pasture	CRIR	55119.05	6.12
Dry land and pasture	CRDY	16766.29	1.86
Residential medium density	URMD	336.35	0.04

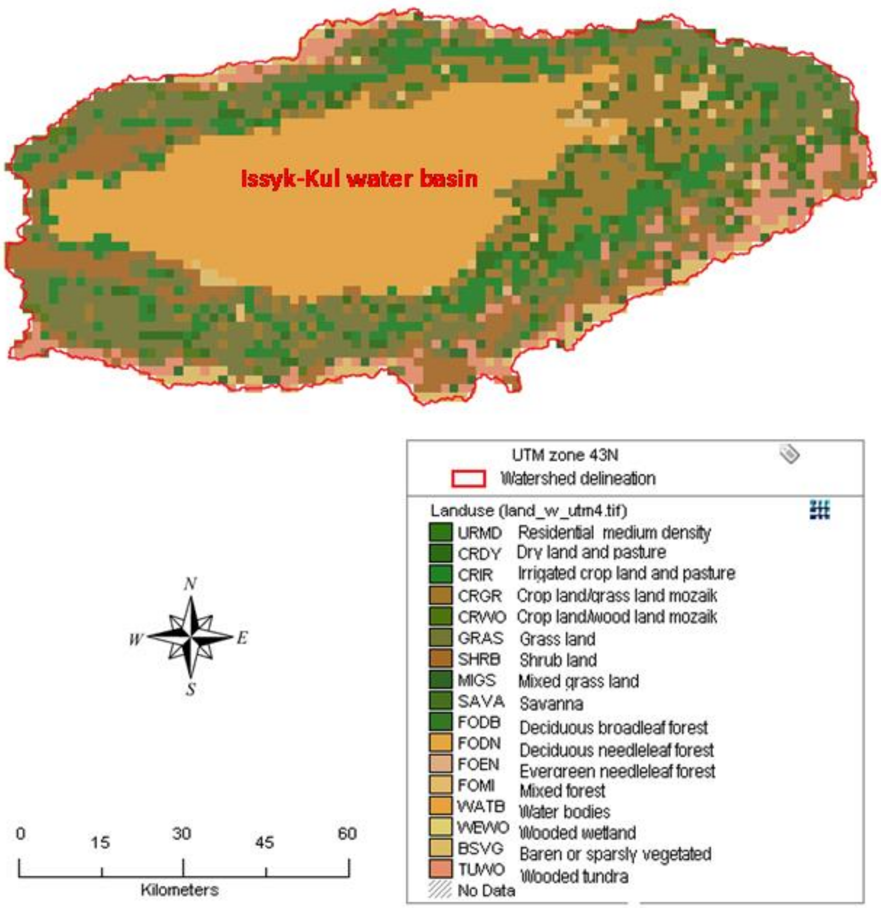

***Figure 1.4** Landuse map of the Issyk-Kul water basin was generated using MapWindow tool (Clip grid with polygon). This landuse map is a GeoTiff raster file and was imported from Landuse data which was constructed from the USGS Global Land Cover Characterization (GL CC) database. (Datum: WGS 1984)*

1.4.3. Soil map

The physical properties of the catchment soils determine the water flow potential (Table 1.7). The soil within the area of interest is primarily classified as arid land in the west and semi-arid soil in the middle and east. The latter one belongs to loam or clayey loam. De-Marton has developed a drought index, depending on precipitation and air temperature

(I = X / T +10), where X is the annual rainfall in centimeters, and T the average air temperature. This index is lower for drier climate. According to the values of the aridity index, increasing from 0.7 in Balykchy (western part of the basin), 1.4 in Cholpon-Ata-Tamga (middle part of the basin) to 4.0 in the east of the basin, dry climate in the basin decreases from west to east (Figure 1.5).

Table 1.7 *Soil features for the Issyk-Kul basin derived from the Food and Agriculture Organization of the United Nations.*

Soil	Code	Area (ha)	Watershed (%)
Loam	I-K-2c-3722	224850.83	24.98
Loam	I-Bh-2c-3094	458140.22	50.89
Loam	I-Y-2c-3733	33657.4	3.74
Glaciers	GLACIER-6998	31587.4	3.51
Water	WATER-6997	6718.85	0.75
Clay_loam	I-Bc-Bh-2-3960	135804.93	15.09
Sandy clay_loam	Xl16-2b-3315	9463.44	1.05

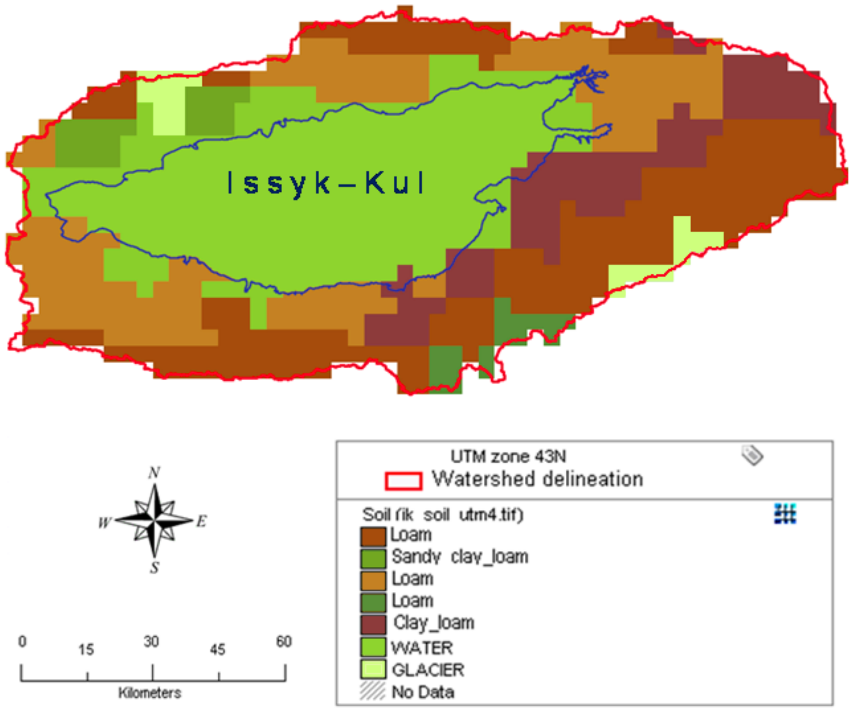

Figure 1.5 *Soil map of the Issyk-Kul water basin was generated using MapWindow tool (Clip grid with polygon). Soil map is a GeoTiff raster file and was produced by the Food and Agriculture Organization of the United Nations. (Datum: WGS 1984)*

1.4.4. Water balance output

The water balance data has been displayed as histograms and diagrams. They are labeled by month as that was the time interval of the MWSWAT output (Figure 1.6). The Issyk-Kul basin is approximately divided into three zones according to climatic differences. The first histogram in Figure 1.6 (A) is related to zone 1 representing an arid area. The second zone is labeled with (B) and is a semi-arid area. The third zone labeled with (C) is a moderate humid area. One weather station was taken as an example for every zone in order to describe the climatic differences of the Issyk-Kul basin. In the histogram the red color illustrates the precipitation (mm), the green color the surface runoff (mm), the blue color the groundwater runoff (mm) and the black color the potential evapotranspiration (mm).

Comparatively, as shown in the histogram, the potential evaporation values of zone 1 and 2 are higher than in zone 3. However, the values of precipitation, surface runoff and groundwater runoff of zone 1 are lower in zone 2 and 3. This implies that relative humidity is increasing from west to east of the basin. Therefore, more surface and groundwater runoff occur in the western part of the Issyk-Kul basin. Besides, the histogram shows monthly time series for 1996-1997-1998 in order to see how the water balance in the Issyk-Kul basin is changing over the time.

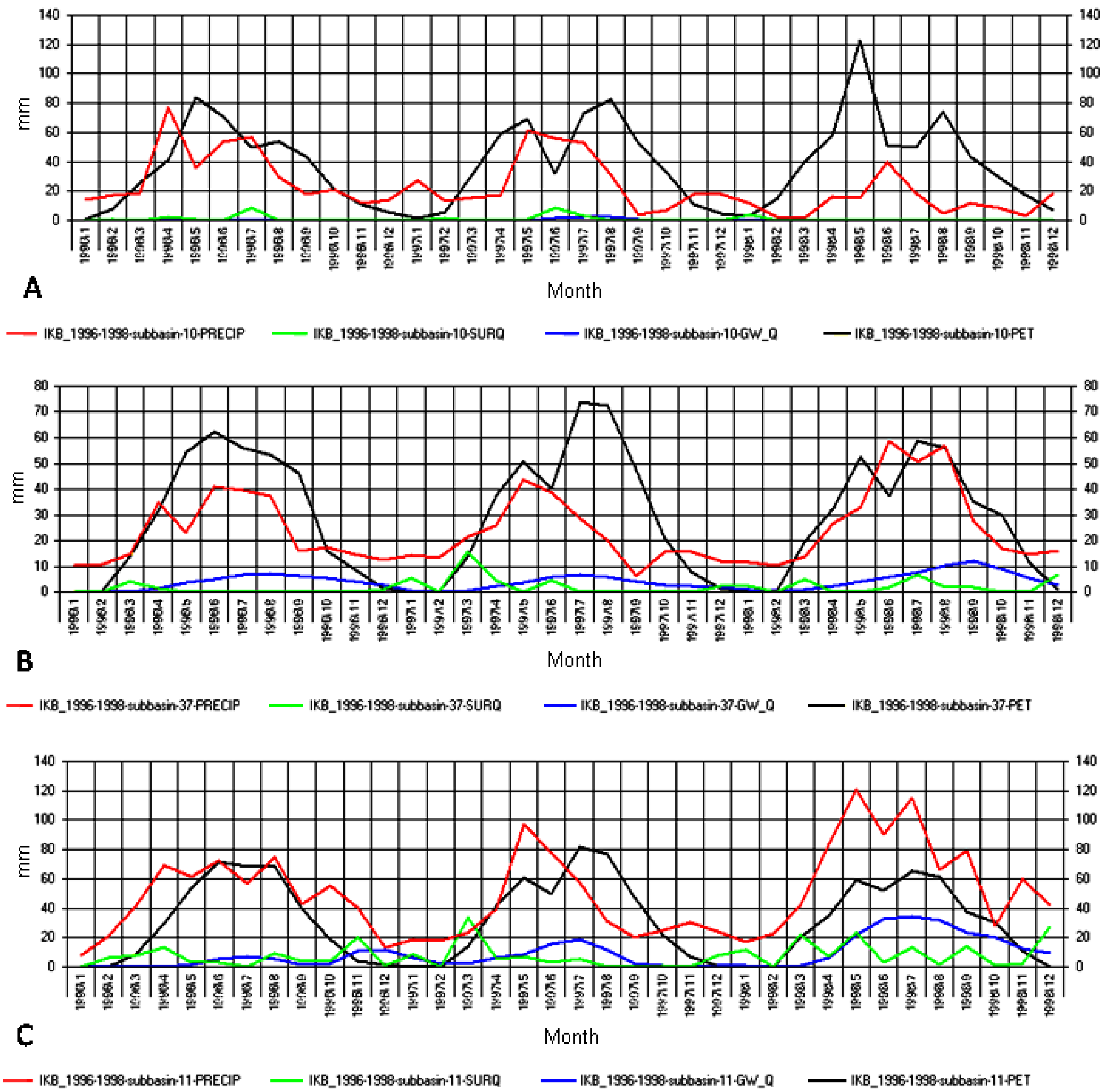

Figure 1.6 *The time series of water balance of the Issyk-Kul water basin for 1996-1997-1998. Histogram (A) is the Kultor subbasin, (B) is the Ton subbasin and (C) is the Tyup subbasin*

1.4.5. Validation of the model output

Validation is a comparison of model results with an independent data set. The manual validation approach demands the user to compare measured and simulated values (Gassman et al, 2007). The validation results were close to the measured data set for the overall basin (surface runoff of 25 rivers) as compared to results obtained for 42 sub-basins of the modeling. The Issyk-Kul water basin was divided into three zones for surface runoff (Figure 1.6, 1.7). The first zone is situated in the western part of the Issyk-Kul water basin. The second zone is situated in the middle and third zone is in the eastern part of the basin. The division of the basin was made due to the different weather conditions.

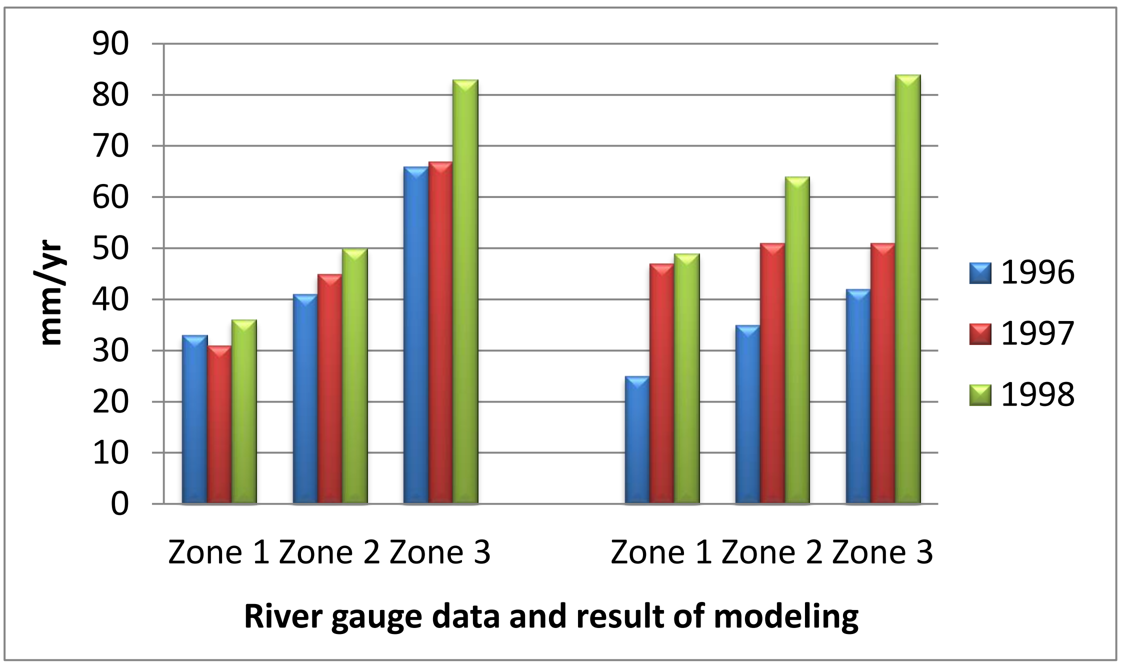

Figure 1.7 *The gauge station data (on the left hand) and the result of modeling (on the right hand) for 1996-1997-1998 in the divided into three zones of the Issyk-Kul water basin. This diagram is represented for the validation of the hydrological model*

The gauge station data on the left side in Figure 1.8 and the result of modeling on the right side is shown for the time series of 1996-1997-1998. The diagram in both cases shows an increase of the surface runoff from west to east of the basin except for the surface runoff of 1997. Probably the reason is due to the influence of land use and soil properties taken from satellite data set.

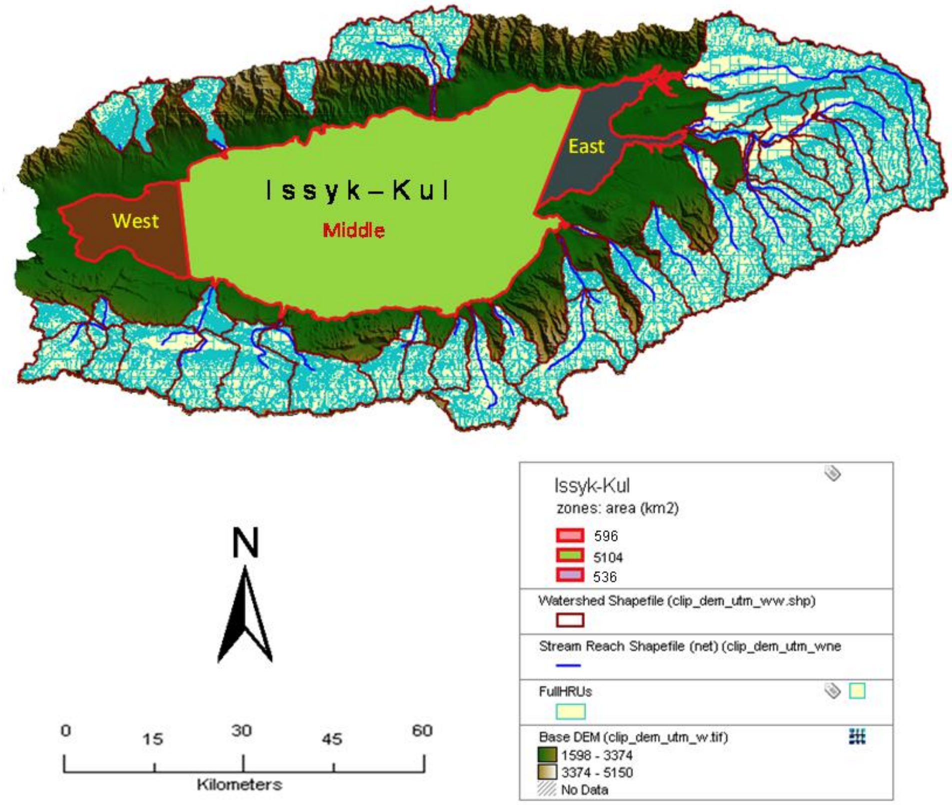

Figure 1.8 *Map of Issyk-Kul Lake divided into three zones due to climatic differences. (Datum: WGS 1984)*

1.4.6. Mineralization of the Issyk-Kul Lake

Dominant ions which are determining the characteristics of the water chemistry of the Issyk-Kul lake are the anions Cl^- (24.1%), and SO_4^{2-} (23.8%) as well as the cations Na^+ (33%) and Mg^{2+} (13%) for a minor extent. Thus, the Issyk-Kul water in its ionic composition is characterized by chloride, sulphate, and sodium (Table 1.8).

Table 1.8 *In situ chemical parameters of two springs and Issyk-Kul Lake at two sites (Kulenbekov and Merkel, 2012b).*

Code	Sample name	Location	T, (^{o}C)	pH	Eh, (mV)	pe	EC, (µS/cm)

MA-Sp	Manjyly-Ata spring	42^o 08\`48.5\`\` $77^o$ 05\`06.5\`\`	19.3	8.3	371	4.2	1416
DjB-Sp	Djiluu-Bulak spring	42^o 09\`31.9\`\` $77^o$ 13\`7.0\`\`	23.8	8.23	367	6.2	2040
MA-L	Issyk-Kul lake (close to outlet of Manjyly-Ata)	42^o 09\`15.3\`\` $77^o$ 05\`27.6\`\`	15	7.57	252	6.2	8400
DjB-L	Issyk-Kul lake (close to outlet of Djiluu-Bulak)	42^o10\`18.2\`\` $77^o$12\`38.7\`\`	19.2	8.3	371	6.2	8380

The concentration of PO_4 is 23.4, 22 and 0.3 mg/l in the lake close to the Djiluu-Bulak stream outlet and in the Manjyly-Ata stream outlet respectively.

The Cl^- index (salinity (TDS) to Cl^- ion ratio) is 3.69 in the open lake (average) (Kulenbekov and Merkel, 2012b) (Table 1.9) which strongly distinguishes the Issyk-Kul Lake from other large water bodies (cf. 1.81 for oceanic water, 1.81 for the Black sea, 1.84 for the Aral sea (lake), 2.39 for the Caspian sea and 5.10 for the Balkhash lake) (Karmanchuk, 1999).

Table 1.9 *Major ions and salinity of the Issyk-Kul Lake and springs (Kulenbekov and Merkel, 2012b).*

	mg/l				
	Issyk-Kul Lake (average)	**lake close to Djiluu-Bulak outlet**	**lake close to Manjyly-Ata outlet**	**Manjyly-Ata spring**	**Djiluu-Bulak stream from spring**
Ca^{2+}	115.9	110	122	31.2	92.3
Mg^{2+}	285.9	274	278	13.4	20.8
$Na^+ + K^+$	1461.7	1502	1537	103	271

HCO_3^-	248.8	57.3	59.7	80	64
SO_4^{2-}	2129.1	2080	2095	156	461
Cl^-	1575.2	1584	1553	89.5	218
TDS	5816.6	5880	5872	991.2	1428
TDS/Cl^-	3.69	3.71	3.78	7.6	6.5

1.4.7. Uranium concentration

Analysis of the uranium content in water (springs, streams, tab water, groundwater, lake water) in the vicinity of Kadji-Sai uranium tailing site was conducted by (Kulenbekov and Merkel, 2012b). According to this analysis uranium concentrations in all water exceed the recommended values of the World Health Organization (WHO) standard which equals 15 µg/l. Also the analyses of water samples conducted by (Gavshin et al., 2004) from below the tailing pile contains 220–240 µg/l that is lower than the results gained by (Kulenbekov and Merkel, 2012b) which contains 288.3 µg/l. The minimum, maximum, standard deviation and residue of the uranium concentrations are represented as well (Table 1.10).

Table 1.10 *The results of uranium concentrations in springs, streams and Issyk-Kul lake water and their minimum, maximum, standard deviation and residue are represented below*

		Uranium concentration, µg/l				
Code	**Sample name**	**Min**	**Max**	**Mean**	**SD**	**%RSD**
ES1	East spring 1	168.8	172.6	170.1	1.486	0.874
ES2	East spring 2	285.7	289.2	288.3	1.788	0.622
ES3	East spring 3	162.2	163.9	163.2	1.387	0.829
WS4	West spring 4	85.27	86.03	86	0.411	0.479
WSt5	West stream 5	99.4	98.08	99.2	0.676	0.684
CP 3	Catchment pool 3	96.73	97.86	97.25	0.57	0.586
Utes	Utes (artesian spring)	106.2	107.8	107.1	0.618	0.577
Ak-Dj	Ak-Djeek (thermal spring)	0.48	0.486	0.484	0.002	0.433

LDjB	Lake (Djiluu-Bulak outlet)	64	65.25	64.9	0.638	0.985
LMA	Lake (Manjyly-Ata outlet)	63.67	64.59	64.08	0.466	0.727

A weighted uranium concentration for the discharge of these 10 rivers (using a weighting factor) was calculated using PHREEQC program (Table 1.11). The calculation of enrichment factor is represented in (Figure 1.10). Sampling points in 2004 (taken by Matychenkov) and taken in 2010 during our field campaign and as well as the concentration of uranium in the rivers are represented in (Figure 4.10). The total discharge to the lake is calculated from the surface of the lake (6236 km^2) and 712 mm potential evaporation and sums up to be 4.44 km^3/year assuming no outflow and considering no change in water level. But water level changes per year in the range of a few cm are of minor importance in comparison to 71.2 cm of potential evaporation. In comparison to this number the discharge from rivers with 0.1438 km^3 is only 3.2 %. However, the discharge/input to the lake of these 10 rivers is only 1.438 E+8 m^3/year the total input to the lake is much bigger. Because no data are available about the smaller rivers and groundwater discharge and quality to the lake, the only option was to assume that input to the lake is equal the evaporation of the lake. A drop in the lake level is of minor impact as can be shown easily. 6236 km^2 lake surface was multiplied by 712 mm potential evapotranspiration (PET) (Table 1.12). PET from a surface area of Issyk-Kul Lake was calculated using Penman-Monteith equation.

Concentrations of major cations and anions of surface water were calculated from data from the 10 major rivers (Matychenkov and Tynybekov, 1999 and Vollmer et al, 2002) as average weighted by the amount of discharge (see Table 1.3). Groundwater concentrations were determined by Kadyrov 1986 and Maskheteli et al, 1987, but these publications were not available. Therefore data given in Table 1.2 (Zekster, 1996) was used to back-calculate the concentrations (Table 1.13). However, the above mentioned authors assume that the total groundwater discharge to the Issyk-Kul Lake is 1.492 km^3/year, while the above shown calculation gives 4.44 km^3/year.

For the calculation of the enrichment of water constituents chloride, sulfate, and uranium was chosen because these elements may be act in this environment as a tracer with little interaction with sediments and no precipitation. Unfortunately uranium concentrations of groundwater are not available, neither from literature or own data. Thus the weighted value from surface water was taken. Based on the total water volume of 1738 km^3 (Kodyaev, 1973) the enrichment factor is calculated to be 1.002561222 per year and 1.026216538 per 10 years respectively. The enrichment was calculated with PHREEQC using 10 years intervals by adding the perspective amount of water an evaporating the same amount. This is a valid approach because the Issyk-Kul Lake is monomictic. The Issyk-Kul Lake is a tropical type of warm monomictic lake (Romanovsky et al, 2004). The simulation was run for 750 years. After about 350 years the nowadays uranium concentrations are reached (Figure 1.9). But for chloride and sulfate only 276 und 536 mg/l respectively are reached. However, the today's chloride and sulfate concentrations are about 1550 and 2100 mg/l respectively. To reach the chloride concentration about 5 to 6 times longer enrichment time would be necessary (1750 to 2100 years). Sulfate is already in equilibrium with gypsum and thus not suited as tracer. However, a problem would to explain the lower enrichment of uranium in that case because uranium is not oversaturated in the today´s lake water. One explanation could be that uranium is sorbed and/or co-precipitated, another that the uranium concentrations in groundwater are much lower than in surface water.

Table 1.11 *Calculation of weighting factor and natural uranium content of the rivers feeding the Issyk-Kul Lake. Natural uranium content data are from the result of measurements in 2003–2004 (Matychenkov, 2004)*

Sampling points (river basins)	Surface runoff (m^3/yr)	Weighting factor	Uranium content (µg/l)
Ak-Terek	1524512	0.01	12.1
Barskon	1231282	0.008	5
Tamga	114343	0.0008	18.4
Chon-Jargylchak	572593	0.004	19.6
Tosor	220791	0.002	26.3

Ton	6918484	0.048	20
Djuuku	659073	0.005	11.9
Chon-Kyzylsuu	1532879	0.01	7.8
Djyrgalan	26671814	0.18	10.7
Tuip	104320830	0.72	5.7
	143766601		

Table 1.12 *Calculated potential evapotranspiration from the surface area of Issyk-Kul Lake. PET was calculated using Penman-Monteith equation*

	Potential evapotranspiration (PET) from Issyk-Kul lake						
Month	**Min Temp**	**Max Temp**	**Humidity**	**Wind**	**Sun**	**Rad**	**PET**
	°C	**°C**	**%**	**km/day**	**hours**	**MJ/m²/day**	**mm/day**
January	-4.5	1.6	82	173	3.6	6.1	0.56
February	-4.6	1.2	83	173	3.8	8.2	0.7
March	0	7.3	80	173	4.6	11.8	1.31
April	1	14.6	70	173	6.3	16.6	2.52
May	7.9	15.9	79	173	5.1	16.9	2.67
June	12.6	18.4	84	173	4.8	17.1	2.9
July	13.3	22.2	79	173	7.7	20.7	3.8
August	13.8	22.1	80	173	6.8	17.9	3.41
September	8.4	17.7	77	173	7.3	15.8	2.64
October	6.3	12.8	82	173	5	10.1	1.51
November	-0.7	6.3	80	173	4	6.8	0.87
December	-3.8	1.5	84	173	3.2	5.2	0.49
Average	**4.1**	**11.8**	**80**	**173**	**5.2**	**12.8**	**1.95**
						PET (mm/year): 712	

Table 1.13 *Calculation of weighting factor and natural uranium content of the groundwater entering the Issyk-Kul Lake. Major ions data from (Zekster, 1996)*

	Cl	**SO4**	**HCO_3**	**Na+K**	**Ca**	**Mg**	**Total ions**	***GD (m^3/sec)**
I	18.61	49.53	184.23	24.29	59.62	15.46	351.74	31.7
II	17.28	49.38	90.12	16.05	30.86	11.11	214.81	8.1
III	147.46	186.44	454.24	159.32	237.29	261.02	1445.76	5.9
IV	17.50	38.75	106.25	35.63	31.25	6.25	235.63	1.6
Total	34.42	66.22	199.15	40.11	75.90	45.03	460.82	**weighted**

**Groundwater discharge*

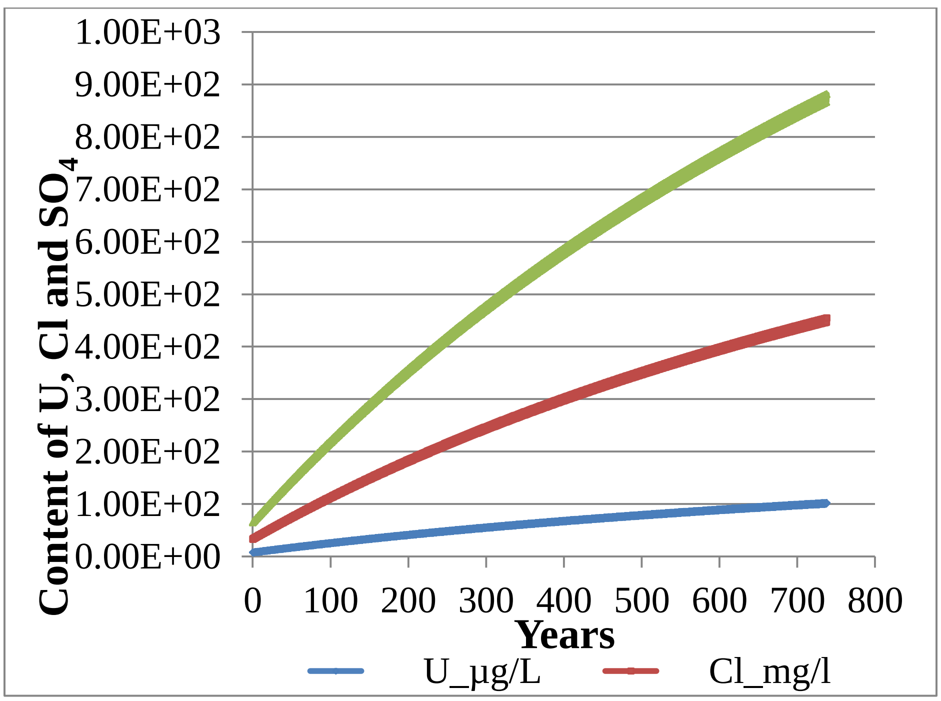

Figure 1.9 *Content of uranium and chloride over years in the Issyk-Kul Lake*

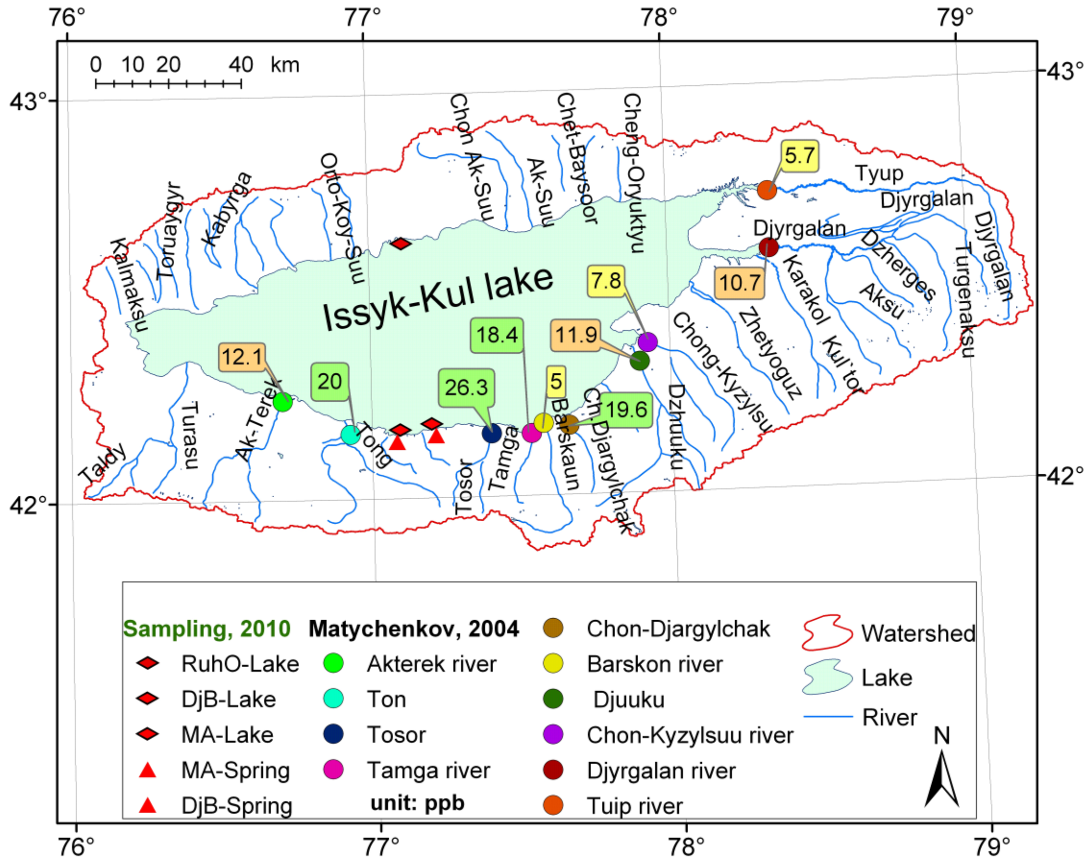

Figure 1.10 *Sampling points of water from springs and rivers and Issyk-Kul Lake. The unit of natural uranium content in rectangles is in ppb. Light green color rectangles mean higher natural U content. Light brown color rectangles mean lower U content and gold color rectangles mean relatively lowest natural U content*

1.5. Conclusion

Five conclusions were drawn from the given study: firstly, an anomalous natural uranium concentration in the Issyk-Kul Lake equals 65 µg/l, secondly, the value of natural uranium content in soil and sediments surrounding the Issyk-Kul Lake is higher than background level, thirdly, shorter distance of rivers (50-103 km) feeding Issyk-Kul Lake than rivers (mainly 1000-6852 km) feeding seas, fourthly, surface runoff was less than groundwater discharge into the lake and fifthly, Issyk-Kul Lake is a terminal lake since about 350 years according to the accumulation of uranium in the lake water over that time. Nevertheless, uranium concentration in surface water and groundwater feeding the Issyk-Kul Lake should be explored in more detail during further investigations. Also the quaternary aquifer system is a key issue for the hydrostatic and hydrodynamic boundary conditions of the lake. There is a significant need for further research about the lake, its chemistry, and discharge to the lake, development of the lake during the Holocene and Little Ice Age from 16^{th} to 19^{th} and the future development of the lake considering stress due to tourism and an increasing population.

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2. Assessment of radionuclides and toxic trace elements mobility in uranium tailings by using advanced methods, Kyrgyzstan

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2.1. Abstract

An assessment of environmental geochemistry of radionuclides and toxic trace elements in the Kadji-Sai uranium tailing site at the south coast of the Issyk-Kul Lake (Kyrgyzstan) was accomplished. The assessment was conducted because the tailing site provides a distinctive case of natural and anthropogenic matters that contain high environmental contaminants that exceeds the (IAEA-433) maximum contamination values of reference materials. As follower of natural uranium decay chain Rn-222 is a gas produced by the decay of Ra-226. Radon is the number one cause of lung cancer. A seven stage sequential extraction procedure was used to investigate the natural radioactive U, Th, and the toxic trace elements Cr, Ni, Cu, Zn, As, and Pb. This method distinguishes between different binding forms of elements in the tailing sediments and catchment pools. A scanning electron microscope (SEM) with EDX-probe was used to characterize tailing sediments. Elemental compounds such as CuO, ZnO, and PbO as well as UO_2 and ThO_2 are dominating in the natural sediments and in the tailings, respectively. The results showed that the trace element concentrations found in the residual fraction were higher than that in the other fractions. Natural radionuclides and toxic trace elements mobility in coal ashes of uranium tailings, as well as in sediment of the Djiluu-Bulak valley and on the Issyk-Kul Lake shore were studied. The mobility of radionuclides and toxic trace elements is enhanced by acidification of tailings due to sulphide oxidation catalysed by microbial activity. Radiochemical analysis of water samples taken from the tailing site was performed by ICP-MS and gamma and alpha spectrometry. Most water samples taken were not in

accordance with the recommendation of the U.S. EPA Groundwater Standards for Inactive Uranium Tailing Sites (40 CFR Part 192).

The mobility of the trace elements Cr, Ni, Cu, Zn, As, Cd, Pb, Th, and U in solid samples of six uranium catchment pools in the vicinity of the Kadji-Sai uranium tailing site was assessed using sequential extraction and calculating the mobility factor. The results showed that the exchangeable fraction was the most important fraction for U, Cu,and Cd with the average level of 6.2 to 8.3%, 5.1 to 5.4%, and 2.9 to 3.8%, respectively, while the organic fraction contained the predominant species of Pb with an average level of 24.0 to 24.4%. For total concentrations Cu was dominant ranging from 43 to 43696 (mg/kg) followed by Ni ranging from 50 to 16451 and then Cr, Zn, Cd, Pb, U, As, and Th with 57 to 5395; 115 to 4585; 2.2 to 1434; 35 to 616; 2.7 to 205; 8 to 43 and 10 to 51, respectively. The mobility factors for the metals in all the catchment pools ranged from 0.03 to 33.7 following the order U>Cd>Cu>Zn>Ni>As>Cr>Pb>Th. The relatively high mobility factor observed in U, Cd and Cu confirms the high liability, and biological availability of U, Cd and Cu in some of the solid samples investigated. Gamma spectroscopy showed significant elevated activities for ^{238}U, ^{226}Ra, and ^{210}Pb. The total concentration of most of the trace elements in the catchment pools samples are elevated in comparison with that of normal soil, as well as with IAEA-433 reference materials values (Analytical Quality Control Service of IAEA, 2004), ((IAEA) 2004). Additionally, a geologic map is represented in order to describe the lithology of the Kadji-Sai uranium dumpsite to the public.

Keywords: uranium tailing site, environment, natural radionuclides, geochemistry, toxic trace elements, mobility factor, spearman correlation, geologic structure

2.2. Introduction

Issyk-Kul Lake is located in the northeast of the Kyrgyz Republic, one of the new independent states of the former Soviet Union, bordered by China, Kazakhstan, Uzbekistan, and Tajikistan. The Issyk-Kul Lake has a maximum depth of 668 m and a surface area of 6240 km^2 and is one of the largest mountain lakes in the world (Hamby and Tynybekov 1999). This region is densely populated by around 450,000 people. The beautiful nature attracts numerous tourists and farming is favorable due to the mild climate. Every summer thousands of tourists from Central Asia countries and Russian Federation have a rest in the resorts which are located nearby Kadji-Sai village with a population of around 5000 people. Uranium tailings and catchment pools of the abandoned mining and processing represent an acute hazard in case of natural disasters such as floods and subsequent landslides in the southern part of Issyk-Kul Lake. These tailings and catchment pools thus endanger people and for the environment. Thus, the threat of radioactive pollution of the lake has become of great public concern. The Issyk-Kul depression was revealed to have extended uranium contents. According to nowadays knowledge uranium in the area comes from weathered granites and carbonaceous-siliceous shales in the surrounding mountains area (Kovalsky 1979). The Kadji-Sai mining site was established in 1948 to extract uranium from lacustrine-palustrine Jurassic brown coal (Nifadiev et al 1996). The deposited total amount of brown coal is approximately 4×10^6 tons with an estimated content of 0.25% to 0.35% uranium. The mining site was set up in the vicinity of the coal outcrop along with a thermal power plant. Uranium was discovered in 1948 and the mining operation started in 1952. The mine got abandoned in 1967 leaving behind a radioactive coal ash volume of 150 to 400 x 10^3 m^3. According to archive data from the Ministry of Emergency Situations of the Kyrgyz Republic the mine tailings and coal mine host rocks, named rock ash disposal area are located 80-400 meters to the southeast of the uranium processing plant territory, partly overlapping with the eastern tributary channel of the Djiluu-Bulak valley. The volume of rock ash disposal is estimated with 200,000 m^3 (Charsky 2003). The uranium extraction process consisted of a two-stage process: coal was combusted in a thermal plant, and then uranium oxide was separated from the ashes by flotation, packed and transported to a plant for further processing (Gavshin, Sukhorukov et al. 2004). Also in 2004 the geological engineering investigation of the Kadji-Sai Uranium Tailing Site was performed by the Ministry of Emergency Situations of the Kyrgyz Republic. The aim was to determine parameters for reliable engineering measurements and protection of facilities from radioactive waste.

In the 1960s the maintenance of tailings piles was in general rather poor. If fences were provided at all they were not maintained or replaced if broken or stolen and no strict regulation with respect to access and concerning re-use of the tailings material were put in place. Livestock grazing on radioactive waste storage facilities and the use of material for construction and domestic needs from waste dumps are widespread. Health and environmental impacts occurred leading diversely to a) disastrous collapse of containments and dams, in some cases causing casualties; b) uncontrolled public access to hazardous sites and inappropriate re-use of tailings, leading to enhanced radiation doses and cancer risks; c) overflow and/or seepage of tailing water into surface water bodies, causing contamination and impacts on the ecosystem along rivers and in lakes; d) infiltration into surface and groundwater bodies, leading to contamination of water resources important for drinking, irrigation, public amenity, and tourism. The identification of radiation exposure due to the re-use of tailings as building material in the USA, mainly as an aggregate for concrete production and for fill material, led to an understanding of the level of risk that tailings pose to human health. A first regulations applying specifically to uranium mill tailings were developed by IAEA-TECDOC-1403 ((IAEA-1403) 2004). In terms of environmental pollution the toxic trace elements originated from mines can become a rather important source of contamination for soil and water as well. Also high mobility factor values for a trace element is an evidence of the relative elevated bio-availability (Kabala and Singh 2001). The most elevated concentration of Pb and Zn in crop grains was recorded in the years of their highest availability to plants (Simunic, Tomic et al. 2002). Hence, to assess the risk of a potential environmental mobility of toxic metals that are contained in this kind of waste, chemical as well as physical properties of tailings is utterly important (Mishra, Bhalke et al. 2007). According to recommendation of the NATO Science for Peace (SfP) project RESCA the Central Asia countries should establish appropriate national regulatory system forming the basis for management of U legacy sites. Furthermore, a national site specific environmental monitoring programme, focussing on radionuclides as well as trace metals, in order to provide scientifically based impact and risk assessments for human and the environment for efficient institutional control of the relevant U legacy sites, should be established (Salbu et al., 2011).

At present the Kadji-Sai tailing and the protective dam and six catchment pools are impacted by natural processes (Figure 2.1). Catchment pools are continuously eroded. Therefore the risk of potential contamination of the Issyk-Kul Lake is increasing. There is a lack of institutional monitoring and control regarding the impact of uranium catchment pools to the environment, especially on the water system.

The brown coal mined was used also for heating purposes in order to supply a semiconductor plant and the Kadji-Sai village respectively except for producing electricity. The name “technology” is used for ash from combustion of brown coal contain a relatively high uranium concentration. Certain radiological and mineralogical studies were performed in the Kadji-Sai tailing site (Gavshin, Sukhorukov et al. 2004). However, geochemical investigations about the mobility of trace elements, chemical composition and morphology of sediments are still lacking. Hence, during May 2009 and June 2010 water and solid materials were sampled. For laboratory explorations of the samples several state-of-the-art techniques were used such as Scanning Electron Microscopy/Energy-Dispersive X-ray (SEM/EDX), X-ray Fluorescence Spectrometry (XRFS), sequential extraction, Inductively Coupled Plasma Mass Spectrometry (ICP-MS), as well as gamma and alpha spectrometry. A geophysical survey was accomplished by the Ministry of Emergency Situations of the Kyrgyz Republic to investigate the geologic structure of the Kadji-Sai uranium tailing site by Vertical Electrical Sounding (VES) with Schlumberger arrays. The electrodes line spreads up to 100 m (Yadav, Dasgupta et al. 2010).

The aim of this work was to carry out an analysis of sediments in the area of interest and the zone that emphasizes the spread of radioactive ash material off-site. Another aim of this research was to assess the risk of the mobility of radionuclides and toxic trace elements with respect to the environment as well as to investigate the different chemical forms of Cr, Ni, Cu, Zn, As, Cd, Pb, Th, and U in the solid samples of the Kadji-Sai uranium tailing site. Another important aspect was to assess the association and bioavailability of these trace elements and their environmental contamination risks among different geochemical phases based on chemical speciation and suggest recommendations for monitoring activities. Also, for the first time a detailed description of the tailings including a digitized map of geology and lithologic structure of the Kadji-Sai uranium tailing site was give.

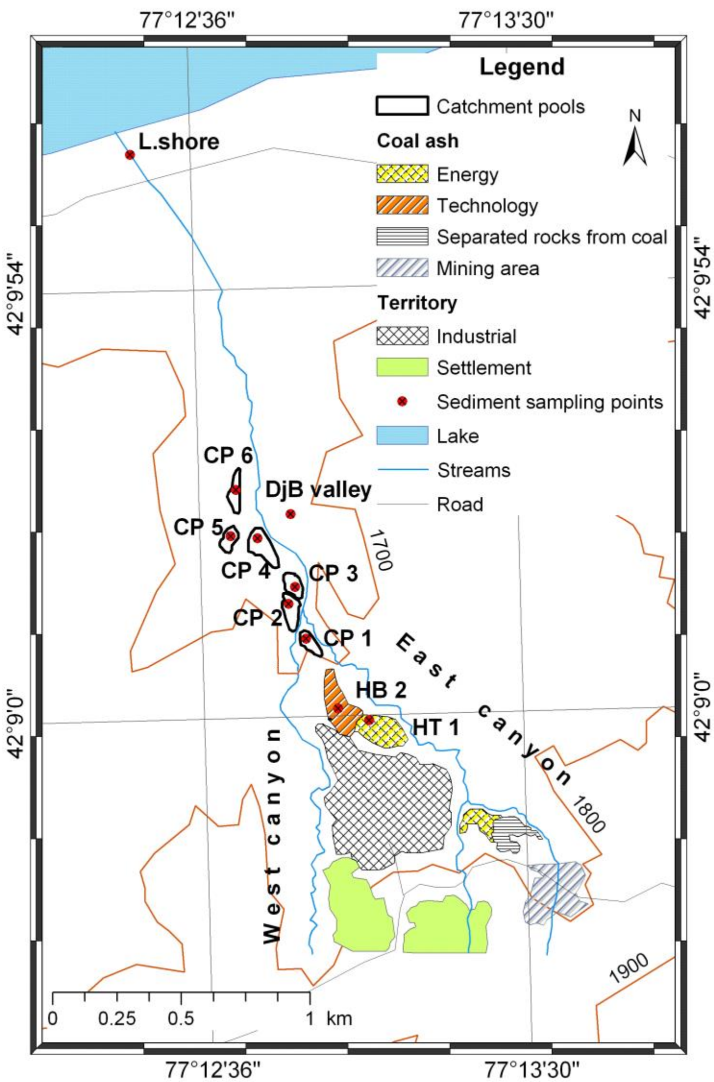

Figure 2.11 *Study area in details (Kadji-Sai tailing site). The Djiluu-Bulak valley and lake shore are located on the north of the tailing dumps. "Technology" and "Energy" coal ash dumps are located in the vicinity of the industrial area. (Datum: WGS 1984)*

2.2.1. Climate

Issyk-Kul Lake, in northeastern Kyrgyzstan is a mountainous lake and the world's fifth deepest lake with a maximum depth of about 665 m. It is located in Kyrgyzstan at a present surface elevation of 1606 m in the midst of Central Asia's Tien Shan Mountains

(Vollmer et al. 2002). Presently Issyk Kul is a terminal lake without outflow and thus accumulating all incoming dissolved constituents. The area around Issyk-Kul Lake is a rather densely populated area, a favorite tourist destination and as well characterized by agricultural activities. However, radioactive waste and tailings of the former Kadji-Sai uranium mine and treatment plant are a high environmental threat. The study area is located in an ecologically adverse zone because the inhabitants of this region are exposed directly or indirectly to the uranium tailing (Tynybekov et al. 2008) (Figure 2.2).

The uranium tailing is located 2 km from Issyk-Kul Lake; Kadji-Sai village with a population of five thousand is 3 km west of the study area. Livestock are grazing around and over the tailing site because the protection fences around the tailing site was destroyed by local people.

The region is characterized by semiarid climate with annual precipitation of 196 to 240 mm, a rather high evaporation rate and thus only minor groundwater recharge rates. Groundwater is therefore a rather vulnerable and precious good in Kyrgyzstan.

Two perennial small rivers courses are passing through the former mining and milling area. The distance of the talweg of the valleys is as close as 30-35 m from the surface of tailing storage and 15-20 m from the foot hill of process coal ash.

The natural tailing storage relief of the tailing storage is impacted by man maid activity; during coal mining and the tailing storage operation. The tailing storage region is limited from the east by “East canyon”, from the west by “West canyon”. It merges with “Djilubulak-Sai” ravine approximately 450 m to the north of “West canyon” area.

Presently Kadji-Sai tailing and the catchment pools are endangered by natural erosion processes and anthropogenic impact as well. Persistent erosion of the tailings with each flood flow and the risk of potential contamination of the Issyk-Kul Lake remain.

The mountain Issyk-Kul lake is a large slightly saline (TDS-5880 mg/l) terminal lake (Kulenbekov and Merkel 2011a) that never freezes during winter (Romanovskii 2000). The mean altitude of the lake surface above sea level is 1608 m. Groundwater in the vicinity of the lake depends on climatic factors, lithological composition of rocks and geostructural features. The semiarid climate with annual precipitation of 196 to 240 mm determines the groundwater recharge in the basin. Precipitation either evaporates immediately or feeds small seasonal rivers. Monthly minimum, maximum and average temperatures are plotted in (Figure 2.2). The meteorological station “Tamga” is located 25 km to the west from the study area at an altitude of 1800 m.

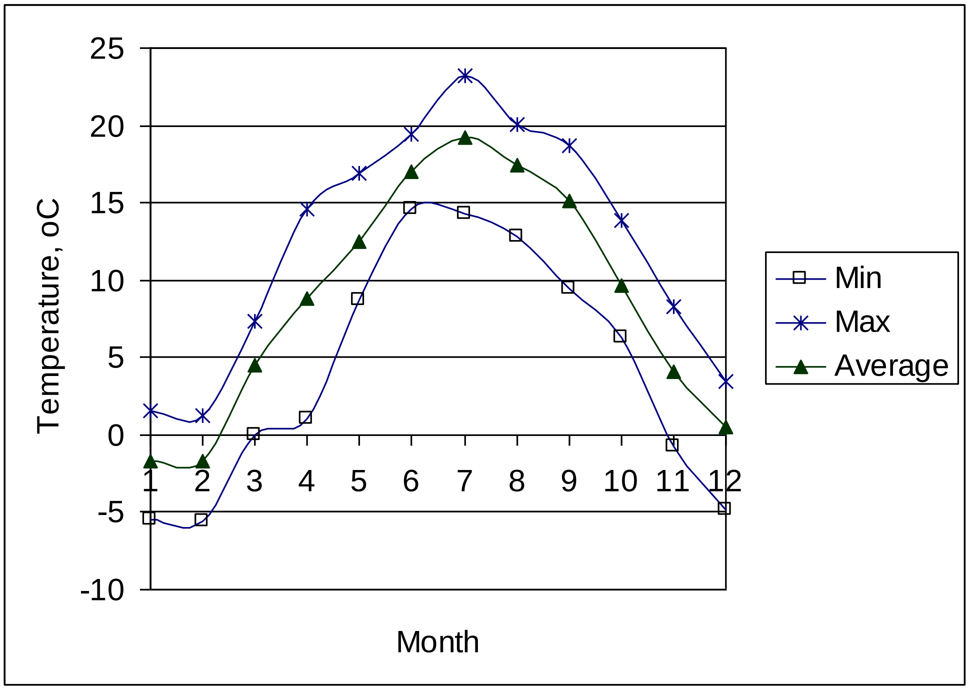

Figure 2.12 *Monthly minimum, maximum and average temperature of the study area (Cholpon-Ata weather station, Lat: 42.65 Lon: 77.08 average elevation: 1666m)*

2.2.2. Geologic structure

According to archive data from the Ministry of Emergency Situations of the Kyrgyz Republic (MESKR 2004) the geological structure of this region is characterized by pre-Paleozoic and Paleozoic eruption, sedimentary and metamorphic formations as well as over-layered Mesozoic rocks and quaternary sediments (Figure 2.3). The pre-Paleozoic and Paleozoic formations are developed in the southern part of the region of interest forming the basic part of the “Terskey Ala-Too” range. The foothill part of the study area is formed by Mesozoic-Cainozoic sediments. Mesozoic sediments lie on coarse and medium-grained rocks as well as monocyte and granitoid in some areas. To the west they changes to coarse-grained biotite Silurian granites which are intruded into "Keregetash" strata including orogenic sandstones, siltstones, microfoliation, and tuff with acid composition. The Mesozoic sediments are characterized by gravelites, conglomerates and sandstones of "Aktash" suite, siltstones and clay of "Koktui" suite which belongs to the upper division of Triassic over covered clay, siltstones and sandstones of "Djilskoi" and "Aksaisk" suites of the lower Jurassic division. Sediments and organic residues of the Mesozoic sediments in the southern part of the Issyk-Kul Lake are typical continental formations which characterize river, shallow-lake water, lake-marsh, and marsh sediments.

The "technology coal ashes" lie within a gorge named "central" (Figure 2.4). The color of the "technology ashes" varies from gray to dark-gray. The natural moisture of "technological ashes" is 70%. The area is characterized by clays which vary from a solid to a fluid-plasticity consistency. The area is also characterized by the large-fragment of soils such as fluvial-proluvial genesis of the middle quaternary age (IQ'iv), see (Figure 2.3) and the sediment of upper subdivision of Oligocene-Miocene (P33-N1κz2). The tailing material was buried on Kyrgyz rock formation. The watershed is formed by the "east canyon" and the "central ravine". The left side of the surface of the "east canyon" slope is exposed and the thickness of large-fragment soils is 1.5 m. Towards the north of the area the thickness of the large-fragment soils is from 3.0-10.0 meters (Figure 2.4).

The left side of the surface of the "east canyon" slope is exposed and the thickness of large-fragment soils is 1.5 m Furthermore, the thickness of the soils is from 3 to 10 meters towards north of the area. On the right side of the surface of the "central ravine" these grounds were completely cut during construction of mud settlers or have an insignificant thickness from 1 to 3 meters.

The deposits of the Kyrgyz (P33N1κz2) formation lie on the base of the geological section, which is characterized by conglomerations, gruss, argillaceous sandstone and ferrous-carbonate-clay cement. In all sections of the area they are inter-bedded but not sustained as well as passing gradually from one layer to another. The thickness of these deposits in the tailings area reaches 300 meters.

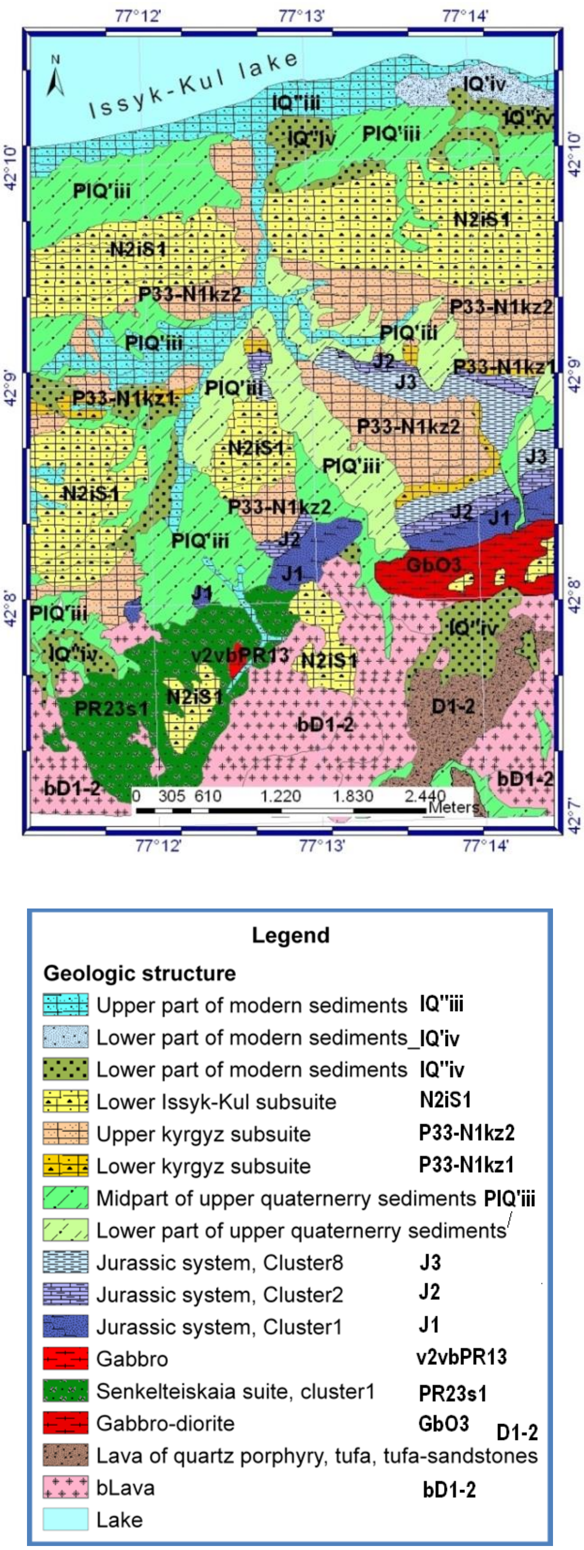

Figure 2.13 *Geologic map (Datum: WGS 1984) of the Kadji-Sai uranium tailing site is digitized based on archive data of the Ministry of Emergency Situations of the Kyrgyz Republic, (2004)*

Lithology of the study area is characterized by the following:

- Lower part: pink-grey sandstones, gravelites, fine pebbly conglomerates, red, brown, greenish-bluish-grayish clays.
- Middle part: various alternatives of pebbles-conglomerates, sandstones, gravelites, greenish-yellow siltstones.
- Top part: alternative strata of conglomerates, sandstones and siltstones, subordinated quantity of clays and marls wastes. The strata thickness is ~ 460-1630 meters.

2.2.3. Uranium tailing site description

According to archive data from the Ministry of Emergency Situation of the Kyrgyz Republic (MESKR 2004) the uranium tailing can be divided into three sections (Figures 2.4, 2.5 and 2.6):

1. The tailing dump itself (section 1) is a dump area with steep slopes. The tailing dump is in the close vicinity of the north part of the milling and extraction facility with a total area of 1.8 hectares. The radioactive coal ash material ("technology coal ash") lies at depths of 1.7-9.8 m under low radioactive coal ash ("energy coal ash"). This is covered with coarse-grained material with a thickness of 0.5-1.0 m. The maximum thickness of the radioactive waste is 7.8 m. The average thickness of the radioactive coal ashes is 5 m. The area covers 14,400 m^2 and the radioactive waste volume is 72,000 m^3. Two small creeks are located ~35 m from the tailing storage and ~20 m from the processed coal ash.

2. The industrial waste tailing No. 2 is located below the section 1 behind the protective dam which is rather close to the riverbed of the east canyon. The radioactive waste of 2.5 m thickness is covered with sandy gravel from 0.15-0.4 m. However, some areas of the section 2 are exposed due to erosion. The radioactive waste average thickness of coal ashes is 1.5 m. The area stretches over 3,900 m^2 and the radioactive waste volume is 5,900 m^3.

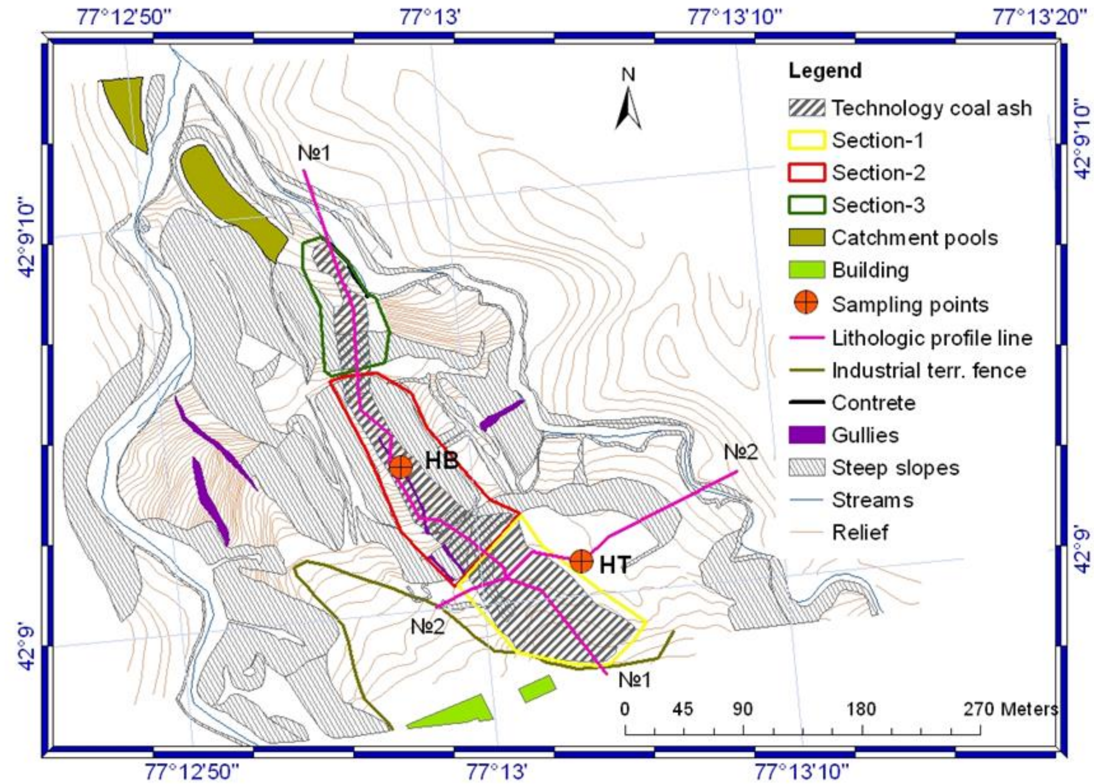

Figure 2.14 *Uranium tailing dump (technology coal ash) and lithologic profile line No.1 and No.2 indicated on this map (detailed profile scheme shown in Figure 2.5 and 2.6). Label HB and HT are sampling points called the technology and energy coal ashes, respectively This map is digitized based on archive data of the Ministry of Emergency Situation of the Kyrgyz Republic (2004).(Datum: WGS 1984)*

3. Section 3 is located between the north part of the tailing site and section 2 in the pit named "central". The thickness of the radioactive waste of section 3 is 5.5 m, but it becomes thinner to the direction of the dam where thickness varies from 0.5 to 0.7 m. Section 3 is covered with sandy gravel material; its thickness varies from 0.15-2.0 m, but is exposed at some places. The radioactive waste average thickness of coal ashes is 1.5 m. The area covers 2,500 m^2 and the radioactive waste volume is 3,800 m^3. The total volume of deposited radioactive waste in the Kadji-Sai uranium tailing dump site is 82,000 m^3.

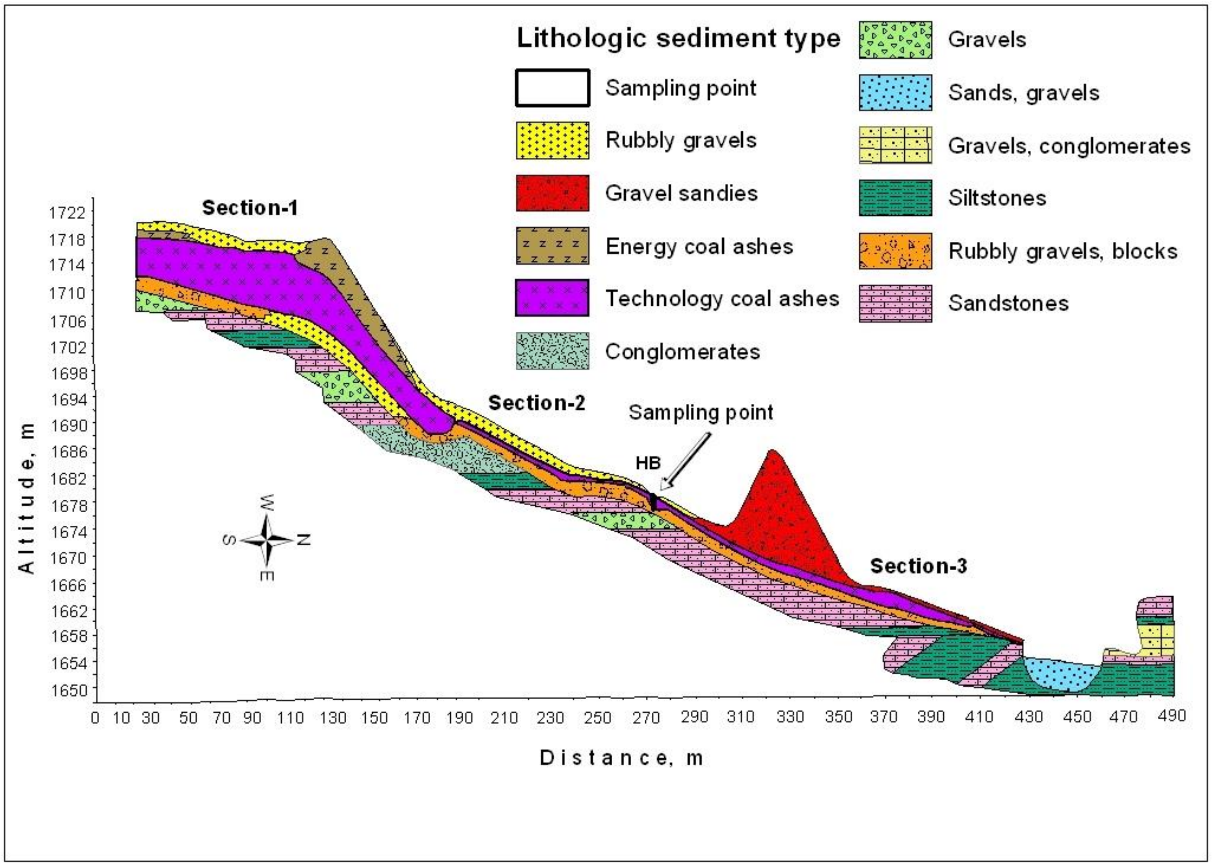

Figure 2.15 *Lithologic cross section No.1 (the position of this cross section is shown in Figure 2.4) and sampling point HB (technology coal ash) on the Kadji-Sai uranium tailing dump. This map is digitized based on archive data of the Ministry of Emergency Situation of the Kyrgyz Republic (2004)*

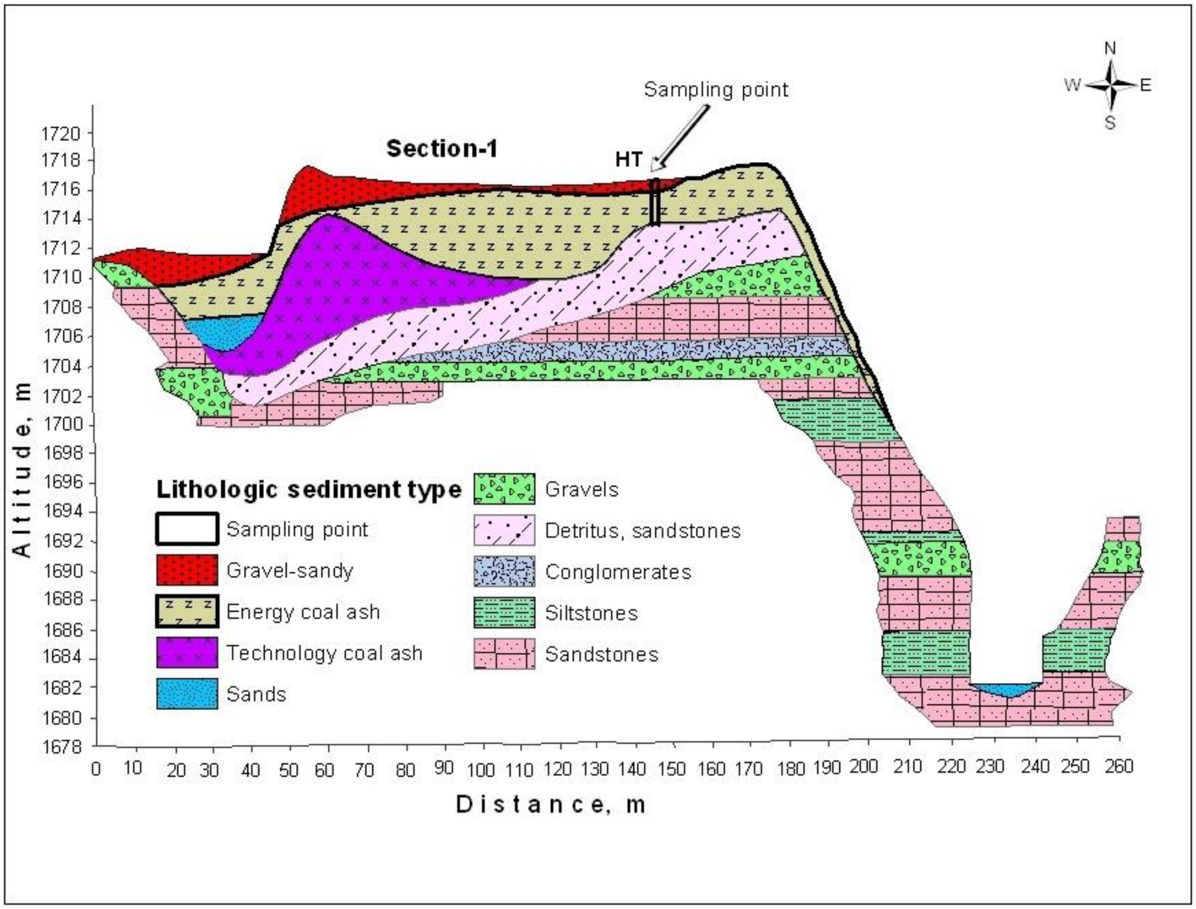

Figure 2.16 *Lithologic cross section No.2 (the position of this cross section is shown in Figure 2.4) and sampling point (energy coal ash) on the Kadji-Sai uranium tailing dump. This map is digitized based on data of the Ministry of Emergency Situation of the Kyrgyz Republic (2004)*

2.3. Methods

2.3.1. Materials and methods

A total of 24 solid samples was randomly collected with 12 solid samples from catchment pools, 2 samples from the Djiluu-Bulak valley, 2 samples from the Issyk-Kul lake shore sediments (at the depths of 0.1m and 0.2m) and 8 samples from uranium tailing dumps. In the latter case 4 sediment cores were taken at the tailings site by drilling two bore holes at different depths (0.1, 1.0, 2.0. and 3.0 m); one borehole in each tailing dump, respectively. Hand auger equipment for hand drilling was used to drill to a depth of approximately 10 meters. All drilling bits were made of stainless steel to avoid contamination of soil samples. Extension rods and accessories are made of electro-galvanized steel. The soil sampler tube was designed for sampling of undamaged soil structure for manual drilling geological boreholes. The weight of each sample was 400 grams. All samples were crushed and milled to a grain size of <60 micrometer in order to get homogenized powders. The samples were then dried at 108^{o}C for 12 hours to ensure that moisture is completely removed.

2.3.1.1. Gamma spectrometry analysis

The powdered samples were put in a standard plastic container (70 x 20 mm) and after properly tightening the threatened lid, the containers were sealed with adhesive tape and left for at least two weeks before counting by gamma spectrometry in order to ensure that the daughter products of ^{222}Rn and ^{232}Th are in secular equilibrium with their respective parent radionuclides and then the gamma ray spectrum was accumulated to for 15 hours. The sample containers were placed at the front of the active volume of a shielded high purity germanium (HPGe) (n-type) detector. The detector has a relative efficiency of about 38% and an energy resolution of 1.9 keV FWHM for the 1332 keV gamma transition of ^{60}Co. The specific activities of the important radioisotopes were determined by comparison with International Atomic Energy Agency (IAEA) standards ((IAEA-148) 1987) RGU-1, RGUTh-1, RGK-1 each with a SiO_2 matrix and the same geometry. Differences in densities of samples and standards were corrected. Gamma spectrometry was performed in the Applied Physics Department, TU Bergakademie Freiberg. The activity concentration of uranium in spring water additionally was measured with the HPGe (n-type) detector in a low level shielding. In that case the sample can be measured without any pre-treatment. A pure water sample causes lines in the range between 80 and 120 keV that means good detection conditions for the uranium double line at 92.5keV. This method has an essentially higher detection limit and lower precision in comparison with alpha spectrometry. The detection limit can be considerably reduced if some liters of water are used and boiled down. For ^{238}U the estimated detection limit in a small container (25 cm^3) was approximately 150 µg/l. The measuring time was about one week. According to IAEA conversion unit the specific activity of natural U-238 is 12.4 Bq which is equal to 1 mg (IAEA).

2.3.1.2. Alpha spectrometry analysis

Alpha spectrometric analysis (ASA) of water samples was performed in the Radioactivity Measuring Laboratory[1] at State Agency for Environmental Radioactivity Measurement, Chemnitz, Germany. High-resolution, high-efficiency alpha spectroscopy with a Si detector (ORTEC, ULTRA) was used. 25 ml of a water sample (ES2) were filtered with a 200 nm membrane filter (Membrex 25CA) and acidified with ultrapure HNO_3 (65%) for ASA in pre-cleaned PE bottles. This method has essentially higher detection limits and similar precision in comparison with ICP-MS. The detection limit of the alpha spectrometry for ^{238}U is <0.001Bq. The natural radionuclides such as ^{238}U, ^{235}U, ^{234}U, ^{226}Ra and ^{210}Po were determined with alpha spectroscopy. However, the main disadvantage of alpha spectrometry is the long analysis time which is a result of the long chemical separation procedure for the complete separation of the target radionuclide(s) from the matrix as well as from interfering radionuclides, and the very long counting time (1-30 days).

2.3.1.3. Sequential extraction analysis

Solid samples were collected at defined depths from the catchment pools and ash deposits which stem from either combusting coal to produce electricity (energy coal ash) or combusting coal to extract uranium (technology coal ash) for the first time at this site.

Sediment samples from the Kadji-Sai uranium tailing site were collected from two drilled boreholes at different intervals (0.0-0.1 m; 0.7-1.0 m; 1.7-2.0 m; 2.7-3.0 m) and from other sampling points at intervals (0.0-0.1 m and 0.1-0.2 m) such as Djiluu-Bulak valley, and lake shore for sequential extraction analysis. The optimized method of Zeien and Bruemmer was applied for the sequential extraction of Cr, Ni, Cu, Zn,

[1] Dr. W. Preusse and MSc. K. Guenther

As, Pb, Th, and U (Table 2.1) (Zeien and Bruemmer 1991). After the prescribed time interval for each extraction plus time for settling, the supernatant water was filtered through a 200 nm membrane filter (Membrex 25CA). The remaining solid sample was twice washed with high-purity DI water before continuing with the next extraction step. Once an entire sequential extraction replication was completed, the samples were analyzed for trace elements by inductively coupled plasma spectrometry (ICP-MS, Thermo Scientific XSERIES 2).

Regarding sequential extraction range of validity shown (Table 2.1) in the sequential extraction is optimized for oxidized carbonate (5% $CaCO_3$) moderately is suitable for carbonate-free soils. However, in this study result from X-ray fluorescence spectroscopy was used instead of the chemical extraction method in step 7. The original method uses strong acid digestion (aqua regia) for this step. The sequential extraction fractionates the trace elements in the soil in the order of decreasing solubility. As a result, the exchangeable and carbonate (F1 + F2) fractions which are the early fractions, capture the most reactive and presumably the most mobile and bioavailable fractions (Kestern and Forstner 1989). The relative index of trace elements mobility is calculated as a mobility factor (MF) (Salbu, Kreling et al. 1998); (Narwal, Singh et al. 1999); (Kabala and Singh 2001) in the following equation (see subheading 2.1.4).

Table 2.1 *Sequential extraction procedure for the speciation of trace metals (Zeien and Bruemmer 1991)*

Group	**Extraction procedure**	**Shaking**
Fractions and binding forms (2 g soil and 40 mL solution)		
Step 1. mobile: water soluble and exchangeable	1M [a]NH_4NO_3	24 h
Step 2. easily deliverable	1M [b]CH_3COONH_4 (pH 6)	24 h

Step 3. occluded in manganese oxides	0.1M [c]NH_2OHHCl + 1M CH_3COONH_4 (pH 6)	30 min
Step 4. organically bound	0.025M [d]NH_4 – EDTA ($C_{10}H_{16}N2O_8$) (pH 4.6)	90 min
Step 5. occluded in poorly crystalline Fe-oxides	0.2M NH_4 oxalic acid buffer ($H_2C_2O_2$) (pH 3.25)	4 h
Step 6. occluded in well crystalline Fe-oxides	40ml 0.1M ascorbic acid ($C_6H_8O_6$) in 0.2M NH_4 oxalic acid buffer (pH 3.25)	30 min boiling
Step 7. Residual	XRF	

[a]*NH_4NO_3 = ammonium nitrate*

[b]*CH_3COONH_4 = ammonium acetate*

[c]*NH_2OH-HCl-NH_3 + Cl = HO = hydroxylammonium chloride*

[d]*NH_4-EDTA = ethylene diamine tetra-acetic acid with ammonia solution*

2.3.1.4. ICP-MS

Inductively coupled plasma mass spectrometry (ICP-MS) is applied in water and leachates. At present, quadrupole-based ICP-MS (X-Series II, Thermo Fisher Scientific) with collision / reaction cell was used. The introduction of the collision cell in ICP-MS was one of the most significant improvements in ICP-MS instrumentation for a more thoughtful analysis of trace elements including radioactive elements in comparison with the commercial quadrupole ICP-MS without collision cell (Becker 2003). The ICP mass spectromter was equipped with an autosampler (Cetac ASX-520), a concentric glass nebulizer and a collision cell. In current study the collision gas was 7% H2 in Helium (He) and the flow of the collision gas was 5 ml/min. The collision mode was Kinetic Energy Discrimination (KED) Mode. The method provides a detection limit about 1 ng/l. Detection limit for Cr (20 ng/l), Ni (100 ng/l), Cu (100 ng/l), Zn (1000 ng/l), As (250 ng/l) and for Cd and Pb (10 ng/l), for Th and U (1 ng/l). An internal standard is a known amount of a compound, different from analyte that is added to the unknown. Signal from analyte is compared with signal from the internal standard to find out how much analyte is present. Internal standards like Germanium was used for the light elements (Cr, Ni, Cu, Zn, As) and Rhodium for the middle masses (Cd) as well as Rhenium for the heavy elements (Pb, U, Th), respectively. The internal standards were added to samples for natural Uranium-238 and Thorium-232. The concentrations of the standard solutions were 0.1, 1, 5, 10 ppb for Thorium and 0.1, 1, 5, 10, 25, 50 ppb for Uranium. For preparation of external calibration standard the following standard solutions were used a) the name of the first multi-element standard is called Merck VI for 30 trace elements including uranium, b) ULTRA's ISO 9001:2000 for 17 elements including thorium.

2.3.1.5. Mobility factor of trace elements

The mobility factor was computed according to Narwal et al. and Kabala and Singh (Narwal, Singh et al. 1999) as

$$MF = \frac{F1 + F2}{F1 + F2 + F3 + F4 + F5 + F6 + F7} \cdot 100$$

Where

F1 = water-soluble + exchangeable trace element content fraction

F2 = trace elements content bound to carbonate fractions

F3 +F5+F6= trace elements content bound to Fe-Mn oxide fraction

F4 = trace element content bound to organic matter fraction

F7 = residual trace element content fraction

2.3.1.6. X-ray fluorescence analysis

X-ray Fluorescence Spectrometry (XRFS - SPECTRO XEPOS, AMETEK) was used to analyze the trace element concentrations. Samples were crushed and milled to a grain size of <60 micrometer in order to have a homogenized sample. The samples were then dried at 108^{o}C for 12 hours to ensure that moisture is completely removed. 5 g of a powder was poured into a cuvette with an inner diameter of 28 mm. The bottom of the cuvette is covered by a 4 μm prolene foil. After pouring, the powder was slightly pressed with a pestle to form a good surface and to avoid any air holes on the bottom.

2.3.1.7. Scanning electron microscope and energy dispersive x-ray analysis

Scanning Electron Microscopy (SEM – JEOL 7SM 7001F, 2010) was used to investigate the morphology of particles as well as the distribution of trace elements. The SEM was equipped with a Si (Li) NORAN X-ray detector (EDX). The samples were crushed and milled to a grain size of <60 micrometer in order to have a homogenized one. The samples were then dried at 108^{o}C for 12 hours to ensure that moisture is completely removed. Samples were coated with a gold-palladium alloy. The EDX detection limit is 0.1 wt %. The magnification used was 100x and 1000 x for smooth surface and crack surface.

2.4. Results and discussion

2.4.1. Local dose rate

In total, 42 measurements of ambient dose rates at 1 m above ground were performed at the sampling points. A histogram of the results is given in (Figure 2.7). The natural worldwide background radiation is 2.40 mSv/y (UNSCEAR, 2010)

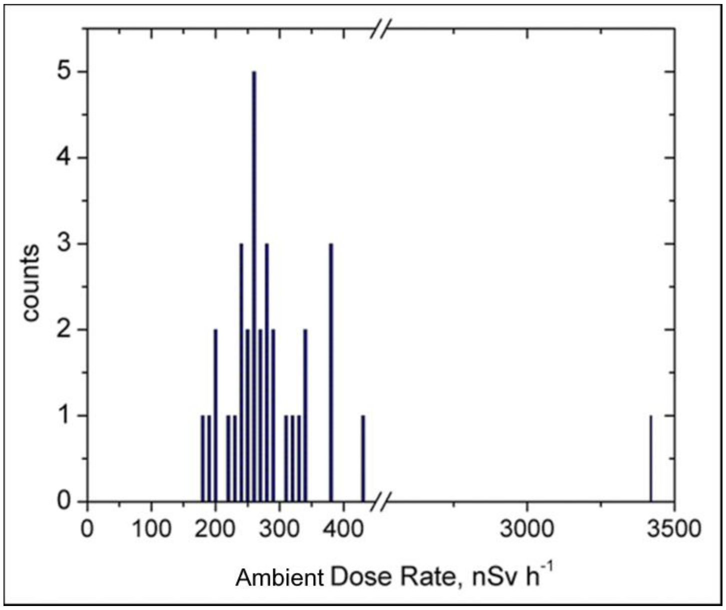

Figure 2.17 *Distribution of ambient dose rates at 1 m above ground (nSv/h) was measured in the Kadji-Sai uranium tailing site*

Gamma radiation dose rates in the vicinity of the tailing site varied between 200 and 400 nSv/h (1.8 to 4.3 mSv/y) with an average of 300 nSv/h (2.6 mSv/y). The average is thus rather close to worldwide natural background radiation. The highest value at one point of the tailings was 3400 nSv/h i.e. 30 mSv/y (1 year = 8760 hours) where technological coal ashes and radioactive equipment are deposited. The total area with a gamma radiation dose rate at 400 nSv/h is about 22000 m^2 and represents a volume of contaminated material of about 11000 m^3.

2.4.2. Specific activity

Regarding the radioactive equilibria or disequilibria, two different phenomena can be distinguished to explain the behavior of the uranium in the sediments:

1. Principally, observations were found at concentrations close to the geogenic background because uranium and its disintegration products are bound in auxiliary material. A radioactive equilibrium between ^{238}U and ^{226}Ra was observed in sediments from the Djiluu-Bulak valley, Issyk-Kul Lake shore

sediment and “energy coal ash” (Figure 2.9). It implies that no chemical processes have altered the geogenic equilibrium.

2. The Kadji-Sai uranium tailing site (“technology coal ashes”) shows a radium enrichment relative to uranium (Figure 2.8 a). The observation of Kadji-Sai uranium tailings indicates that the uranium concentration is less than radium in the “technology coal ashes” because most of the uranium oxide was extracted in the treatment plant.

Radium and uranium reveal a different transport and migration behavior due to their different chemical properties. Separation of elements occurs by exogenous processes; in particular transport processes in aqueous phase are distinctive. In low activity sediments from catchment pools the content of uranium is elevated with respect to radium but is not much higher than background levels (Gavshin, Sukhorukov et al. 2004). In the catchment pools 3, 5 and 6 uranium and radium are in equilibrium with the natural background levels. However, in the catchment pools 1, 2 and 4 the sediments are enriched in uranium. According to sampling in 2009/2010, the lower content of uranium in the catchment pool CP 3 probably is due to erosion issues. CP 3 was covered with sediments during flood events from east and west canyon of Djiluu-Bulak valley in the vicinity of the uranium tailing dump. At present, CP 3 is filled with water coming from the spring water of the west canyon. This situation is due to the excavation of a small trench by local inhabitants to divert the water flow into CP 3 in order to feed livestock. Water analysis from CP 3 shows uranium concentration of 97µg/l, which is rather elevated with respect to WHO drinking water guidelines of 15 µg/L (World Health Organization, 2003). According to the water sample taken were not according to the recommendation of the U.S. EPA Groundwater Standards for Inactive Uranium Tailing Sites (EPA 1989) (Table 2.2).

Hence, the concentration of uranium elevated with respect to radium in low activity sediments from catchment pools but is not much elevated in comparison to background levels, except for catchment pool number one. Radioactive equilibrium in CP 5 and CP 6 and disequilibria in the CP 1, 2, 3 and 4 between ^{238}U and ^{226}Ra observed in solid samples from the six catchment pools of Kadji-Sai uranium tailing site shown in Figure 2.9 implies that obviously most uranium has been precipitated in the upper catchment pools. Gamma spectroscopy showed significant elevated activities for ^{238}U, ^{226}Ra, and ^{210}Pb (Kulenbekov and Merkel 2011a).

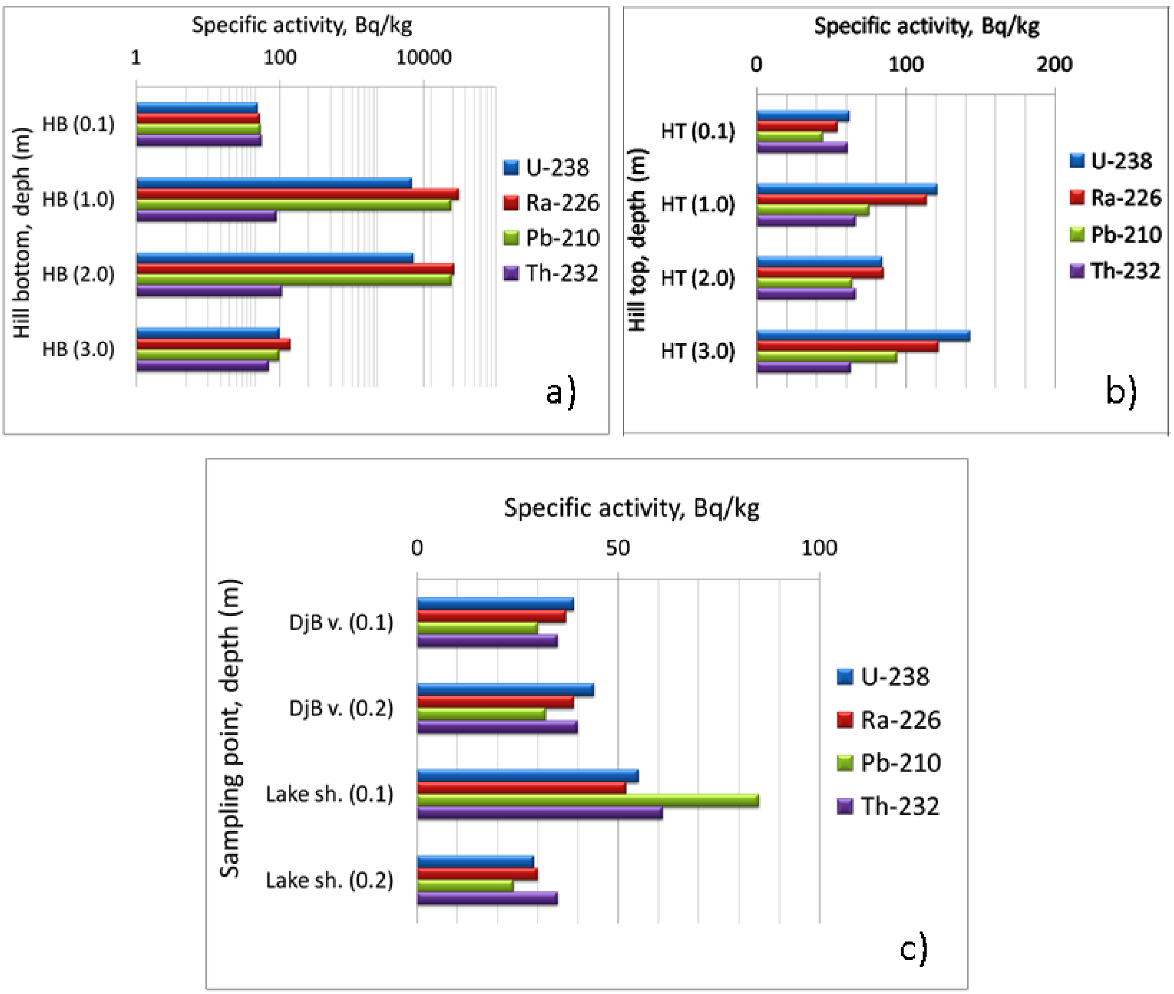

Figure 2.18 (a, b, c) *Specific activity of natural radionuclides (U, Ra, Pb, Th) in solid samples from the Kadji-Sai uranium tailing site were observed: a) technology coal ashes, b) energy coal ashes, c) Djiluu-Bulak valley and Issyk-Kul lake shore sediments*

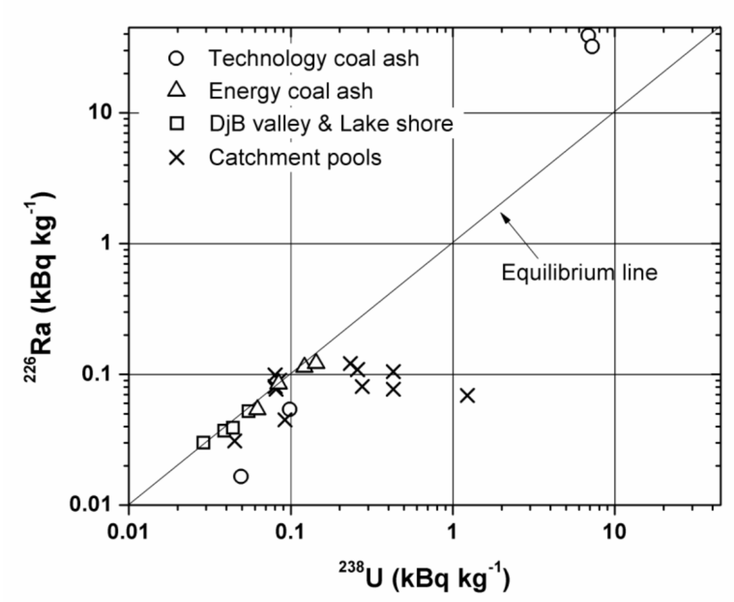

Figure 2.19 *Radioactive equilibrium and disequilibria between ^{226}Ra and ^{238}U natural radionuclides in all observed solid samples from the Kadji-Sai uranium tailing site (logarithmic scale) are shown here*

Also the $^{234}U/^{238}U$ ratio in spring water (0.98 and 1.50 in two samples) is close to the maximum value found earlier by (Chalov, 1975) in the tributaries of Issyk-Kul Lake. The analyses of water samples indicated that the outflow from underneath the ash dumps contains four times more uranium (170 to 280 µg/l), than that the water from Issyk-Kul lake, (64±2 µg/l of uranium).

Most water samples taken were not in accordance with the recommendation of the U.S. EPA Groundwater Standards for Inactive Uranium Tailing Sites (40 CFR Part 192). However, for natural radionuclides such as ^{235}U, ^{226}Ra and ^{210}Po activities were lower than the threshold value of 1.11 Bq/l and 0.185 Bq/l respectively (Table 2.2). The concentration of uranium in springs, streams and lake one can get from (Kulenbekov and Merkel 2012b). Also some water sample such as spring water (ES2) and (ES3) on the east canyon showed low level gamma activities. Gamma spectrometry for ^{238}U in a water sample (ES2) showed 3.3 ± 1.0 Bq/l (equivalent to 265 ppb) while alpha spectrometry produced 3.6 Bq/l (equivalent to 289 ppb). It implies that the two methods are providing comparable results. Water samples taken in 2010 from two spring waters (ES2 and ES3) beneath the coal ash dumps on the east canyon contained 170-288 ppb with $^{234}U/^{238}U$ ratio 1.5 and 0.94, respectively. This is a slight difference to water samples taken by Gavshin in 2001 from the outflow beneath the ash dumps containing 220-240 ppb U and a ratio of $^{234}U/^{238}U$ of 1.43 and 1.60. These values are close to the maximum value found earlier by Chalov in 1975 in the tributaries of the Issyk-Kul Lake.

Table 2.2 *Results of alpha spectrometry of water samples taken from spring waters such as (ES2) and (ES3) on the east canyon as well as from surface water (WSt5) flowing from spring waters (WS4) in the west canyon. All mentioned spring waters are located in the direct vicinity of the uranium tailing dump*

Probe	**^{234}U**	**^{238}U**	**^{235}U**	**^{226}Ra**	**^{210}Po**	**$^{234}U/^{238}U$**
	Bq/l	**Bq/l**	**Bq/l**	**Bq/l**	**Bq/l**	
ES2	3.4±0.2[c]	3.6±0.2	0.14±0.01	0.036±0.004	< 0.03	0.94
ES3	2.4±0.2	1.6±0.1	0.06±0.002	0.042±0.005	[a]nd	1.5
WSt5	1.9±0.1	1.0±0.1	0.05±0.002	0.039±0.004	nd	1.9
[b]MCL	**1.11**	**1.11**	**1.11**	**0.185**		

[a]*nd - not detectable (detection limit: <0.001 Bq)*

[b]*MCL - Maximum Contaminant Level U.S. EPA (United States Environmental Protection Agency) Groundwater Standards for Inactive Uranium Tailing Sites (40 CFR Part 192)*

[c]*± error*

2.4.3. Characterization of sediments and coal ash samples

Sequential extraction procedures are commonly applied because they provide information about the mobility of metals in different lattices of the solid sample which is a good compromise to give information on environmental contamination risk (Mishra, Bhalke et al. 2007). Table 2.3 gives the result of the total concentration of toxic trace elements of uranium tailings, Djiluu-Bulak valley, and Issyk-Kul lake shore at different depths. The concentration of most of the trace elements in “technology coal ash” samples (labeled as HB), (see Figure 2.3) is extremely elevated in comparison with that of normal soil, as well as with IAEA-433 reference materials ((IAEA-433) 2004). Cr, Pb, Th, and U are slightly elevated in cover material. However, in bottom material U is elevated more than three times. This is expected due to the uranium waste deposit. Concentration of the trace elements in “energy coal ash” samples (labeled as HT), (Figure 2.3) is comparable with IAEA-433 reference materials. However, Cu, Pb, Th, and U are elevated even more. Most trace elements in DjB v. samples (Djiluu-Bulak valley) and L. shore samples (Issyk-Kul Lake shore) are similar to IAEA-433 reference materials, except for Pb and Th. The concentration of Pb in Djiluu-Bulak valley samples as well as Pb and Th in lake shore sediments is slightly elevated. Most probably the uncovered energy coal ashes have reached the Djiluu-Bulak valley and Issyk-Kul Lake shore by stream water which flow along the east canyon during flood flows. Comparable concentrations of rare soil elements measured by means of instrumental neutron activation analysis (INAA) were found for samples of volatile fly ashes in Poland (Smolka-Danielowska 2010).

Table 2.3 *Distribution of total radioactive and toxic trace elements in seven fractions (uranium tailing – sediments and technology coal ash at the depths of 0.1 m-3.0 m as well as sediments of the Djiluu-Bulak valley and Issyk-Kul Lake shore at the depths of 0.1 m-0.2 m, investigated with sequential extraction analysis. The technology and energy coal ash samples are labeled as HB (hill bottom) and HT (hill top)*

Total concentration (µg/g) of mean ± standard deviation (n=3)				
Sediments and technology coal ashes of tailing dump in depth of 0.1m-3.0 m				
	HB (0.1)	**HB (1.0)**	**HB (2.0)**	**HB (3.0)**
Cr	47±2	105±3	100±3	642±2
Ni	47.7±0.8	112±1	109±1	36.8±0.7
Cu	29.5±0.7	130±1	127±1	37±1

Zn	84.4±0.8	305±2	287±2	122±1
As	16.3±0.4	73±1	91±1	17.1±0.4
Pb	41.7±0.6	109±1	116±1	47.6±0.6
Th	20.9±0.3	38±1	38.4±0.6	21.5±0.3
U	5.1±0.2	912±2	930±3	13.1±0.4
Sediments and energy coal ashes of tailing dump in depth of 0.1m-3.0 m				
	HT (0.1)	**HT (1.0)**	**HT (2.0)**	**HT (3.0)**
Pb	33.4±0.6	26.7±0.7	25.8±0.6	26.6±0.6
Th	19.3±0.3	17.4±0.5	19.8±0.4	18.3±0.4
U	6.1±0.3	14.1±0.4	8.7±0.3	15.6±0.4
Sediments of Djiluu-Bulak valley in depth of 0.1m-0.2 m				
	DjB v. (0.1m)	**DjB v. (0.2m)**		
Pb	44±1	40.3±0.5		
Th	13.1±0.3	18.2±0.3		
U	3.5±0.1	2.7±0.1		
Sediments of Issyk-Kul Lake shore in depth of 0.1m-0.2 m				
	L. shore (0.1m)	**L. shore (0.2m)**		
Pb	41.5±0.5	35.9±0.4		
Th	21.6±0.1	14.5±0.1		
U	4.7±0.2	2.0±0.1		
***Ref**	Cr-136±10	Ni-39.4±3.1	Cu-30.8±2.6	Zn-101±8

	As-18.9±1.8	Pb-26.0±2.7	Th-9.8±0.57	U-2.45±0.24

***Ref** – Observed values in IAEA-433 marine sediment certified reference materials*

Table 2.4 shows the total concentration of toxic trace elements in the uranium catchment pools (CP) in the Djiluu-Bulak valley at different depth. The total concentration of Cr and Zn in 0.1 to 0.2 m depth of CP 3, CP 5 and CP 6, As in 0.1 to 0.2 m of CP 3 as well as Th, U in 0.2 m of CP 3 and Cd in 0.1 to 0.2 m of CP 5 and CP 6 were close to natural background levels. However, the total concentration of Pb, Th, and U were twice in 0.1 m depth of CP 5 and CP 6. Moreover, the total concentration of most of the trace elements in catchment pools is extremely elevated in comparison with that of normal soil, as well as with IAEA-433 reference materials values (Analytical Quality Control Service of IAEA, 2004), except for Cd, Pb, Th and U slightly elevated in 0.1 m depth of CP 3.

***Table 2.4** Distribution of total trace elements in seven fractions, six uranium catchment pools at depths of 0.1 to 0.2 m according to sequential extraction method*

Total concentration (µg/g) ***(Depth - 0.1 m)***						
	CP No.1	**CP No.2**	**CP No.3**	**CP No.4**	**CP No.5**	**CP No.6**
Cr	1679±12	449±5	87.4±1.9	999.3±7.2	69.3±2.4	56.8±2.2
Ni	6918±22	1535±7	379±2	5216±10	54.4±0.9	50±1
Cu	13176±32	4442±12	363±1	7695±17	48.8±0.3	42.9±0.1
Zn	1497±2.9	655±10	170±1	1989±6	230.6±0.5	114.9±0.3
As	33.5±6.8	32.6±0.2	16.9±0.2	36.9±0.3	42.9±0.5	36.6±0.3
Cd	559.3±1.6	181.5±0.3	14.3±0.9	509±1	2.3±0.5	2.2±0.5
Pb	372±2	105±1	45.6±0.5	101±1	60.2±0.5	52.6±0.7
Th	28.4±0.5	27.1±0.5	17.6±0.3	29.1±0.8	47.8±0.5	44.8±0.7
U	59.8±0.7	28.2±0.6	9.9±0.3	49.1±0.7	6.8±0.2	7.8±0.2
Total concentration (µg/g) ***(Depth - 0.2 m)***						

	CP No.1	CP No.2	CP No.3	CP No.4	CP No.5	CP No.6
Cr	5395±21	533.6±5.3	59.4±1.6	1426±10	70±4	96.6±3.1
Ni	16451±30	12480±7	400±2	8009±34	64.6±1.5	59±1
Cu	43696±111	5439±11	395±1	10942±21	49.6±4.7	45.8±0.1
Zn	4585±15	751±13	147.2±0.4	2543±4	137.5±13.4	139.1±0.5
As	40.1±0.1	34.1±0.2	7.5±3.9	29.5±0.8	43.4±4.9	42.1±0.4
Cd	1434±3	228.5±0.4	10.5±0.6	690. ±2	2.3±1.7	2.2±0.3
Pb	616.6±3.1	111±1	34.7±0.4	124.2±0.6	65.6±0.5	56.1±0.8
Th	19.6±0.7	28.1±0.4	10.7±0.6	30.7±0.7	50.5±0.9	49.7±0.6
U	205.4±1.4	35.2±0.6	2.7±0.1	83.7±0.9	6.7±0.3	7.5±0.3
***Ref**	Cr 136±10	Ni39.4±3.1	Cu 31±3	Zn 101±8	As 19±2	Cd 0.2±0.1
	Pb 26±3	Th 9.8±0.6	U 2.5±0.2			

**Ref – Observed values in IAEA-433 marine sediment certified reference materials*

2.4.4. Distribution of trace elements in different fractions and bio-available species

Speciation of Cr, Ni, Cu, Zn, As, Pb, Th, and U in the tailing dumps (technology coal ash), and speciation of Pb, Th and U in the tailing dumps (energy coal ash), DjB valley and Issyk-Kul lake shore are represented in Figures 2.11, 2.12 and 2.13 respectively. Diagrams as a, b, c, d, e, f, g, h (hill bottom) (Figure 2.11) and i, j, k, (hill top) l, m, n, (DjB valley) o, p (lake shore) (Figures 3.12 and 3.13) are represented by the formula of (F)/(M), where [F] is the concentration of speciation fraction; [M] = total element concentration of trace elements at the different depth of 0.1 to 3 m. To evaluate the bioavailability, mobility and chemical reactivity in soils and sediments the knowledge of the chemical species of soluble trace elements conjugated with particulates/colloids are essential (Hickey and Kittrick 1984). Trace elements are conjugated with diverse soil components in different ways and these conjugations determine their mobility and availability (Ahumada, Mendoza et al. 1999). The speciation of Cr, Ni, Cu, Zn, As, Cd, Pb, Th, and U in the six catchment pools of CP1 to CP6 (in the following 7 fractions of sequential extraction technique) is plotted in Figure 2.1 to 2.9 (see Appendix 1).

2.4.4.1. Step1, water soluble and exchangeable

The mobile fraction includes water-soluble, readily soluble organic complexes, and weakly absorbed trace elements. Therefore, the mobile fraction has a particular ecological importance. Uranium solubility and mobility are enhanced by formations of carbonate and hydroxyl carbonate complexes, which is one effect on uranium bioavailability (Radgnarsdottir and Charlet 2000). In "energy coal ash" the concentrations of Cr, Ni, Cu, Zn, As and Pb was not considered in this work due to the low concentrations in comparison to IAEA guidance values, while for Pb and Th the observed concentration indicated comparably low shares of 0.01% to 0.025% and of 2.6% to 13.75% at a cover material (at the depths of 0.1 m and 0.2 m), respectively. For U the concentration was of 2.1% to 3.8% in bottom material (at 3.0 m depth). In energy coal ash (at the depths of 1.0 and 2.0 m) for U the concentration was of 2.8% to 4%, respectively (Figures 2.11 and 2.12). In the Djiluu-Bulak valley (at the depths of 0.1 and 0.2 m) Th and Pb concentrations were in the range of 0.01% and 0.04% respectively, but U was at 12.5% at 0.1 m depth and from 2.73% to 4.53% at a depth of 0.2 m. In the Issyk-Kul lake shore for Pb and Th the concentrations were from 0.05% to 0.13% and from 0.01% to 0.05% at the depths of 0.1 and 0.2 m, respectively, but for U from 5.4% to 2.5% at a 0.1 m depth and from 8.4% to 10% at a depth of 0.2 m, respectively. Therefore, the above mentioned trace element shares show that in Djiluu-Bulak valley the U concentration at a depth of 0.2 m was relatively elevated than that at a depth of 0.1m. A contrary situation was observed in Issyk-Kul Lake shore: concentration of U at a depth of 0.1 m was relatively elevated in comparison to that at a depth of 0.2 m (Figures 2.12 and 2.13).

This fraction of step 1 represents those trace elements soluble in water. For the six catchment pools, mean fractional content of the trace elements was as follows: Cr (0.08%), Ni (1.2 to 1.3%), Cu (5.1 to 5.4%), Zn (0.6 to 2.6%), As (0.5 %), Cd (2.9 to

3.8%), Pb (0.009 to 0.01%), Th (0.03%), and U (6.2 to 8.3%). Generally, the total metal content of this phase decreases with depth, except for Cd and U in the catchment pool CP3 (Figure 2.1 to 2.9 in Appendix 1).

2.4.4.2. Step2, easily deliverable (carbonate-bound fraction)

The adsorbed fraction contains easily deliverable, carbonate-bound species, and metal-organic complexes. For Cr, Ni, Cu, Zn, As, Pb, and Th the observed rates varied between 0.11% and 0.52% at a depth of 0.1 m and 0.19% to 0.63% at a depth of 3.0 m. For U rates between 7.64% and 9.10% were determined in cover and bottom sediments of HB sampling point. In "technology coal ash" Cr, Ni, Cu, Zn, As, Pb and Th concentrations were found in the range of 0.15% to 0.96% at a 1.0 m depth, while U was in the range of 1.9% to 2% (Figures 2.11).

The catchment pools contained the following shares of trace elements: Cr: 0.07 to 0.12 %, Ni: 0.82 to 1.14%, Cu: 4.52 to 4.62%, Zn: 2.6 to 4.0%, As: 9.67 to 10.4%, Cd: 9.67-10.35%, (%), Pb: 0.27-0.31%, Th: 0.009-0.01% and U: 4.18-5.05% (Figure 2.1 to 2.9 in Appendix 1).

2.4.4.3. Step 3: species bound in Mn oxide:

Manganese oxides are better accumulators of trace elements than other oxides (Figures 2.11, 2.12 and 2.13). They are able to sorb trace elements strongly over a wide pH range. They dissolve at a very low pH or under reducing conditions. In cover material (at a depth of 0.1 m) of technology coal ashes in the third fraction the concentrations of Pb, U, and Ni shares were in the range of 5.3%, 1.4%, and 1.2%, respectively. The other five trace elements (Cr, Cu, As, Zn, Th) showed a small percentage (<0.8%). In bottom sediments (at 3.0 m depth) the four trace elements (Cr, Ni, Cu, Th) showed a small percentage with a value of <0.9%, but Zn (2.1%), As (1.4%), Pb (2.8%) and U (2.2%) had higher values. In technology coal ashes (at the depths of 1.0 and 2.0 m) the concentrations of Ni, Zn and U were in the range of 3.4%, 2.7% and 3.6%, respectively. In cover material (at 0.1m depth) of energy coal ash the concentrations of Pb and U were in the range of 5.2% and 4.9%, respectively but the share of Th (0.3%) had a lower value. In bottom sediments (at a depth of 3.0 m) the U concentration showed 3.1%, but the shares of Pb (0.3%) and Th (0.1%) had a lower value. The trace element U in coal ash (at the depths of 1.0 and 2.0m) showed 4.3%, but the shares of Pb (0.3%) and Th (0.1%) had lower values as well (Figures 2.11 and 2.12). In sediments of the Djiluu-Bulak valley and Issyk-Kul Lake shore the concentration portions of Pb and Th were 6% and 0.3%, respectively. The concentration of trace elements in this fraction was elevated and comparably with the first and second fractions except for Cu.

Shares of trace elements for the six catchment pools in this steps are Cr (0.43 to 0.48%), Ni (0.86-1.19%), Cu (3.77-3.90%), Zn (2.33-2.74%), As (0.76-0.77%), Cd (9.77-11.66%), Pb (3.83-4.27%), Th (0.04-0.09%) and U (5.02-6.99%) (Figure 2.1 to 2.9 in Appendix 1).

2.4.4.4. Step 4: Species bound in organic matter

Figures 2.11, 2.12 and 2.13 (appendix) show that organic matter in cover and bottom sediments binds only weakly for U and Cr (<1%). The shares of the other six trace elements are between 1.8% and 11.2% in cover material and 4% and 18.5% in bottom materials of the sampling point HB. U (<0.1%), Th (0.8%) and As (<1.6%) have even low shares in technology coal ashes. The rates for the other six trace elements are 2% to 13.2% in technology coal ashes. This indicates that binding of organic matter to Ni, Cu, Zn, As, Pb, and Th is stronger than to Cr and U in cover and bottom sediments. However, in “technology coal ash” binding of organic matter to Cr, Ni, Cu, Zn and Pb is stronger than to As, U, and Th. The concentrations of U and Th were in the range of 0.5% to 0.8% and 4% to 5.5% at the depth of 0.1m and 0.2 m in the Djiluu-Bulak valley and Issyk-Kul lake shore sediments, respectively. The share of Pb was 6.3% to 11% at depths of 0.1m and 0.2 m in the Djiluu-Bulak valley. However, the Pb ratios varied between 12.7% and 6.0% at depths of 0.1m and 0.2 m in the Issyk-Kul Lake shore (Figures 2.11, 2.12 and 2.13).

Shares of trace elements for the six catchment pools in this extraction steps are as follows. Cr: 2.5 to 11.8 %, Ni: 8.1 to 5.0%, Cu: 10.5 to 10.8%, Zn: 14.6 to 14.7%, As: 3.0 to 3.2%, Cd: 7.4 to 8.5%, Pb: 24.0 to 24.4%, Th: 3.5 to 3.8%, and U: (0.6 to 0.8%) (Figure 2.1 to 2.9 in Appendix 1).

2.4.4.5. Step 5: Species bound in Fe oxide

The poorly crystalline and well crystalline iron oxides and residual fraction present in the trace elements contents that are held firmly (Figures 2.11, 2.12 and 2.13, see appendix1). Under normal environmental conditions and reasonable periods of time these trace element fractions are not released and therefore not taken up by plants. They can be converted into more mobile forms only after longer periods and greater dissolution attack by acids and / or reducing agents (Zeien and Bruemmer 1991). Shares of trace elements for the cover sediments of sampling point HB in well crystalline Fe oxide fraction are as follows. Cr, Ni, Zn, As, Pb, Th, and U: from 10.5 to 33.6% while in poorly crystalline Fe oxide fraction: from 1.5 to 8.6%. However, the concentration share of Cu is 7% in poorly crystalline Fe oxide fraction while in the well crystalline oxide fraction it is 5.5%. Similar shares (1% to 17.3%) were observed in bottom sediments, except for U and Cu, with shares of 0.4% to 11.5% and 8.3% to 12%, respectively. For Pb, Th, and U shares (12.2 % to 66.3%) in the well crystalline Fe oxide fraction in cover sediments of the sampling point HT are more elevated as well than those in poorly crystalline Fe oxide fraction (7% to 19.2%). However, for Pb, Th, and U in all four depths the rates (4.3% to 23.9%) in the poorly crystalline Fe oxide fraction are almost twice as those in the well crystalline Fe oxide fraction (1.1% to 9.1%). Rates of Pb, Th, and U in two layers in well crystalline Fe oxide fraction were observed to be more elevated in the Issyk-Kul Lake shore sediments (7.5% to 27.5%) than in the poorly crystalline Fe oxide fraction (3.7% to 15.5%). Rates of Th and U (19% to 28%) in fraction 6 were elevated in comparison with fraction 5 (6.6% to 14.6%) (Figures 2.11, 2.12 and 2.13).

Shares of trace elements for the six catchment pools in this phase are as follows: Cr: 18.9 to -19.9%, Ni: 7.6 to 8.3%, Cu:(9.0 to 9.9%, Zn: 6.1 to 8.2%, As: 9.0 to 10.4%, Cd: 0.6 to 0.7%, Pb: 1.6-1.8%, Th: 14.1 to 15.2%, and U: 14.1 to 17.2%. The concentration of Cr^{3+} in well aerated soils is controlled by the formation of chrome oxides or hydroxides which are stable and have a very low solubility (Jones and Jarvis 1981). Shares of trace elements for the six catchment pools in this extraction step are as follows: Cr: 11.1 to 12.9%, Ni: 7.6 to 8.3%, Cu: 7.5 to 14.6%, Zn: 9.7 to 14.5%, As: 30.5 to 34.5%, Cd: 0.67

to 0.76%, Pb: 6.8-8.1%, Th: 17.2 to 19.3%), and U: 14.2 to 15.9% (Figure 2.1 to 2.9 in Appendix 1).

2.4.4.6. Step 6: Species in residual fraction

Concentration of most trace elements studied in this fraction is rather high. In the case of Cr, Ni, Cu, Zn, and Pb the residual fraction accounts for more than 75% and for U accounts for more than 60% at almost all depth of energy coal ash and sediment samples (Figures 2.11, 2.12 and 2.13). This is a clear indication that these elements are geologically enriched in the bedrock and sediments of the area of investigation.

Shares of trace elements for the six catchment pools in this phase are Cr: 56.5 to 65.0%, Ni: 62.7 to 72.7%, Cu: 52.2 to 58.1%, Zn: (54.6 to 62.7%, As: 51.8 to 54.3%, Cd: 66.4 to 66.8%) Pb: 61.2 to 63.4%, Th: 61.7-65.1%, and U: 48.7 to 52.9%. Cd, Ni, Th, and Pb have their highest rations in this fraction. Schintu et al. (1991) showed that most cadmium is bound to exchangeable site, carbonate fraction, and iron-manganese oxide minerals which can be exposed to chemical changes at the sediment-water interface and are susceptible to remobilization (Figure 2.1 to 2.9 in Appendix 1).

2.4.5. Elemental composition and particle morphology of solid samples

The composition of the chemical element species of coal ashes and sediments from the tailing site was investigated by means of SEM with EDX probe. UO_2 was found with 52.8 wt % at 1.0 m and 10.6 wt % at 2.0 m depth respectively. On contrary, UO_2 was not detected in the cover material at 0.1 m and in the bottom at a depth of 3.0 m. PbO was detected with 35.6 wt % at a depth of 0.1m, but was below detection limit at the depths of 1.0, 2.0 and 3.0 m. CuO and ZnO at 0.1m of the surface layer of the Djiluu-Bulak valley was 24.7 wt % and 17.0 wt %, respectively. ThO_2 at a depth of 0.1m of the surface layer of the Issyk-Kul lake shore was determinant to be 41 wt % (Figure 2.10).

The precise knowledge of the elemental composition of radioactive wastes in the closed down mine is important for the remediation program following the mine closure (e.g. migration of radioactive elements and stability of secondary minerals being formed in the catchment pools). To achieve this, a combination of scanning microscope with micro-analytical techniques SEM/EDX was applied. The task of this research was to determine the dominant elemental composition of the samples formed in the uranium catchment pools of the Kadji-Sai tailing site. CdO in 0.1 and 0.2 m depth of CP 1 was dominant. Cu_2O and NiO in CP 1 were detected as well. ThO_2 and UO_2 at 0.2 m depth of CP 2 as well as PbO, Cr_2O_3 and Cu_2O were detected in CP 4. PbO and ThO_2 were detected in CP 6 as being dominant as well. In comparison with results (Smolka-Danielowska 2010) of the ThO_2 concentration in the monazite crystallites ranged from 2.33% to 6.50 wt%, and, from 0.03% to 0.46 wt% for UO_2, whereas in this study elemental composition of UO_2 and ThO_2 were rather elevated such as 52.8 wt % and 41 wt %, respectively.

However, these metals were not found in CP 3 and CP 5. Hence, the most dominant phase was CdO, Cu_2O, and PbO in four catchment pools (Table 2.5).

Table 2.5 *The elemental compositions of the solid samples from six catchment pools*

	SEM/EDX	
	Depth (0.1m)	**Depth (0.2 m)**
CP 1	CdO (28.4 wt %) Cu_2O (6.5 wt %) NiO (2 wt %)	CdO (42.8 wt %) Cu_2O (10.5 wt %)
CP 2	Cu_2O (5.8 wt %) ThO_2 (1.5 wt %)	ThO_2 (3.5 wt %) UO_2 (1.2 wt %)
CP 3	* no detectable	no detectable
CP 4	PbO (54.7 wt %) Cr_2O_3 (18.6 wt %) Cu_2O (5.0 wt %)	PbO (88.4 wt %)
CP 5	no detectable	no detectable
CP 6	ThO_2 (4.3 wt %)	PbO (26.0 wt %)

** No detectable (According to (Reed,1996) the theoretical detection limits in SEM–EDS measurements are about 0.08 wt% but practically is in the range of 0.1-0.5 wt%. General definitions - less than 1wt%. (trace), 1-10 wt% (minor), 10 wt% (major))*

SEM was also used to investigate the morphology of the coal ash particles and solid samples from the Djiluu-Bulak valley and Issyk-Kul Lake shore in the range of 0.1-50 μm (Figure 2.10). In many cases, nearly all of the solid samples particles were not spherical, except technology coal ash. The spherical shape of the technology coal ash might be due to boiler slag fuse into round, glassy beads during free fall through a vertical tube furnace heated to 1250 °C. Self-cemented pellets of coal fly ash fuse under these conditions into round beads with equally high sphericity (Meyer 1999). The boiler slag is the molten bottom ash collected at the base of slag tap and cyclone type furnaces that is quenched with water. When the molten slag comes into contact with the quenching water, it fractures, crystallizes, and forms pellets. This boiler slag material is made of hard, black, angular particles that have a smooth, glassy appearance (EPA 2009). Approximately one quarter of the particles from the technology coal ash was glassy smooth; the remaining particles were irregularly spaced nodules of rather similar size. In contrast, almost all the particles from the Kadji-Sai were not smooth. Nearly 25% of the particles from the Bull Run Steam Plant were smooth as vitraform glassware; the remaining particles had a few irregularly spaced but permanently sized nodules. Contrastingly, all of the particles from the Mojave Plant (Laboratory 1983) were not smooth; nodules of varying diameter covered the surface of the particles (Lichtman and Mroczkowski 1985).

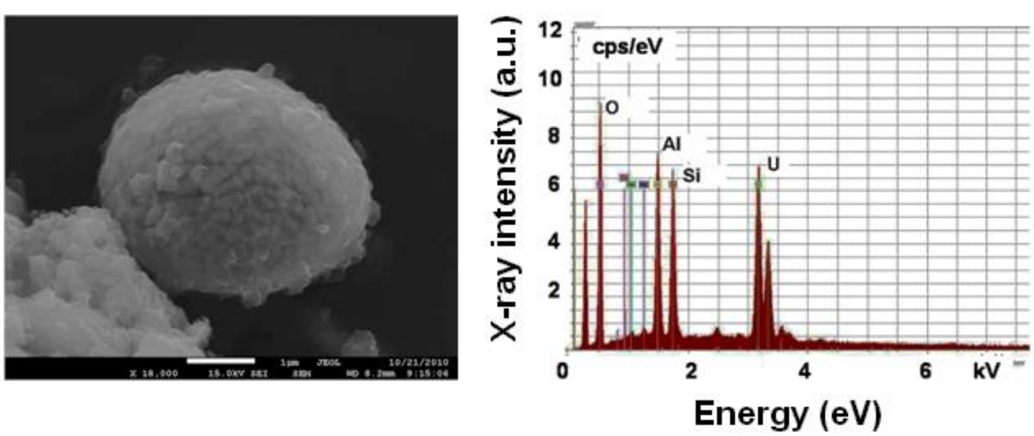

Figure 2.20 *SEM and EDS spectrum of technology coal ash particles collected from the uranium tailing dump at a depth of 1 m (M1 shell)*

2.4.6. Spearman correlation

The non-parametric Spearman correlation analysis was performed to identify probable statistical relationships that may exist among the observed trace element concentrations. The Spearman correlation coefficient is not significant for at least 50% of the trace elements (Table 2.6). Spearman correlation coefficients between trace elements of residual fraction related to energy coal ash at the HT (hill top) sampling point, Djiluu-Bulak valley and Issyk-Kul lake shore sediments are not significant either (Table 2.7).

Table 2.6 *Spearman correlation coefficient r and probability (P) between toxic trace elements of residual fraction of sequential extraction analysis of technology coal ash at the HB (hill bottom) sampling point*

	Ni	**Cu**	**Zn**	**As**	**Pb**	**Th**	**U**
Cr (P-value)	0.20 0.8	0.31 0.68	0.40 0.60	0.20 0.80	0.20 0.80	0.31 0.68	0.20 0.80
Ni (P-value)		0.74 0.26	0.80 0.20	0.60 0.40	0.60 0.40	0.74 0.26	0.60 0.40
Cu (P-value)			0.95 0.05*	0.95 0.05*	0.95 0.05*	1 0.0001**	0.95 0.05*
Zn (P-value)				0.80 0.20	0.8 0.2	0.95 0.05*	0.80 0.20
As (P-value)					1 0.0001**	0.95 0.05*	1 0.0001**
Pb (P-value)						0.95 0.05*	1 0.0001**
Th (P-value)							0.95 0.05*

**Correlation coefficient is significant at p=0.05 level (2 tailed), ** Correlation coefficient is significant at p<0.01 level (2 tailed). Correlation coefficient is not significant at p=0.20-0.80 level (2 tailed).*

Table 2.7 *Spearman correlation coefficient and probability (P) between trace elements of residual fraction of sequential extraction analysis of energy coal ash at the HT (hill top) sampling point and Djiluu-Bulak valley and Issyk-Kul Lake shore sediments*

	Th (HT)	**U (HT)**	**Th (DjB v.)**	**U (DjB v.)**	**Th (Lake sh.)**	**U (Lake sh.)**
Pb (HT) (P-value)	0.50 0.50	- 0.31 0.68	0.4 0.60	0.4 0.60	0.8 0.20	0.8 0.20
Th (HT) (P-value)		- 0.31 0.68		0.4 0.60		0.2 0.80

Correlation coefficient is not significant at p=0.20-0.80 level (2 tailed)

The Spearman correlation coefficient are shown in Table 2.8 and 2.9 for natural U and toxic trace elements such as Cr, Ni, Cu, Zn, As, Cd, Pb, and Th in the six sampling points at 0.1 m and 0.2 m sediment depths. Hence, this indicates a perfect positive and negative association of ranks. The correlation coefficient is assumed as not significant at p≥0.05.

Table 2.8 *Correlation observed between toxic trace elements of residual fraction of sequential extraction analysis of the catchment pools CP1-CP6 (Spearman correlation coefficient r and p-value) at 0.1 m sediment depth*

Depth: 0.1 m		**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Th**	**U**
		CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6
Cr	CP1-6	0.94	0.94	94	0.54	0.90	0.94	-0.143	0.83
	p	**0.0001	**0.005	**0.005	0.266	*0.05	**0.005	0.787	*0.042
Ni	CP1-6		1	1	0.26	0.99	0.83	-0.429	0.94
	p		**0.0001	**0.0001	0.623	**0.0001	*0.042	0.397	**0.005
	CP1-6			1	0.26	0.99	0.83	-0.42	0.94

Cu	p			*0.0001	0.623	**0.0001	*0.042	0.397	**0.005
Zn	CP1-6				0.26	0.99	0.83	-0.429	0.94
	p				0.623	**0.0001	*0.042	0.397	**0.005
As	CP1-6					0.15	0.60	0.49	0.03
	p					0.784	0.208	0.329	0.957
Cd	CP1-6						0.812	-0.46	0.99
	p						*0.050	0.354	**0.0001
Pb	CP1-6							0.09	0.77
	p							0.872	0.072
Th	CP1-6								-0.49
	p								0.329

Table 2.9 *Correlation coefficients observed between toxic trace elements of residual fraction of sequential extraction analysis of the catchment pools CP1-CP6 (Spearman correlation coefficient r and p-value) at 0.2 m sediment depth*

Depth: 0.2 m		**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Pb**	**Th**	**U**
		CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6	CP1-6
Cr	CP1-6	0.77	0.83	1	0.49	0.81	1	-0.03	0.99
	p	0.072	*0.042	**0.0001	0.329	*0.050	**0.0001	0.957	**0.0001
Ni	CP1-6		0.94	0.77	0.14	0.93	0.77	-0.60	0.75
	p		**0.005	0.072	0.787	**0.008	0.072	0.208	0.084
Cu	CP1-6			0.83	0.09	0.986	0.83	-0.54	0.81
	p			0.042	0.872	**0.0001	**0.042	0.266	*0.050
Zn	CP1-6				0.49	0.81	1	-0.029	0.99
	p				0.329	*0.050	**0.0001	0.957	**0.0001
As	CP1-6					0.06	0.49	0.37	0.46
	p					0.913	0.329	0.468	0.354
Cd	CP1-6						0.81	-0.58	0.82

	p		*0.050	0.223	*0.044
Pb	CP1-6			-0.03	0.99
	p			0.957	**0.0001
Th	CP1-6				-0.06
	p				0.913

2.4.7. Mobility factor of trace elements in sediments and coal ashes profile

A high mobility factors (MF) for trace elements in soil can be interpreted as evidence of a relatively high mobility and biological availability (Karczewska 1996); (Ma and Rao 1997); (Narwal, Singh et al. 1999); (Kabala and Singh 2001). The mobility factors of the trace elements for all sites at different depths are presented in (Table 2.10 and 2.11). High mobility factors were observed for uranium at different depths (from 0.1 m to 3 m) of sediments and coal ashes in sampling points hill bottom, hill top, DjB valley and lake shore and for zinc at hill bottom (1 and 3 m depth) and for nickel at hill top (1 and 2 m depth). The mobility factors of trace elements in cover material at hill bottom follow the order U > Zn > Cu > As > Ni > Pb > Cr > Th. Samples in bottom material from hill bottom follow the order U > Zn > As > Cu > Ni > Pb > Th > Cr. In “technology coal ashes” at hill bottom the order is U > Ni > Zn > As > Cu > Cr > Pb > Th. The mobility factors of trace elements in cover material and coal ash of the HT, DjB valley and lake shore follow the order U > Pb > Th. These values are not related to any particular trend with respect to sediment and coal ashes depth. Bioavailability for trace elements was found to be very low. The mobility factor for eight trace elements was lower than 12.5%. The highest mobility was determined for uranium and the lowest one for Th except for the bottom material of HB in which the lowest mobility was obtained for Cr.

Table 2.10 *Mobility factors of trace elements from the samples of “technology coal ashes”, at the HB (hill bottom) sampling point*

	Depth (m)	**Cr**	**Ni**	**Cu**	**Zn**	**As**	**Pb**	**Th**	**U**
HB	0.1	0.16	0.7	1.7	2.1	1	0.3	0.04	10

HB	1.0	0.27	1.4	0.6	0.9	0.6	0.05	0.03	4
HB	2.0	0.35	1.4	0.5	0.7	0.7	0.04	0.03	7
HB	3.0	0.01	0.4	0.9	4	1.2	0.3	0.05	12.5

Table 2.11 *Mobility factors of trace elements from the samples of energy coal ashes at the HT (hill top), sediments in the Djiluu-Bulak valley and Issyk-Kul Lake shore sampling points*

	Depth (m)	**Pb**	**Th**	**U**		**Depth (m)**	**Pb**	**Th**	**U**
HT	0.1	0.12	0.04	16.3	**DjB v.**	0.1	0.07	0.02	15
HT	1.0	0.08	0.02	6.7	**DjB v.**	0.2	0.08	0.01	17
HT	2.0	0.04	0.01	4.2	**Lake sh.**	0.1	0.1	0.01	14
HT	3.0	0.02	0.01	6	**Lake sh.**	0.2	0.1	0.02	12.4

Mobility factors for six catchment pools and depths are shown in Table 2.12. The mobility factors are low for Cr, Pb, and Th at all catchment pools. Therefore, there elements are not readily available, and poses no risk to the development of plants and human health. The mobility factors are at a medium level for Ni and As at all catchment pools. The mobility factors of U, Cd ,and Cu was elevated for CP 2, 3, 5 and 6, therefore elevated bioavailability in the solid samples of Kadji-Sai uranium catchment pools was revealed except for CP 1, 2, 3, 4 and in the lower depth (0.2 m) of CP 5. This is a threat to the ecosystem. Mobility factors are only high for Zn in CP 2 and 5. The mobility factors for the trace elements in all catchment pools ranged from U: 1.84 to 33.7; Cd 1.28 to 30.1; Cu: 0.78 to 27.4; Zn: 0.78 to 11.5; Ni: 0.2 to 6.4; As: 0.37 to 1.6; Cr: 0.03 to 0.64; Pb: 0.12 to 0.45; and Th:0.007 to 0.1 in the following order U>Cd>Cu>Zn>Ni>As>Cr>Pb>Th. Trace elements Pb and Th have low mobility factors in the sediments of Kadji-Sai uranium catchment pools and hence a low bioavailability. They pose no environmental threat at present.

Table 2.12 *Mobility factor for trace elements assayed for in six catchment pools of Kadji-Sai uranium tailing site*

Mobility factor							
Metals	**Depth (m)**	**CP1**	**CP2**	**CP3**	**CP4**	**CP5**	**CP6**
Cr	**0.1 m**	0.13	0.23	0.27	0.13	0.06	0.05
	0.2 m	0.08	0.19	0.64	0.12	0.05	0.03
Ni	**0.1 m**	2.89	5.53	4	1.67	0.24	0.28
	0.2 m	2.93	0.74	6.38	1.56	0.19	0.2
Cu	**0.1 m**	11.26	27.39	7	12.15	1.02	0.81
	0.2 m	11.25	21.72	12.45	11.43	0.91	0.78
Zn	**0.1 m**	4.91	9.4	2.31	1.62	11.52	1.7
	0.2 m	2.2	7.84	4.5	1.67	0.58	10.78
As	**0.1 m**	0.95	0.97	1.3	0.92	1.05	0.63
	0.2 m	0.37	1.05	1.63	0.98	0.83	0.59
Cd	**0.1 m**	12.28	27.26	20.76	15.72	2.05	1.49
	0.2 m	8.09	25	30.08	14.5	2.04	1.28
Pb	**0.1 m**	0.45	0.54	0.31	0.36	0.16	0.13
	0.2 m	0.2	0.5	0.41	0.32	0.12	0.12
Th	**0.1 m**	0.09	0.03	0.04	0.03	0.01	0.008
	0.2 m	0.1	0.03	0.06	0.03	0.02	0.007
U	**0.1 m**	6.44	12.73	17.31	6.42	12.24	12.55
	0.2 m	1.84	10.56	33.69	4.19	12.6	12.24

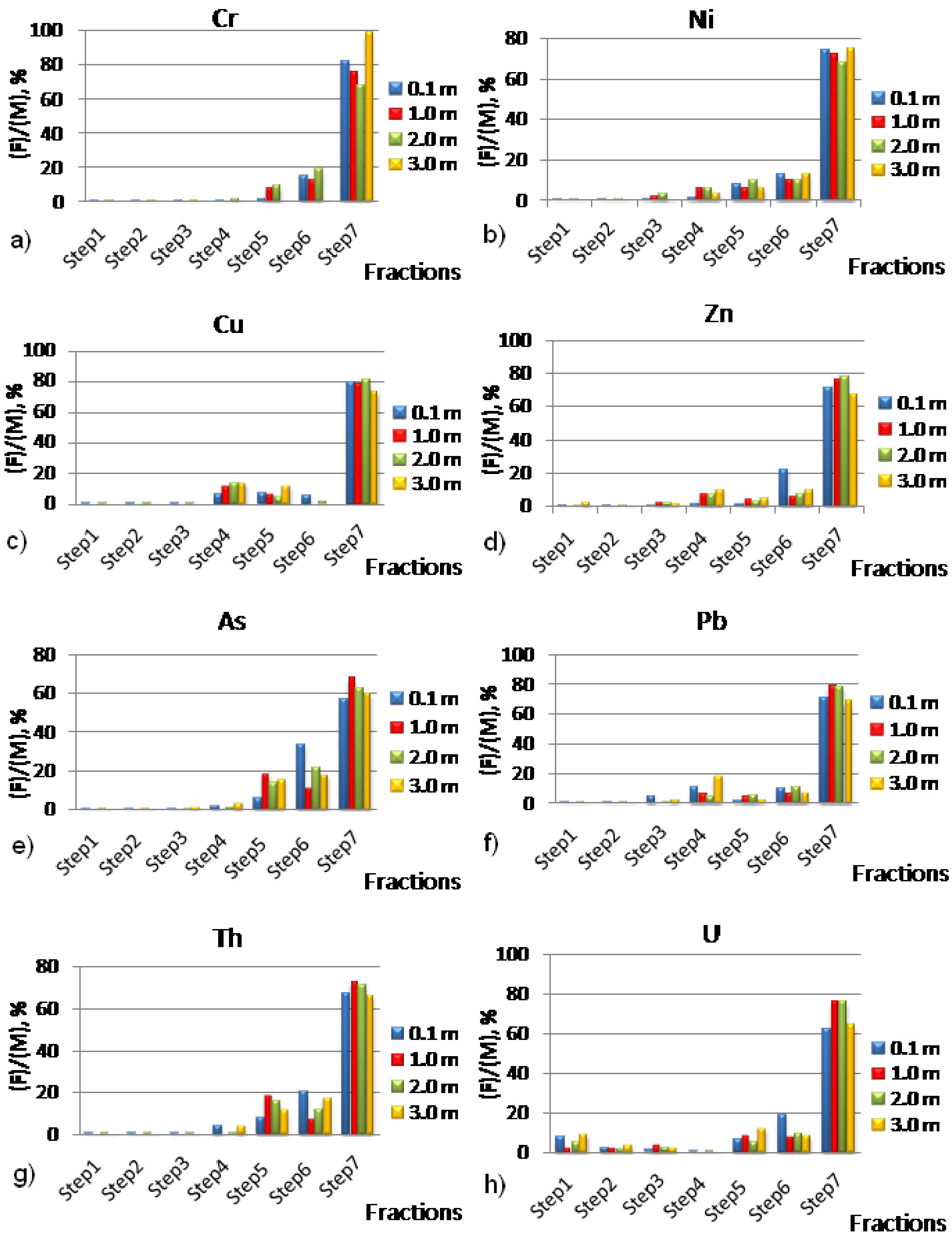

Figure 2.21 (a, b, c, d, e, f, g, h) *Speciation of Cr, Ni, Zn, As, Pb, Th and U in the tailing dumps: Diagrams of (Hill bottom) is represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.3 m*

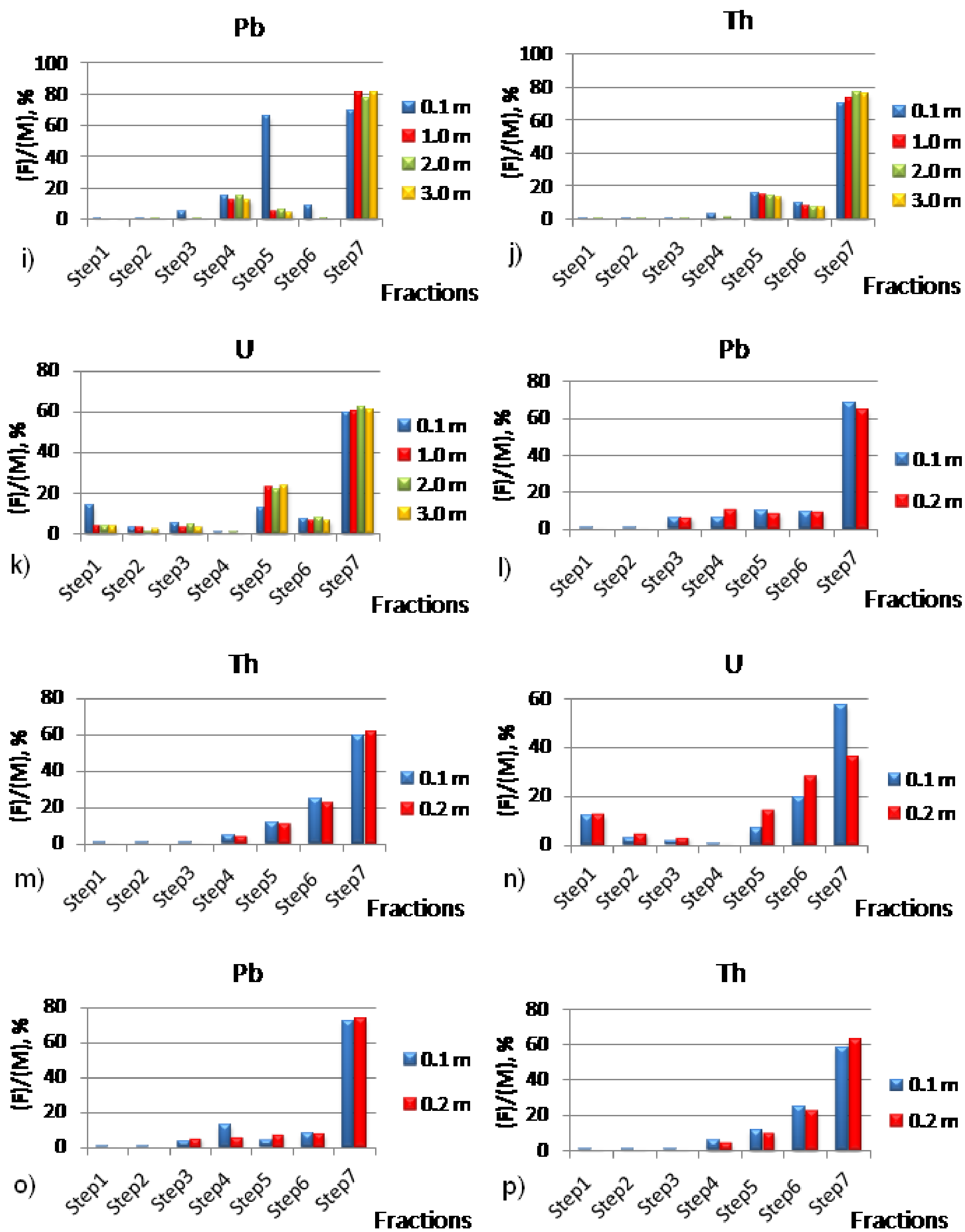

Figure 2.22 (I, j, k, l, m, n, o, p) *Speciation of Pb, Th and U in the tailing dumps, valley and lake shore: Diagrams as i, j, k, (Hill top) l, m, n, (DjB valley) o, p (Lake shore) represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1 m-3 m*

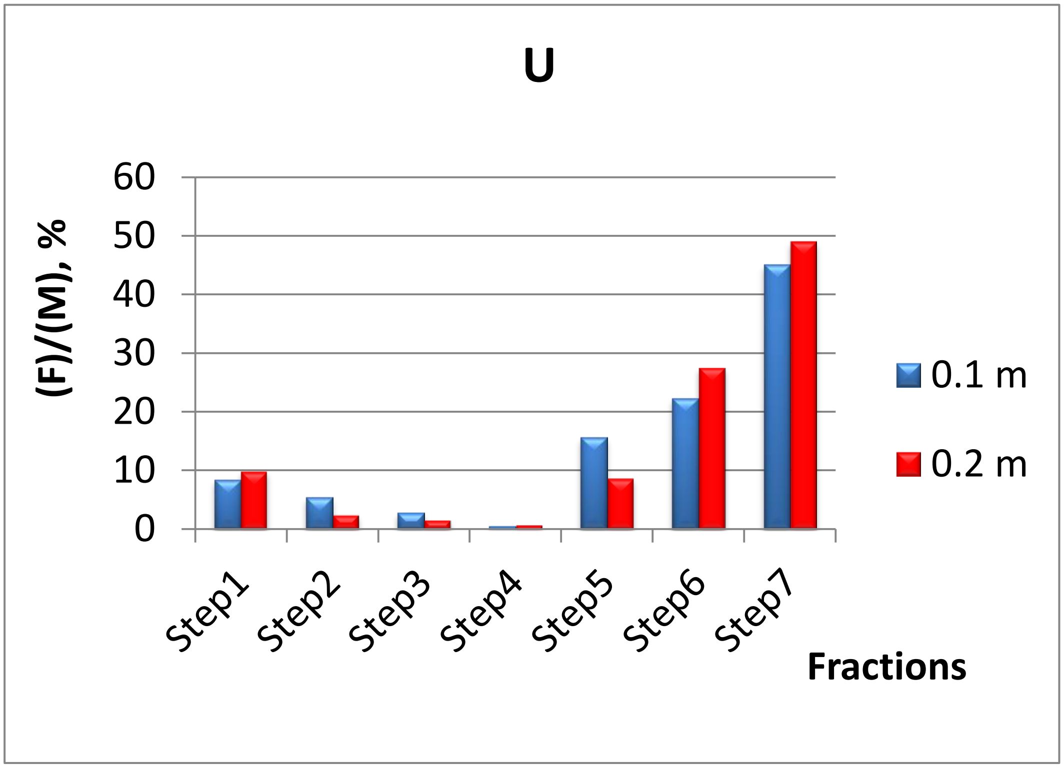

Figure 2.23 *Speciation of U in the Issyk-Kul Lake shore: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*

2.5. Conclusion

The Kadji-Sai uranium tailing site is hazardous due to radioactive and toxic elements that remain in the deposits. Sudden or continuous release of contaminants may have a substantial impact on the environment.

The tailing and geology-lithologic structure of the study area was mapped and described based on the archive data of the Ministry of Emergency of the Kyrgyz Republic.

The bottom of the tailing dumps and ash wastes consist of fluvioglacial–proluvial sediments, coarse gravels and complex inter-bedded layers in horizontal section. In deeper layers there are gravels, conglomerates, sandstones, and siltstones of the Kyrgyz suite. Gravel infiltration rate is higher than other rocks. Therefore, rain water in the tailing dump after leaking downward from the “technology” coal ash in section three might infiltrate in higher rate down through pebbly-gravel layer and reach the shallow water. This is probably a reason of elevated concentration of uranium in the vicinity of the springs.

The chemical fractionation of trace elements revealed the geochemical nature of eight trace elements investigated and their probable association with different chemical forms in the sediment and coal ashes in the uranium tailing site. The results showed that the trace elements concentrations found in the residual fraction were rather high in comparison with the other fractions. The mobility of eight trace elements in “technology coal ashes” and three samples of “energy coal ash”, the Djiluu-Bulak valley and the Issyk-Kul Lake were lower than 12.5%. The highest mobility was determined for uranium and the lowest one for Th except for the bottom material of hill bottom sampling point in which the lowest mobility was obtained for Cr. At present the uranium tailing site does not endanger the environment at a high risk. However, in a worst-case scenario when a debris flow would happen in this area due to strong rain events, first of all the Issyk-Kul Lake will be polluted with uranium and toxic trace elements.

The chemical fractionation of the trace elements studied revealed the geochemical nature of the nine trace elements and their probable association with different chemical forms in the solid samples around the six uranium catchment pools in the vicinity of the Kadji-Sai uranium tailing site. The results showed that the trace elements concentrations found in the residual fraction was higher than those observed in any of the preceding extractions except for U, Cd, and Cu where water soluble and exchangeable fractions were slightly elevated. The trace elements fractionation results give an overall picture that high percentage of the trace elements were found to be strongly bound to soil matrix i.e. in a form not readily available for uptake into the food chain except for U, Cd and Cu. This dominance of the residual fraction clearly illustrates the difficulties of distinguishing between background and anomalous levels of trace element contamination when only total trace element analysis is performed. The relatively high mobility factor observed for U, Cd, and Cu confirms the high liability, and biological availability in some of the solid samples.

Consequently, the government cannot be encouraged to reclaim and utilize the sites for agricultural, residential, commercial or industrial purposes without a thorough clean-up. Furthermore, the precise knowledge of the elemental composition of the radioactive waste buried in the Kadji-Sai uranium tailing site and in the vicinity of the closed mine is important for a remediation program following the mine closure (e.g. migration of radioactive elements and stability of secondary minerals being formed in the dump piles).

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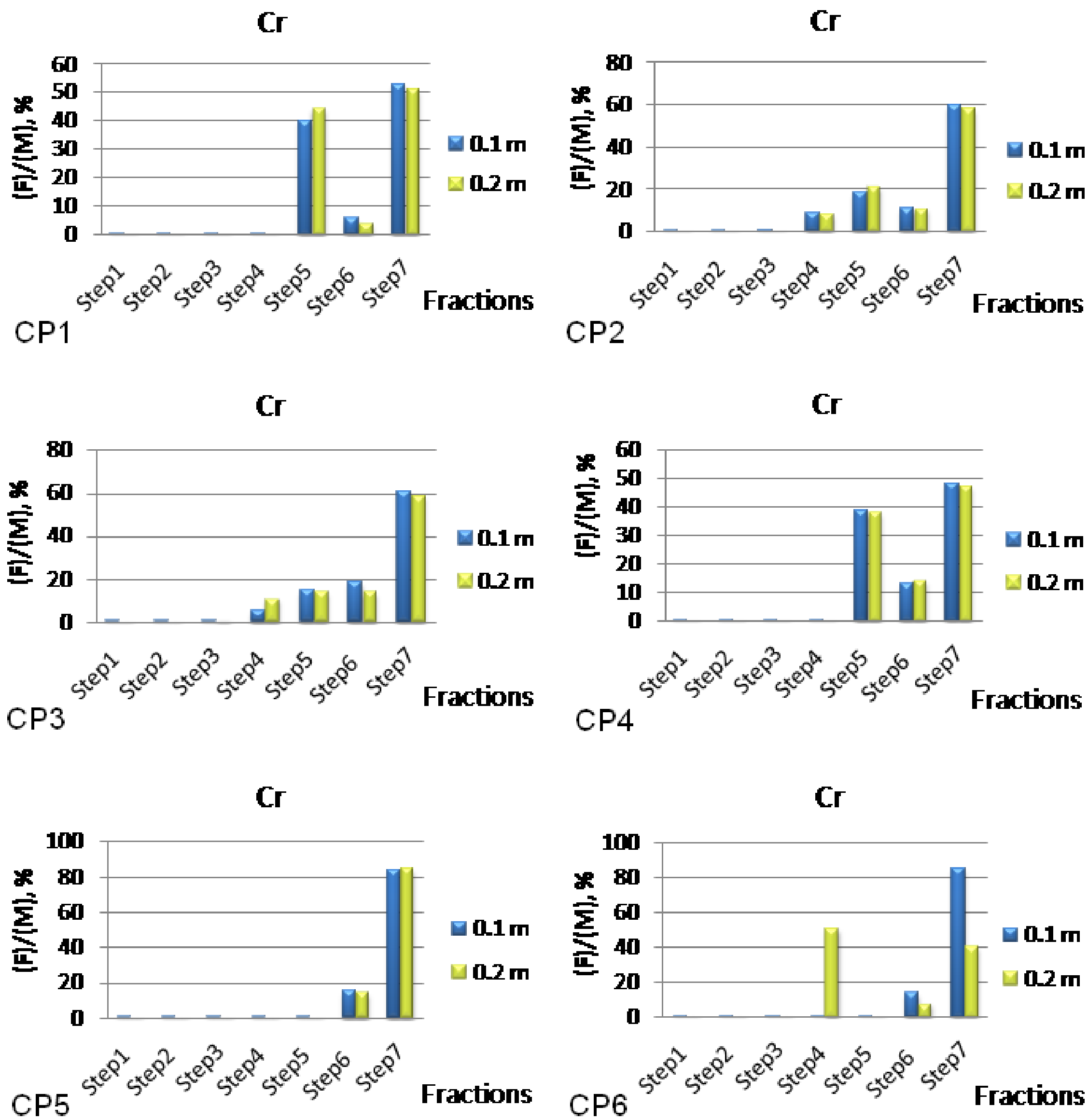
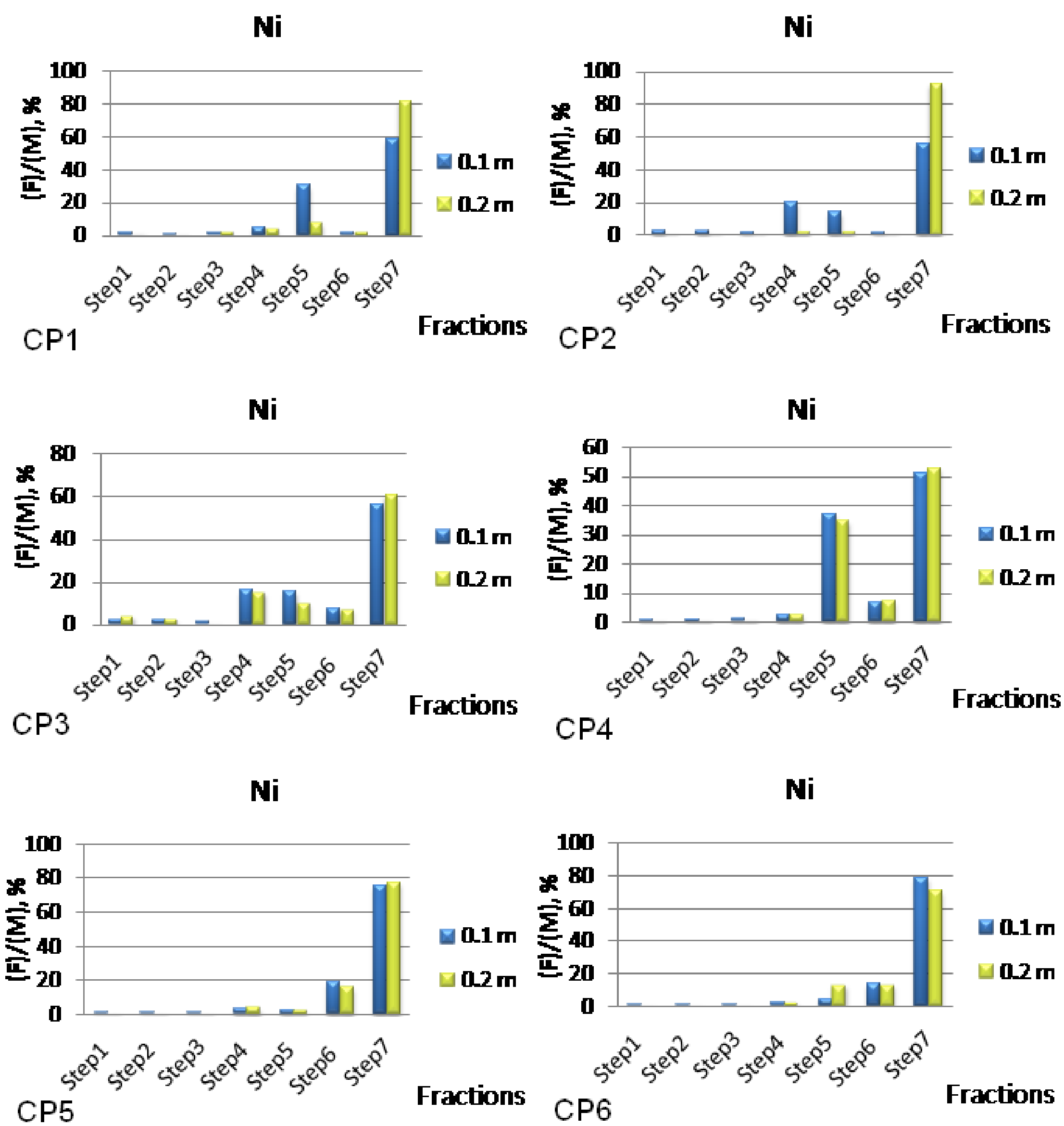
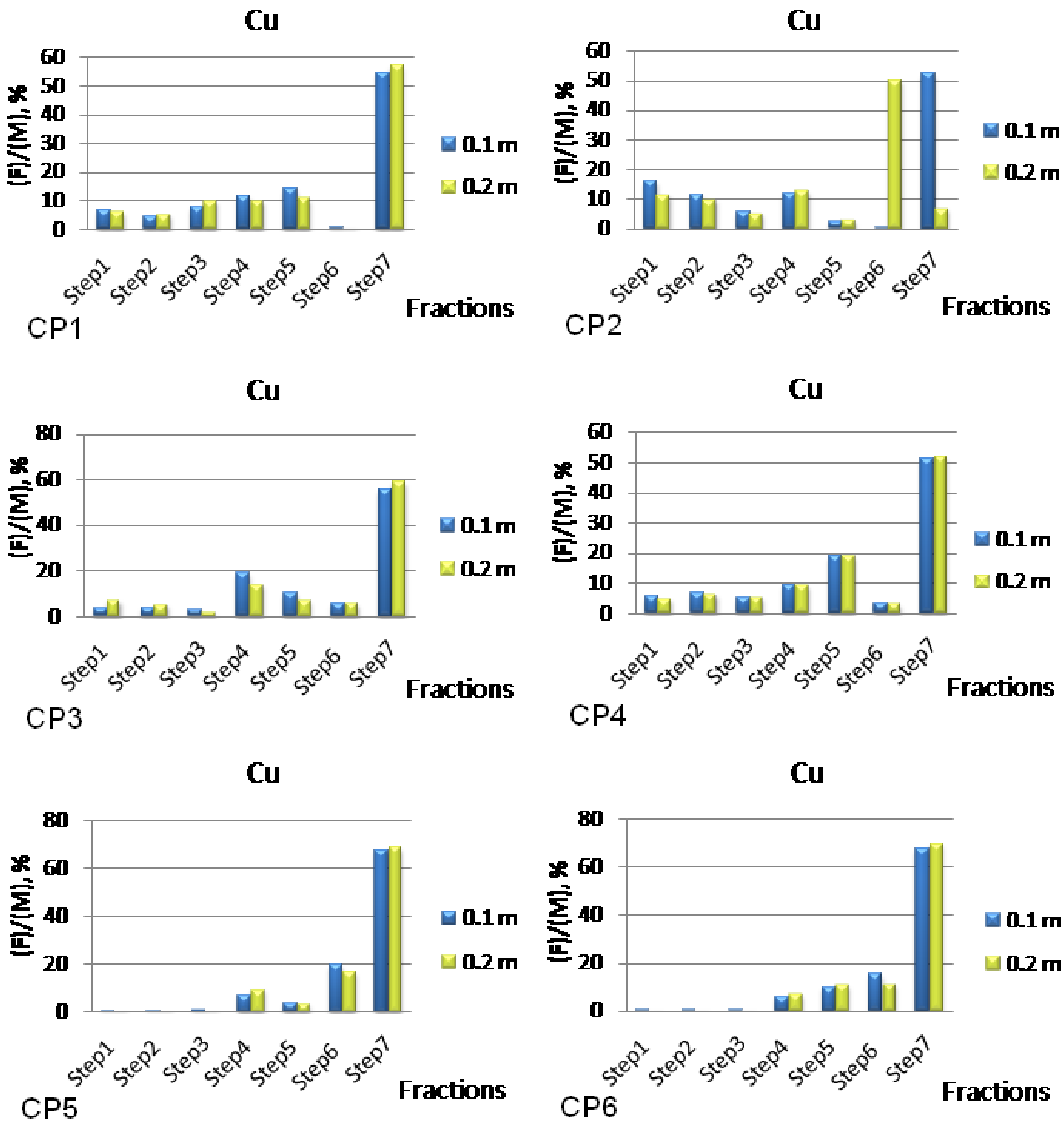
Appendix 1



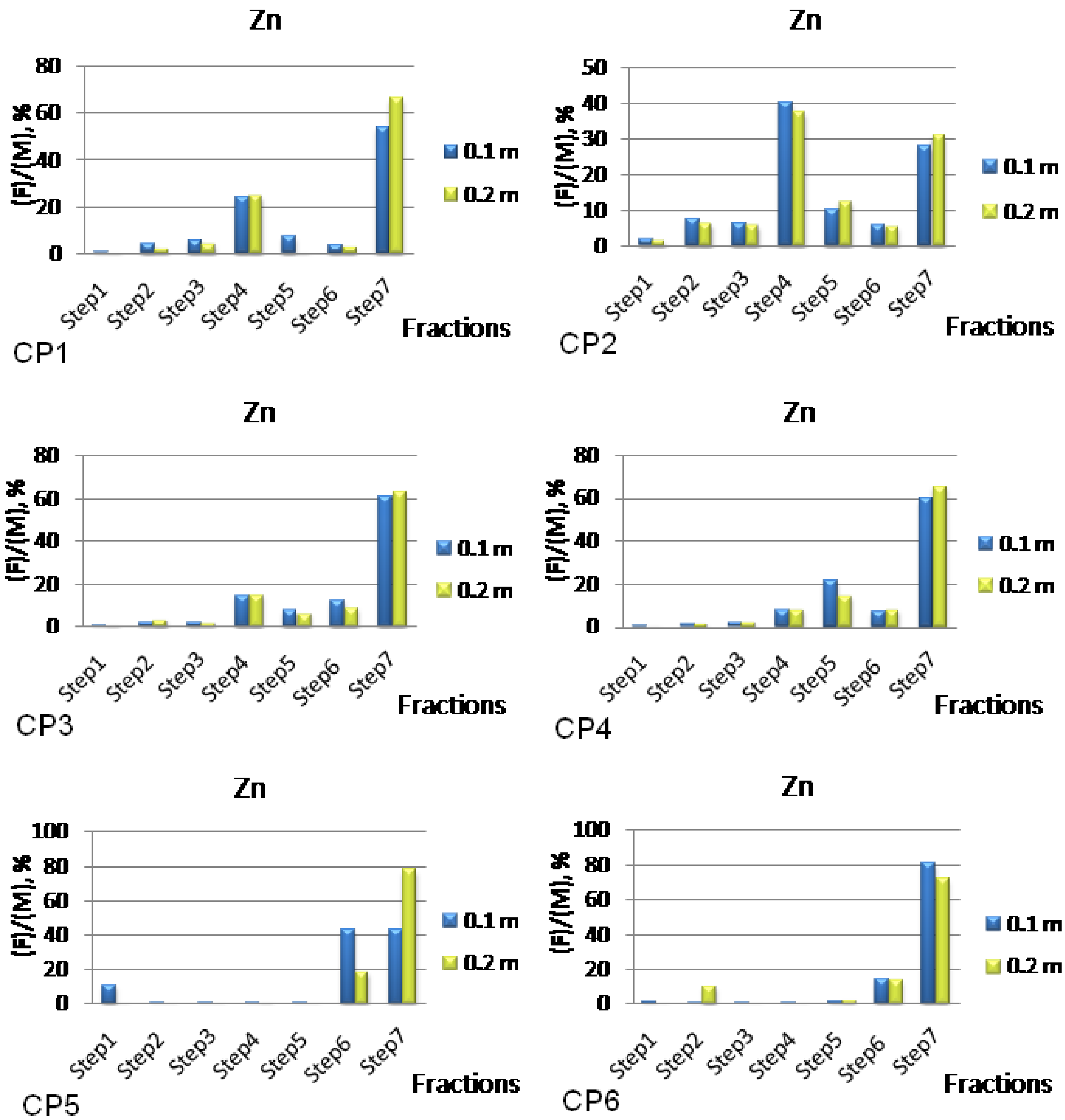
(Appendix 1) Figure 2.1 *Speciation of chromium (Cr) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



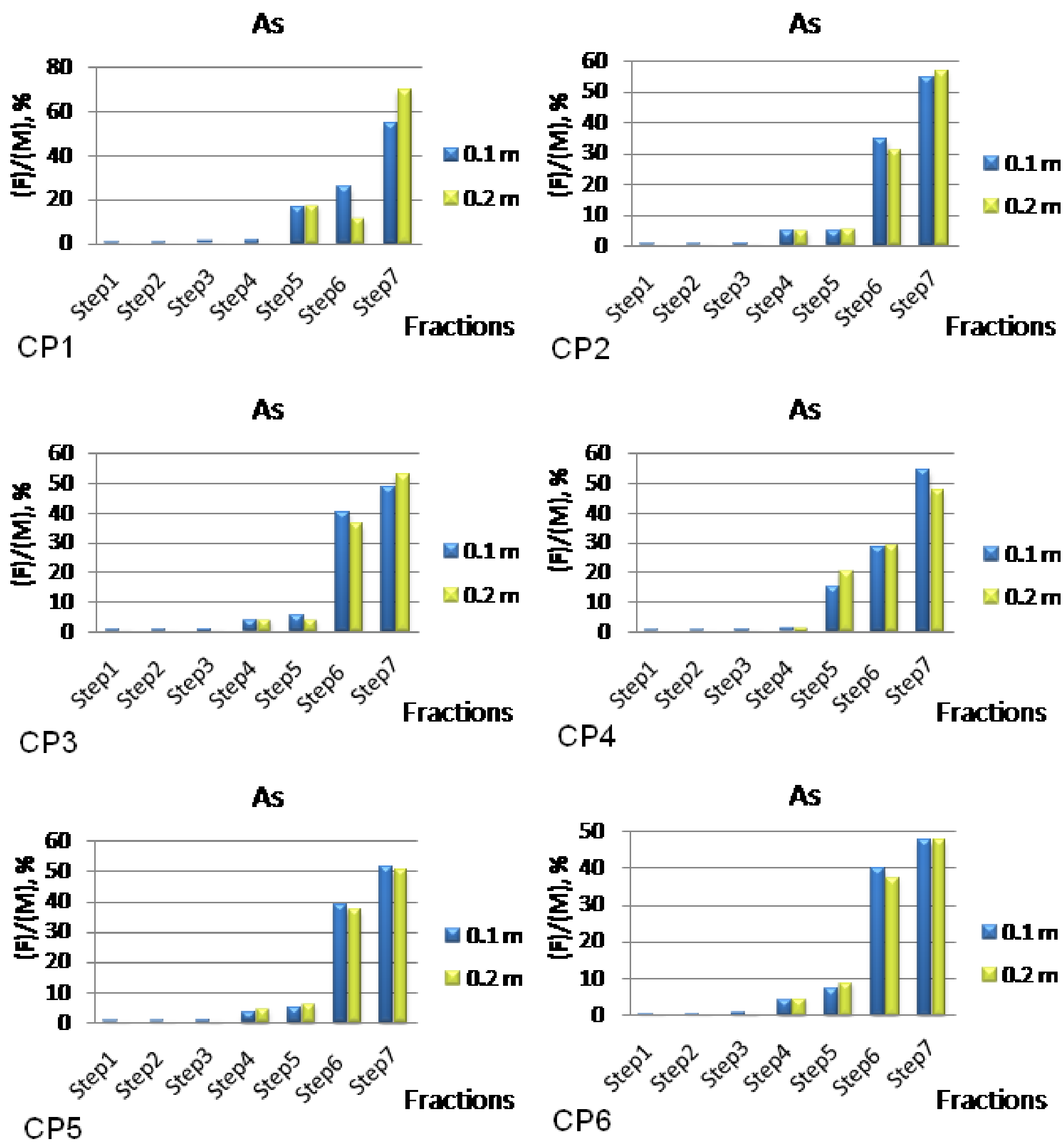
(Appendix 1) Figure 2.2 *Speciation of nickel (Ni) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



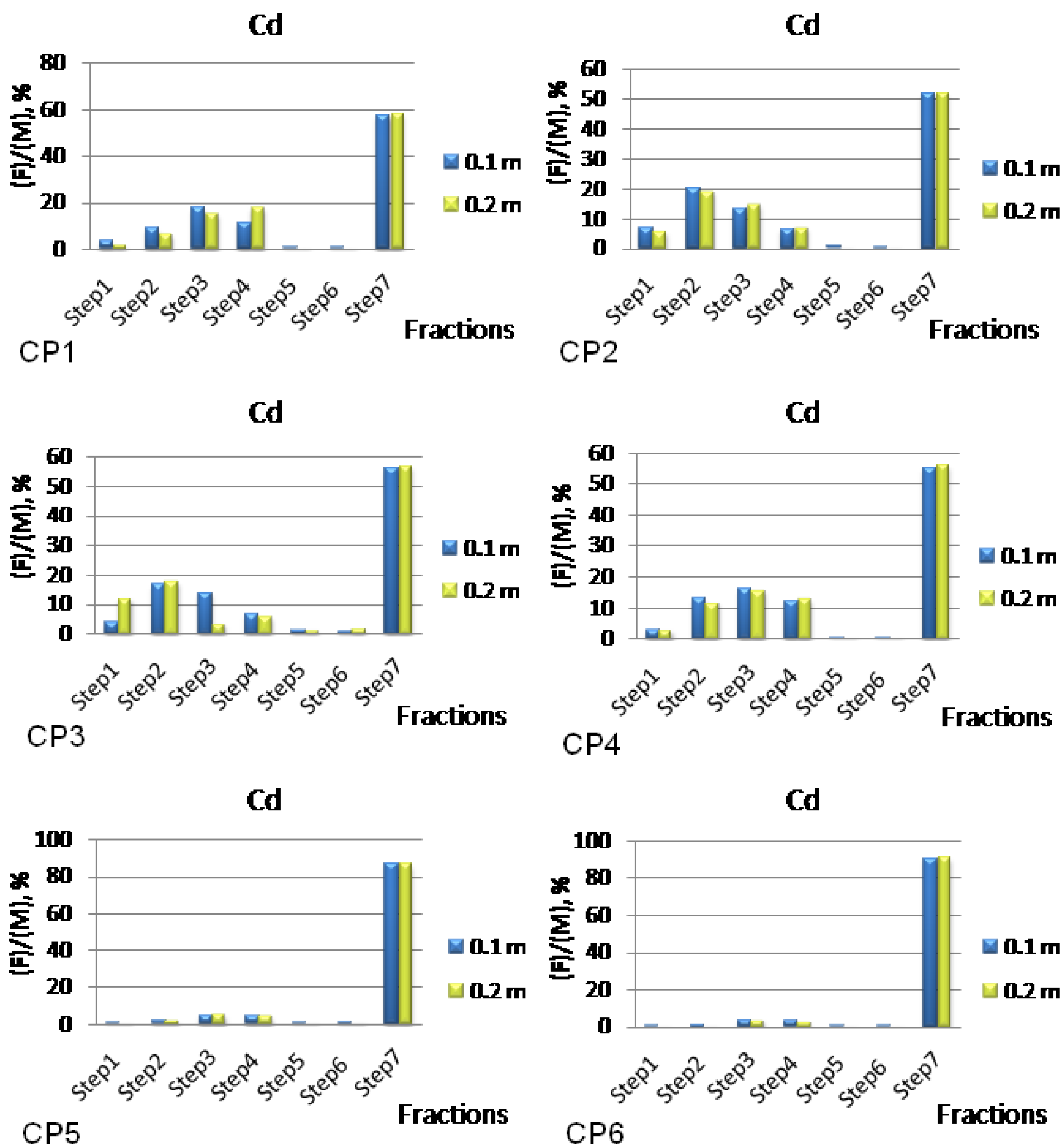
(Appendix 1) Figure 2.3 *Speciation of copper (Cu) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



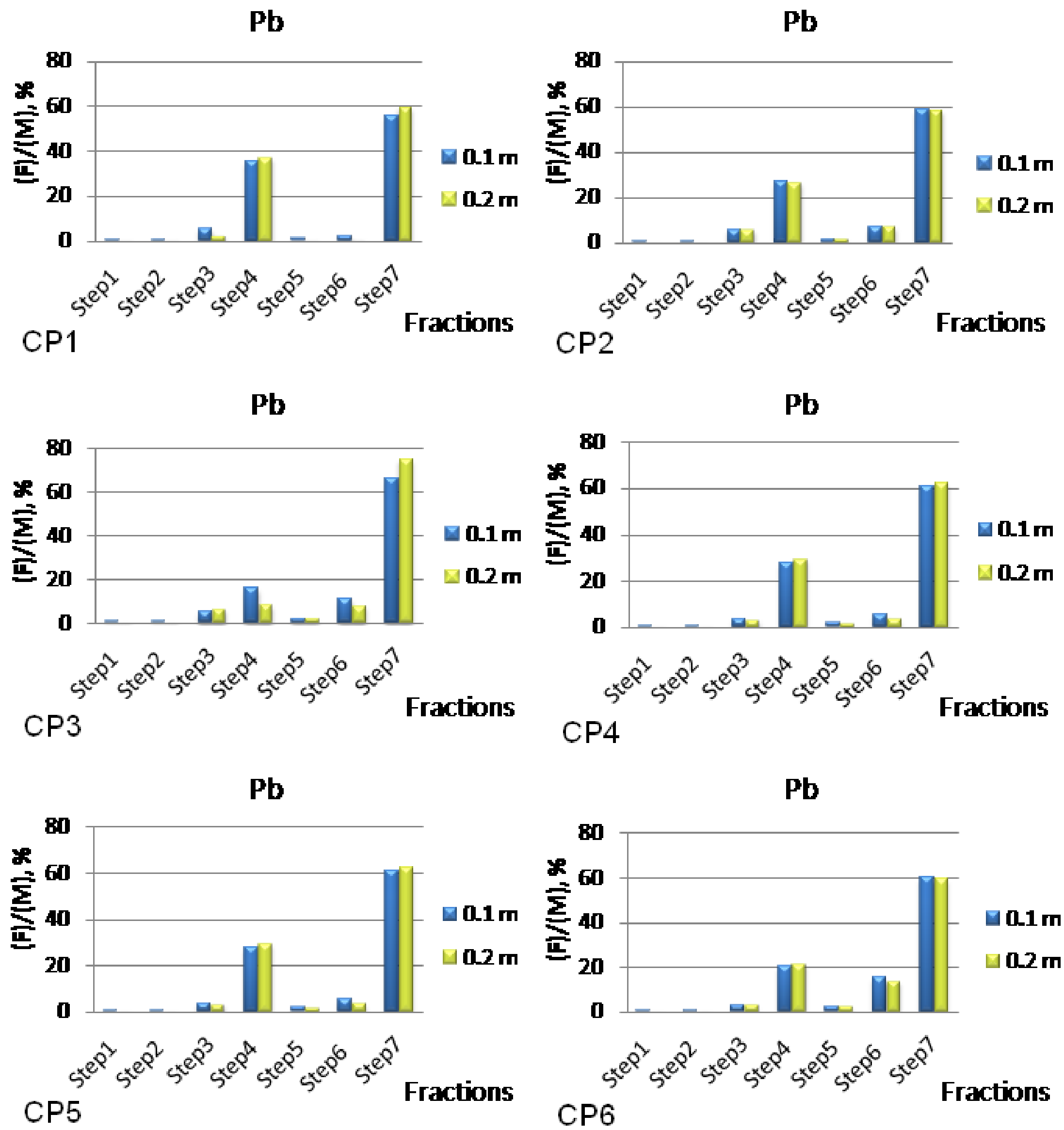
(Appendix 1) Figure 2.4 *Speciation of zinc (Zn) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



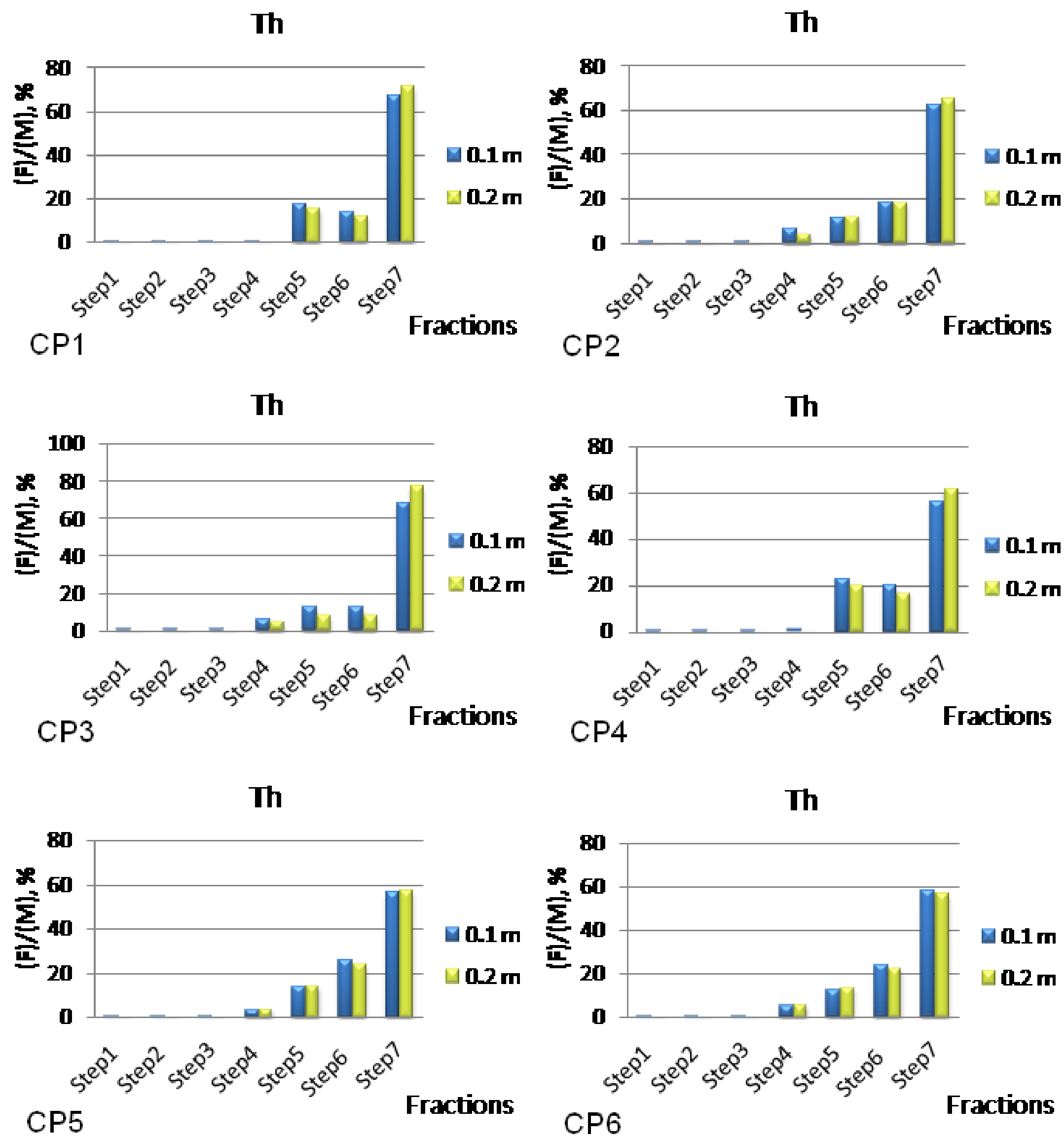
(Appendix 1) Figure 2.5 *Speciation of arsenic (As) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



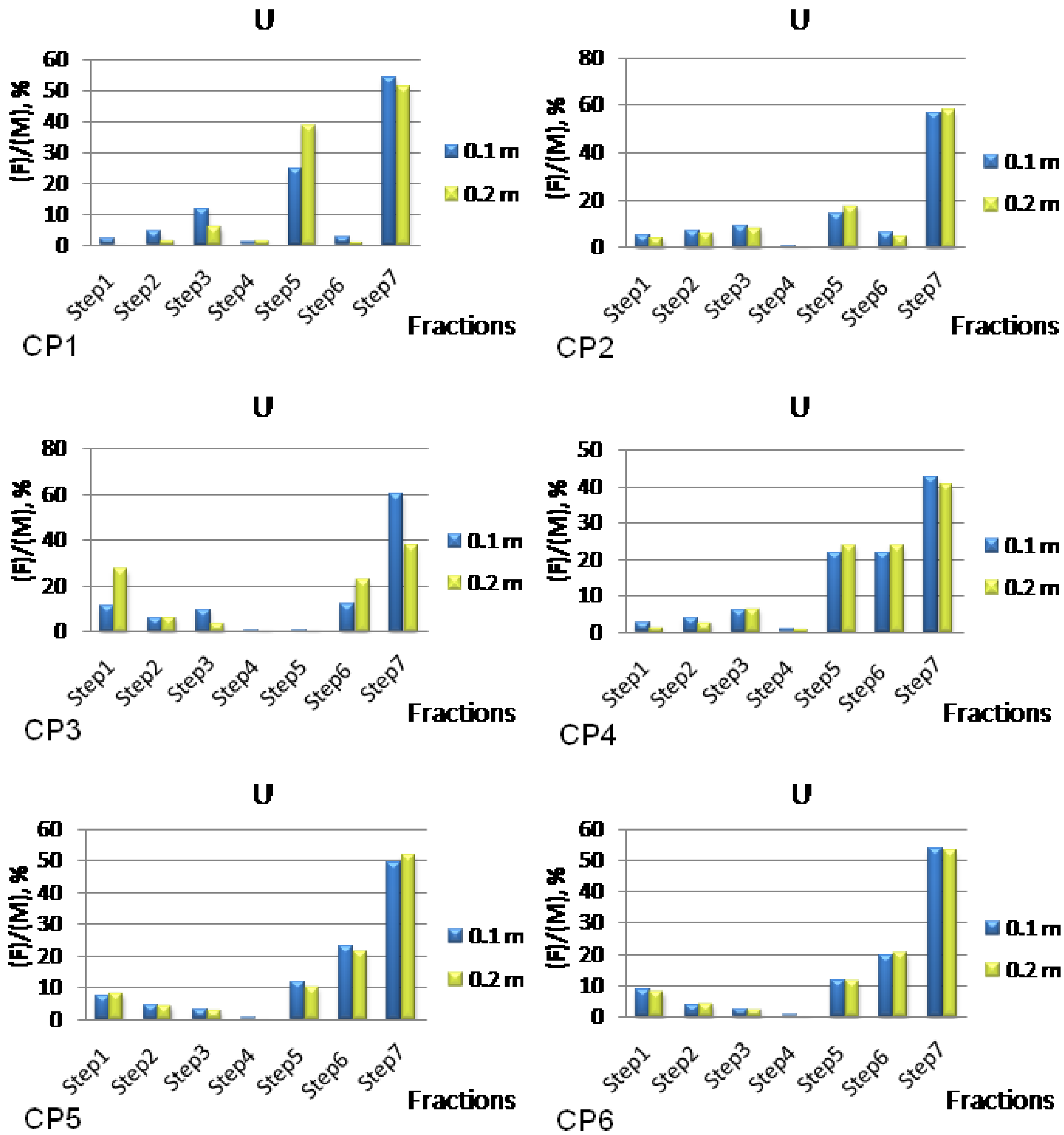
(Appendix 1) Figure 2.6 *Speciation of cadmium (Cd) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



(Appendix 1) Figure 2.7 *Speciation of lead (Pb) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



(Appendix 1) Figure 2.8 *Speciation of thorium (Th) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1-0.2 m*



(Appendix 1) Figure 2.9 *Speciation of uranium (U) in the six catchment pools of CP1-CP6: represented by the formula of (F)/(M), where [F] = concentration of speciation fraction; [M] = total element concentration of trace elements at the different depths of 0.1 m-0.2 m*

3. Danger and risk of natural and man-caused disasters in the mountains of Kyrgyzstan

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3.1. Abstract

Among the 70 types of worldwide natural hazards and phenomena causing severe harm to people and economy, more than 20 occur in the territory of Kyrgyzstan. The most destructive natural disasters include earthquakes, mudflows and floods, landslides and rockfalls, snow and glacial avalanches, movements and pulses of glaciers, stone streams, breaches of morainic and glacier lakes, heavy showers and snowfalls, subsidence and salinization of soil, groundwater elevation, etc. Natural and man-caused catastrophic events destabilize the economy of Kyrgyzstan and, in the context of budget gap, impel the government to divert a considerable part of the budget to eliminate consequences of disasters and render help to the population. The number of disasters and associated losses steadily increases. Consequently, the approach of forecasting and preventing natural and man-caused catastrophes and technologic emergencies is a highly topical, high-priority issue.

Keywords: disasters, Kyrgyzstan, forecasting, prevention

3.2. Introduction

The major characteristic of the physiographic conditions of Kyrgyzstan is a complex mountain topography related to major folds of Tien Shan. It is well known that Tien Shan belongs to the most stretched and highest mountain structures of the Asian continent.

The general appearance of Kyrgyzstan and its natural specific features is predefined by mighty mountain chains stretched in latitudinal direction and ample closed and semi-closed intermountain areas and depressions dramatically differing in landscape character and economic use. Great differences in elevation (400–7500 m), dissected topography, the continuous geologic development of Tien Shan, its location in the center of the Eurasian continent, its vicinity to the biggest deserts, and other factors caused a wide variety of physiographic conditions and the abundance of natural resources.

The present shape of Tien Shan is a result of the interaction between endogenic and exogenic geological processes. Satellite data on horizontal and vertical crustal movements (GPS) (Hager et al., 1995) as well as frequent earthquakes and numerous river bench dislocations bear evidence of ongoing mountain formation. The aim of this paper is to investigate danger and risk of natural and man-caused disasters in the mountains of Kyrgyzstan.

3.3. Results and discussion

3.3.1. Risk and natural disaster

The characteristics of the mountain areas of Kyrgyzstan are thoroughly described in literature (Aidaraliev et al., 2001 and Kosgoev, 1996). Summing up the environmental features of the mountains, the most important ones are as follows:

- Considerable spatial variability of all environmental components even within small mountain areas reflecting altitudinal climatic zoning and expositional contrasts of mountains, as well as orthographic striation of mountain landscapes;
- The ubiquity of various natural hazards and phenomena in mountain areas – earthquakes, avalanches, landslides, rockfalls, mudflows, glacier movements – that can have an impact on settlements, and critical engineering constructions posing environmental risk (dumps and tailings ponds, reservoirs and hydraulic structure dams, chemical and metallurgic plants);
- Increased natural and anthropogenic variability of natural hazards in mountains, vulnerability of the mountain ecosystems as a result of geo-mechanical instability of mountain slopes, diversity and rapidity of slope erosion processes, denudation and climate change;

- Prevalence of mechanical mass transport over chemical one, and also mass transport in a "mountain slope-river bed" system; in connection with this any disequilibrium of local slope or river section can unbalance natural processes, and consequently the environment far downstream, along with the initiation of cascade effects and synergetic catastrophes on a regional scale.

Mountains contain elements of all other ecosystems: arid zones, forests, swamps, fields, coastal areas, and frozen zones. However, a unique feature of mountains, which is of considerable importance for environmental science, is their elevation. It defines the three-dimensional character of mountains and classifies them as a special category of ecosystems thanks to altitudinal zoning.

The combination of the above-mentioned natural peculiarities of the mountain areas in Kyrgyzstan is characterized by great diversity of geologic, climatic and landscape conditions, only slightly stable equilibrium, increased susceptibility to climate change and vulnerability to anthropogenic impacts. This contributes to the development of natural hazards as well as natural and man-caused catastrophic events.

From the 70 types of natural hazards and phenomena causing severe harm to people and economy worldwide, more than 20 occur in the territory of Kyrgyzstan (Myagkov, 1981). The most destructive and dangerous natural disasters include earthquakes, mudflows and floods, landslides and rockfalls, snow and glacier falls, movements and pulses of glaciers, stone streams, breaches of morainic deposits and glacier lakes, heavy rain- and snowfall, subsidence and salinization of soil, groundwater rising, etc.

It is evident, that the territory of Kyrgyzstan is exposed to genetically diverse natural hazards associated with the specific character of the mountains. Development and manifestation of these hazards in form of catastrophes and natural disasters causes damage to the environment and the economy of the country and causes high death tolls. More than 1500 natural and man-caused emergencies were registered between 1990 and 2000 in Kyrgyzstan; they were responsible for killing more than 300 persons and for causing estimated average annual economic losses of 30 million USD. The distribution, frequency of occurrence, and the damages caused by the above-mentioned natural hazards vary from year to year. Nevertheless, in retrospect, the most dangerous natural disasters in Kyrgyzstan include earthquakes, mudflows and floods, landslides and rockfalls, and avalanches.

Figure 3.1 depicts a synthetic risk map of the most dangerous natural disasters in the territory of Kyrgyzstan compiled by means of overlaying seismic, mudflow and avalanche risk maps (Torgoev & Alioshin, 1999). The map is of great practical value for choosing appropriate locations for economic activities in mountain areas. It shows that in the southern part of the country the natural hazards are greatest. According to statistics of the Ministry of Ecology and Emergency Situations, more than 65% of all natural catastrophes and disasters occur in Batken, Osh, and especially Jalal-Abad oblast. 16% of all registered natural emergencies take place in Chui oblast. The remaining 19 % occur in Issyk-Kul, Naryn and Talas oblasts. The most vulnerable areas of the country (Figure 3.1) are the foothill and mountain territories of Fergana Valley: the south-west slopes of Chatkal, the Atoinok and Fergana ridges, the north slopes of Turkestan and the Alai ridges.

In terms of loss of life and economic loss probability as a result of natural disasters, the most risky areas in Chui oblast are: Alamudun, Issyk-Ata, Kant raions; in Talas oblast – Manas raion; in Naryn oblast – Naryn raion; in Jalal-Abad oblast – Suzak, Nooken, Bazar-Korgon raions; in Osh oblast – Karasuu, Aravan, Uzgen, Alai, Chon-Alai raions; and in Batken oblast – Kadamzhai raion. Bishkek, Osh, Kok-Jangak, Mailuu-Suu, Kyzyl-Kia, and Tashkomyr can be listed among the towns most exposed to hazards of natural character. Here we should note another feature of the mountainous areas, i.e. the natural hazards that increase vulnerability of people’s health by natural threats and environmental damage from man-made disasters.

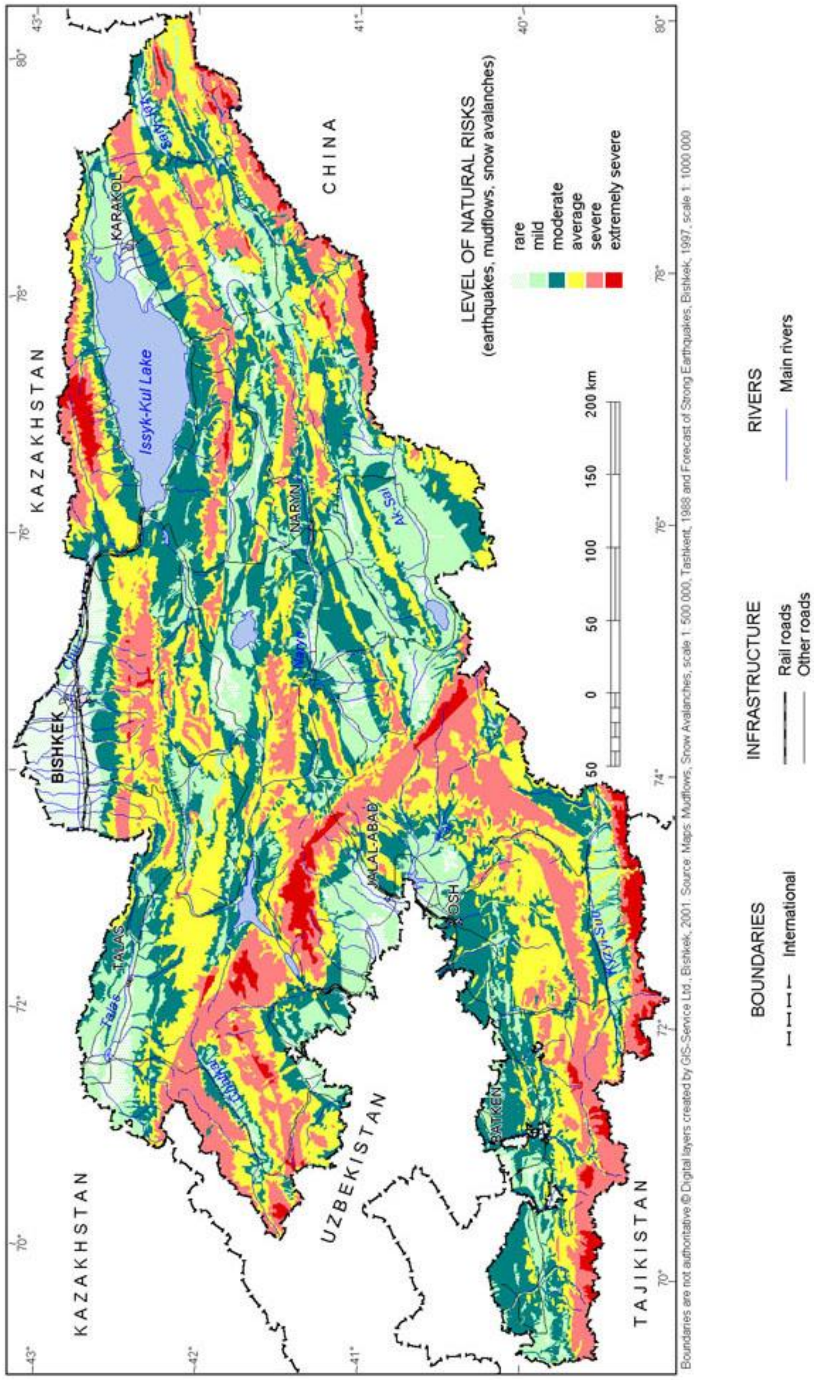

Figure 3.1 *Risk of natural disasters (earthquakes, mudflows, avalanches). Sorce of the map is Mudflows and snow avalanches, scale 1:500000, Tashkent, 1988, and Forcast of strong earthquakes, Bishkek, 1999, scale 1:1000000*

There is a generally accepted opinion about the mountain areas as areas with high natural risk and high frequency of natural processes hazardous for the population in these areas. In the complex mountainous terrain, people choose river valleys, hollows, canyons, soles of the slopes of the valley of the watercourse and proluvial cones as places for settling. At a first glance, these sites are advantageous as they provide fertile soil for agriculture, less rugged, accessible area for vehicles, good conditions for housing, utilities, and industrial constructions. However, at the same time all these mountainous areas are known for their increased risk and the impact of hazardous natural and man-made disasters. Thus, the risk for humans in mountainous countries like Kyrgyzstan is quite high.

3.3.2. Natural and man-caused hazards

Intruding into nature and creating powerful and complex engineering structures, humans generate new complex technogenic systems (CTS) in nature, including the technosphere and regularity (law) of interaction with the complex nature of the mountains whyle humans do not understand yet completely all aspects of complex nature of the mountains. Thereby, information uncertainty on the long-term perfomance of such systems in mountains, the risk of cascade and multistage man-caused failures in industry, energetics and transport, the risk of pollution of the biosphere and mountain catchment areas by highly toxic and radioactive industrial wastes is increasing.

As can be seen from the experiences in Kyrgyzstan (Torgoev and Alioshin, 1999, 2009), business risk increases with increasing altitude of the regarded areas because high-altitude areas are characterized by adverse natural, climatic, and geologic conditions and increased anthropogenic vulnerability (mines Kumtor, Sary-Djaz, Makmal, etc.).

In recent years, the territory of Kyrgyzstan became widely exposed to so-called natural and man-caused hazards in regions of intense economic development. The influence of humans either triggers new relatively slow natural processes or speeds up already existing ones.

Human intervention in the mountain environment during exploitation of the diverse resources has a negative impact on the environment not only on a local scale in a specific area but also reaching far beyond that.

In Kyrgyzstan, the most widespread anthropogenic impacts include: large-scale mining associated with exploitation of mountain resources rich in minerals, construction and use of hydraulic structures (chains of power plants), arterial roads, tunnels and communication engineering, agricultural development of mountain slopes, recreational activities and urbanization of mountain areas. As the mountain areas are only weakly stable and fragile at the moment, all of the sites and complexes listed above might turn to be extra-hazardous in future (Torgoev & Alioshin, 2009).

In terms of posing the risk of natural and human induced catastrophic events in mountain areas, potentially hazardous industries and entities in Kyrgyzstan include: mining and processing complexes, water development and hydroelectric facilities, transportation and communication engineering.

3.3.3. The mining industry

Kyrgyzstan is overflowing with diverse natural resources in its mountain areas. Their development holds out hope for economic advancement of the country on the whole. A number of mining and metallurgic plants in Kyrgyzstan played an important role in the former tsarist Russia (radium) and the USSR in terms of volume and uniqueness of their products (uranium, antimony, mercury, rare earth metals) contributing to defensive capacity and economy of the countries. However, the seamy side of plant activities on the strategic account of the former Soviet Union was not only degradation of beautiful mountainous landscapes, but also pollution, irreversible degradation of the environment at mining and processing sites and adjoining densely populated lowland areas (Fergana valley).

Continuous and intensive man-caused impacts on the interior of the earth are related to exploring, mining, and processing of mineral resources. They caused considerable changes of the geological media (GM) of mountain areas in some mining areas, and in a number of cases resulted in the development of a wide range of natural and man-caused geological processes which did and continue to do great economic and ecological harm. In an array of geo-ecological problems both inherited from the Soviet mining and metallurgical industries, and “acquired” lately after dissolution of the USSR, safe maintenance of large amounts of mining wastes comes to the fore. By the XXI century, in a number of districts of Kyrgyzstan (Figure 3.2) huge amounts of wastes (about 1 billion cubic meters including more than 50 million cubic meters of radioactive wastes) were accumulated in dumps, tailings and slim ponds, on relatively limited areas as a result of longstanding operation of the mining industry.

Analysis of the current geo-environmental situation in waste disposal areas (Torgoev & Alioshin, 2009) shows that their negative impact on the environment manifests itself in two ways:

- Pollution of the environment, especially catchment basins with radionuclides and ecotoxins;
- Increased risk of hazards (landslides, rockfalls, sagging) and large-scale failures with disastrous effects.

The gravest threat for the environment and population is posed by tailing ponds (Figure 3.2), which, depending on type of processed ores and concentrates, include radionuclides (towns Mailuu-Suu, Kara-Balta, Min-Kush, Kadji-Sai, Shekafter, Ak-Tyuz), harmful metal compounds (Khaidarkan, Kadamzhai, Terek-Sai, Chauvai, Kan), as well as toxic substances – cyanides (Makmal, Kumtor), used as reagents in ore processing and beneficiation. Given the dissected and constrained mountain topography of the country, tailing ponds were constructed in catchment areas mainly by diking gullets, streams and rivers flowing to densely populated valley and foothill regions where they were used as a source of drinking water and irrigation. Poorly designed and constructed dams of low stability and impermeability turned to be prone to erosion, flooding due to precipitation and groundwater, and also to geodynamic impacts (seismicity and tectonics) typical for mountainous areas.

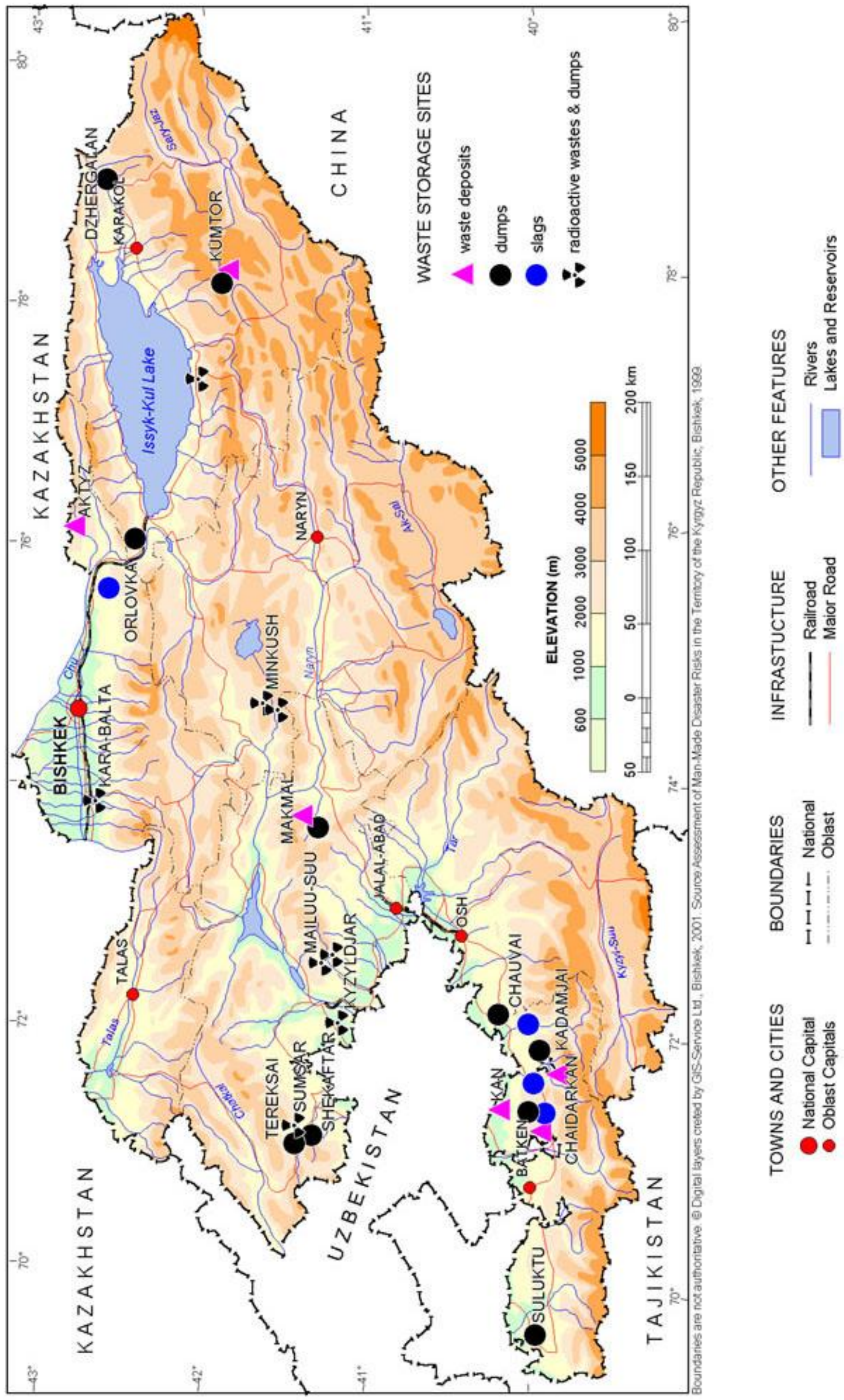

Figure 3.2 *Waste storage sites. Source of the map is Assessment of man-made disasters risks in the territory of Kyrgyz Republic, Bishkek, 1999*

The factors pointed out above became, in the course of time, a fundamental reason for degradation and failures of these hydrotechnic structures in the form of mud-flows, sagging, suffusion or breach in case of abnormal precipitation or/and earthquakes. A number of tailing pond failures that occurred in the past in Min-Kush, Mailuu-Suu, Ak-Tyuz, Kara-Balta, and Sumsar (Figure 3.2) were of disastrous character. Vast territories have been contaminated and time- and money-consuming efforts have been required to remediate their effects (Torgoev and Alioshin, 2009).

The risk of failure for operating and closed tailing ponds and dumps due to insufficient stability of their dams, the water saturation of tailings, as well as the effects of natural hazards (earthquakes, landslides, mudflows, floods, erosion, etc.) is increasing with time. The most critical environmental situation exists at tailing ponds of old uranium mines in Mailuu-Suu, which are located in a landslide- and mudflow-prone area. It is assumed that the entire tailing pond № 3 content (i.e. ~110000 m^3) is thrust to the river. By this thrust and in case of earthquake the dam break might be occurred. We further assume the sludge will be evacuated by the river in a few days by considering a sediment load of 10 kg/m^3 water and a river flow rate of $1.6 \cdot 10^9$ m^3/a. Calculations show that in case of failure of the tailing ponds № 3, 5, 7 (Figure 3.3) in Mailuu-Suu town in consequence of landslides and earthquakes, the amount of fine-grained radioactive tailings which may escape into Mailuu-Suu river and then into Fergana valley will be about 1 million cubic meters. The total activity of the radionuclides dispersed in case of failure will amount 10,000 Ci, and the total contamination area including territories in Uzbekistan will account for 300 km^2 (Alioshin et al, 2000, 2002). In the territory of many mining agglomerations (Kadamjai, Khaidarkan, Kadji-Sai, Sumsar, Shakaftar, Mailuu-Suu, Kok-Jangak, Sulukta), subsidence and deformation of the earth’s crust, rock mass displacements with formation of collapse zones, and conical depressions can be observed against the backdrop of natural tectonic movements of the earth’s crust. The processes, associated with technologic factors – formation of large quantities of underground cavities and extraction of underground water – considerably exceed tectonic horizontal and vertical dislocations of the earth’s crust by their speed and adverse effects (deformation and damage to buildings and engineering structures triggering landslides).

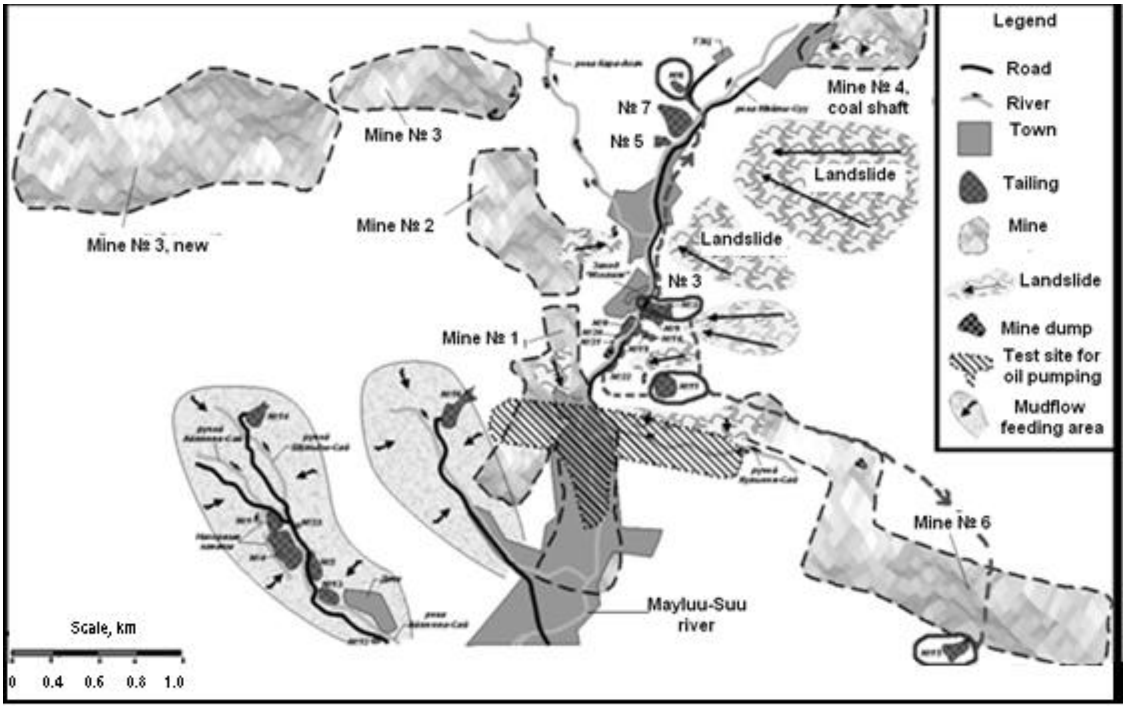

Figure 3.3 *Arrangement of pits, dumps, uranium tailings and large landslides in the area of Mailuu-Suu: ovals marked alternative sites for the transfer of radioactive waste from the tailings № 3, dashed arrows indicate routes for the "tails" of the tailing № 3 on the alternative sites. (Modified after Torgoev, 2002)*

Subsidence and deformation of the earth's surface and subsidence of rock mass more often than not cause development and activation of man-caused landslides in the context of slightly stable mountain areas. The analysis of the more than 40 years history of landslide development in Kyrgyzstan shows that in the 1950th the share of man-made landslides in their total number were negligible. In the ensuing years, as a result of slope stability disturbance by mining activities the number of landslides increased considerably (up to 80%). Features that make landslides related to mining activities different from landslides with natural origin are first of all their considerably larger size and the increased length of landslide displacement. Secondly, the development of man-caused landslides is of long-lasting character, which means that larger mountain slope areas which are far beyond the mining sites are later on gradually involved in the landslide movements.

In the territory of many mining agglomerations, mines and pits (towns Mailuu-Suu, Tash-Kumyr, Kok-Jangak, Sulukta, Chauvai, Shekafter), technological landslides caused by intense mining are quite common and inflict considerable losses. In Mailuu-Suu, and nearby Yuzhnyi-Karagach village and in old mines № 1-3, the index of territory destruction by landslides exceeds 50%. Such an extreme destruction by landslides is related to the combination of adverse technologic (underground cavities, undercutting, overloading slopes with dumps) and natural (presence of active tectonic faults) factors. The development of technologic landslides in Mailuu-Suu town began in the beginning of fifties when uranium mining rates and mining scales increased considerably.

Other natural and man-caused hazards in the mining industry of Kyrgyzstan include:

- Failures at surface/underground sites due to intensification of geodynamic phenomena and decrease in stability of mountain masses (caving and creeping of pit edges, deterioration of pillars and dumps);

- Endogenous fires in coal mines; effects of coal-bed fire at Djergalan mine that claimed the lives of miners in 1998 are not yet nullified.

It will not take many more years until the mining industry, worldwide and in Kyrgyzstan, reaches a point at which a number of mineral resources do not occur under favorable geologic conditions anymore and mining industry will therefore be forced to exploit deposits under increasingly difficult conditions. Among such deposits are the gold mines that are located in hard-to-reach Tien-Shan areas at high altitudes. Among those that are currently under development: Kumtor, Makmal, Solton-Sary. For example, Kumtor deposit is located in the largest permafrost and glacier area in Central Asia: Ak-Shiirak (Figure 3.2).

Presence of glaciers, ice soils and cryogenic phenomena related to frost penetration freezing/ defrosting itself is rather an indicator of complexity than for risks posed by a territory. Nevertheless, damage of ice soil and rocks as well as different types of loads on glaciers (for example, waste storage or precipitation of dust from an explosion) as a result of technologic impacts may not only cause continuous irreversible adverse environmental effects but also the development and intensification of natural and man-caused hazards: collapse of rock-streams and stone glaciers including dumps, their abrupt shifts or sharp change in solifluction rate, dangerous glacial processes (abrupt glacier shifts, breach of morainic lakes, glacial mudflows, etc.).

Areas where the above-listed large gold deposits are exploited are not only characterized by the extreme high-altitude natural environment, but also by their increased, as compared with other areas, vulnerability to technologic impacts, especially related to mining and processing of mineral resources. In particular, high-altitude ecosystems are characterized by a low rate of recovering if the natural balance and landscape is once disturbed by technological impacts. Moreover, these ecosystems are also characterized by slow degradation of contaminants and wastes, and risks of irreversible processes and cascade effects. In addition, under extreme high-altitude conditions, environmental impacts can have a cumulative character, especially due to climate change.

For a five-year period of Kumtor mine exploitation, despite all measures taken to prevent development of hazardous exogenous geologic processes and aimed at mitigation of potential natural hazards, the obscure beginnings of natural and man-caused hazards was reported (Torgoev and Alioshin, 2009).

They include:

- Degradation of permafrost and related water filtration, thermal sagging, and thermal erosion processes in the area of influence of the Arabel river bypass channel routed around the tailing pond;
- Intensification of thermokarst on a dam of glacial-moraine origin, embanking and containing Petrov's lake located upstream the tailing pond;
- Solifluction and mud-stream at mountain slopes undercut by a technologic road and sludge pipeline which is used to transport tailings from the gold extraction plant;
- Conditional change of the glaciers Davydov and Lysyi due to spoil rock deposition.

Thus, the mining industry of Kyrgyzstan poses currently the greatest risk of natural and man-caused hazard and pollution to the natural environment in weakly stable and susceptible mountainous territories. The spectrum of the effects of the mining industry is so wide that in a number of mining agglomerations (Kok-Jangak, Sulyukta, Kadji-Sai, Mailuu-Suu, Sumsar, Shekafter, Ak-Tyuz, Min-Kush, Chauvai) with a total population of more than 100,000 it causes social and economic strain, degradation and urban blight, depopulation and migration primarily because of difficult environmental conditions and the risk of natural and man-caused hazards.

3.3.4. Hydraulic structures

Kyrgyz Republic possesses ample surface water resources. Considerable resources are rivers, permanent glaciers and snow massifs. There are more than 3000 rivers flowing through Kyrgyzstan and running out to Kazakhstan, Uzbekistan, Tajikistan, and Uighur Autonomous Region of Sinkiang in China. The largest river is Naryn. Other rivers that have lengths of over 200 kilometers are Kara-Daria, Chui, Talas, Sary-Jaz, and Kyzyl-Suu. Head runoffs of Syr-Daria and Amu-Daria, the main tributaries of the Aral Lake basin, are formed in Kyrgyzstan. The total average river runoff is 44.5 km^3. Water in Kyrgyzstan is distributed for agricultural, industrial and household usage. Water demand for irrigation is 89% of total usage, while household and industrial demands accounts for about 11%.

To increase the water availability for irrigated lands and to more effectively regulate streams under consideration of the interests of the agricultural industry and energy production, fifteen major reservoirs (Figure 3.4) with a total storage volume of 20 cubic kilometers were constructed in Kyrgyzstan. Two of them were built only for electricity production, 10 mainly for irrigation, but also household and industrial water supply. Moreover, there are 24 small reservoirs with a total storage volume of 1 million cubic meters, as well as tens of basins with seasonal, decade and daily regulation of the flow of small streams. Generally, such constructions are located near or above densely populated areas. They cause an increased risk as their dams can fail and consequently create an emergency situation. It remains to add that in Soviet times the government provided certain financial aid and support to provide safe use of hydroelectric structures including means for state supervision and control, monitoring, reconstruction and maintenance. After the disintegration of the Soviet Union in 1991 funding was canceled and the acute problem of providing further safety of large hydraulic structures and cascades of power plants increased. In future, the problem can become even more acute in connection with further “ageing” of constructions and privatization of hydroelectric facilities. Besides that, it is necessary to take into account that most of such unique and large structures were erected in mountainous earthquake-prone areas with increased risk of natural disasters (landslides, rockfalls, mudflows, etc.). It is sufficient to recall that a chain of lower Naryn hydropower plants (Figure 3.4) gives an example of unprecedented proximity of high dams to seismogenerating faults. The deep part of the Toktogul reservoir is located at the intersection of Talas-Fergana and Naro-Chychkan faults.

The combination of the above-listed contemporary political, social and economic, organizational and technical factors and the extreme natural environment predetermines the necessity of taking urgent measures to provide long-term stability and safety of large hydroelectric and hydrotechnic structures, primarily dams and dikes.

Every year more than 3000 different dam failures take place worldwide; every seventh of them occurs in Commonwealth of Independent States (CIS) (Kozlitin et al., 2001). It is necessary to note that in a case of dam breach there emerges a so-called outburst wave which may cause disastrous consequences of regional and transboundary character and scale: flooding of vast territories (including those outside valley boundaries), paralysis of economic activity, complete change in a way of life (social and political catastrophe), huge economic loss, or loss of lives.

The most commonly encountered natural and man-caused risks associated with construction and operation of hydraulic structures, include:

- Decrease in waterworks dam and levee stability during their operation caused by both natural (geodynamic and climatic) and man-caused factors (turbine and hydroelectric unit vibration, operation of spillway structures)

- Induced seismicity in the vicinity of large reservoirs is a result of accumulation and quick withdrawal of huge amounts of water which, on the one hand, put additional load on the earth crust, and on the other hand, causes hydrostatic pressure change in reservoir floor and slope rocks in vast territories. The latter phenomenon seemingly prevails as hydrostatic pressure increase in joints and rocks smooth friction on contacts of crustal blocks promoting “seismic failure”. Intensification of slight earthquakes was registered in Kyrgyzstan while constructing Orto-Tokoi and Toktogul hydroschemes.

- Reservoir capacity decrease and dam stability degradation due to drift (silting)

- Underflooding of areas adjacent to hydraulic structures

The combination of the above-listed natural and man-caused factors leads to a change of the condition of different dams and dykes, the kind of their “ageing” or “wearing”, thus resulting in malfunctions, failures, including those with catastrophic consequences. In many countries there is an official system of dam safety rating involving potential danger to life, property damage in case of floods, dam overflowing and its partial or complete failure. The risk level depends on the performance of a dam and reservoir storage, potential loss in tail water, and requirements on evacuation of population living below the dam. In the aggregate of the above factors and parameters a number of dams in Kyrgyzstan are classified as to be of greatest risk; Orto-Tokoi, Kirov (Talas oblast), Toktogul and Kurpsai can be listed among them. It is necessary to note that the likely consequences of numerous seismic loads from weak induced and massive earthquakes include residual deformation in joints and contact surfaces of a dam body, foundation seal failure with increase in water permeability, stress redistribution in a body with a possible change in a margin of stability. As stated above, a deep part of Toktogul reservoir is located directly at the intersection of Talas-Fergana and Naro-Chychkan faults. Dams themselves (Toktogul, Kurpsai and Tash-Kumyr) belong to the category of facilities where highest reliability is required (Marchuk et al., 1999).

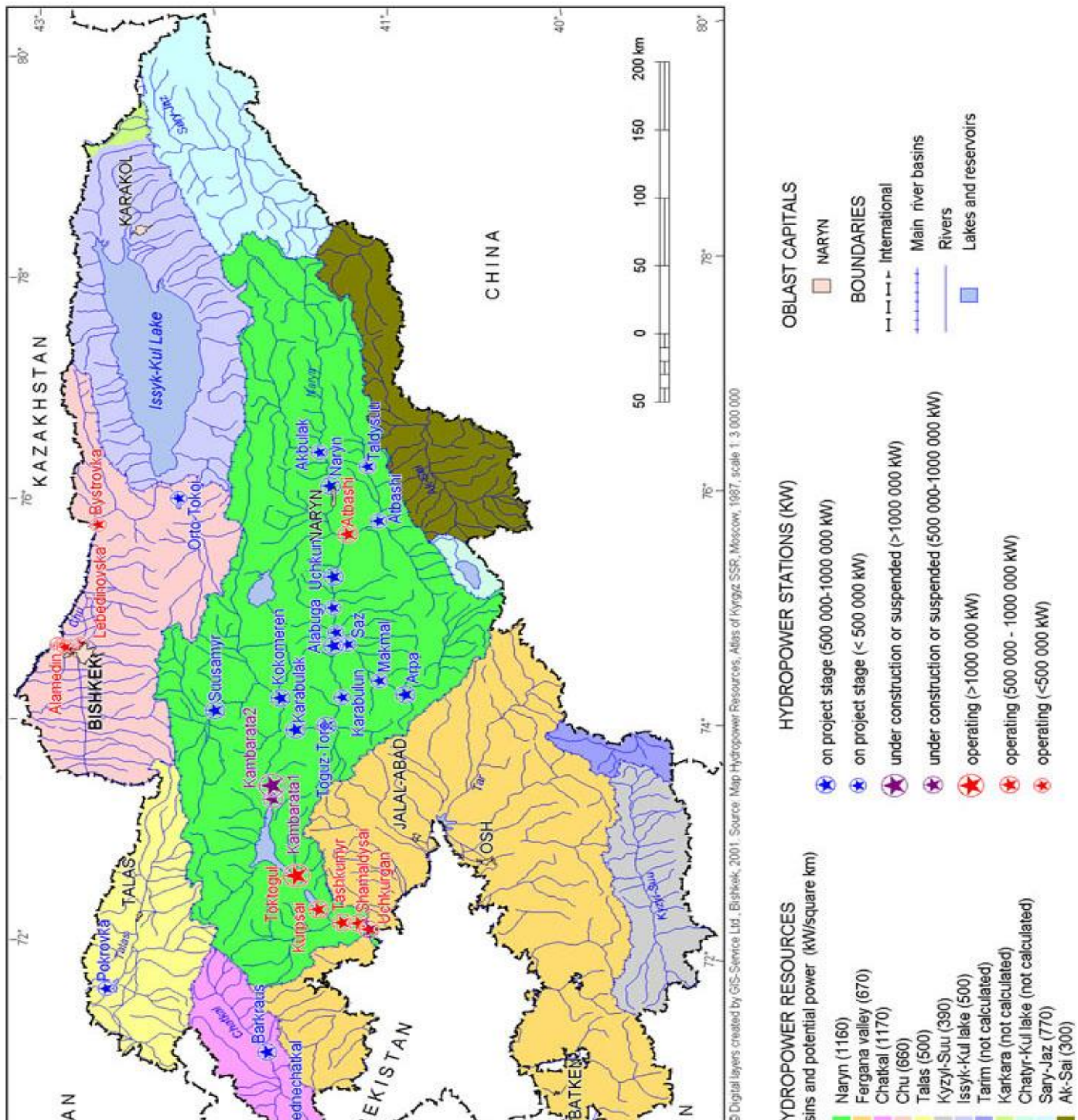

Figure 3.4 *Hydropower resources of Kyrgyz Republic. Source of the map is Map of hydropower resoursorces. Atlas of Kyrgyz SSR, Moscow, 1987, scale 1:3000000*

The seismic stability of dams passed a severe test during Suusamyr earthquake (magnitude 7.3 points and intensity in epicentrum 9 points) in August 19, 1992. The seismic focus was located at a distance of 90 kilometers from Toktogul hydroelectric plant. The calculated earthquake intensity at Toktogul dam location was 7.6-7.8 points, and at Kurpsai dam location it was 7.2-7.3 points. The earthquake was unexpected and unpredicted. It is necessary to note that not long before Suusamyr earthquake, namely on May 15, 1992, a severe Kochkorata earthquake and series of aftershocks struck the area. On the whole, the unique concrete dams belonging to Naryn chain of power plants stood the proof with the devastating Suusamyr earthquake. Toktogul dam demonstrated high seismic resistance and adequacy of project decisions. Reservoir capacity decrease as a result of silting is a problem that is as important as that of “ageing” of hydraulic structure dams. According to the World Bank Technical Paper number 289 (Dinar et al, 1995), the average reservoir capacity loss reaches 50 km^3 per year or 1% of its total volume. Between 390 thousand and 32 million tons of drift including silt, flow into to the reservoirs of Syr-Darya river basin. From this amount, the share of glacier drift is 30-50%. For example, the annual inflow into the Toktogul reservoir is 6.8 million tons of glacier milk (Marchuk et al., 1999).

The number of reservoirs and season/decade run-off ponds silted by 50-70% or up to a crest level (for example, season run-off pond at Mailuu-Suu River, downstream Kok-Tash village) has increased in Kyrgyz Republic lately. Taking into account the importance of the silting issue in connection with dam stability it is necessary to execute a work package on anticipated silting, analysis of countermeasures offered, or measures aimed for mitigation of silting impacts on safety or service life decrease of reservoirs. In particular, in case of known reservoir service life it is necessary to provide conditions of service life expiry. For example: In the case of increased siltation of the reservoir it is necessary to assess if it will be stable if it is silted up to the top of the ridge; at what level of silting operation of the dam should be discontinued, and which actions should be taken regarding the passage of flood waters and sedimentation.

Underflooding of areas is one of the most widespread and damaging natural and man-caused hazards. It manifests itself in groundwater level rise resulting in soil over moisturization, swamping, and basement flooding. As a result of underflooding, seismicity of the territory is increasing (Pulatov & Irgushev, 1995). In this way, a slight earthquake of magnitude 3-4 occurred in Jalal-Abad oblast in autumn 1997 and caused damages equivalent to an earthquake of magnitude 6. Moreover, soil strength is decreasing and as a consequence of this premature deformations, damage of constructions and utility lines occur along with environmental degradation in settlements. In many cases underflooding triggers landslides, sagging, sinking, soil swelling, pollution of groundwater, promotes corrosion in underground structures, causes soil degradation and inhibits the activity of plants. In those territories where groundwater is polluted with oil and petrochemicals, underflooding results in uprising liquid and gaseous hydrocarbons to the earth surface posing explosive and fire risks. Underflooding of developed areas became prevalent in Kyrgyzstan in the last 5-10 years (Feinberg & Esenov, 1995). At present, most of the settlements in Chui oblast – from town Kaindy in the west to Chui-Tokmok in the east, and from Bishkek city in the south to Nizhnaya Alarcha in the north; in Talas oblast –Amanbaevo village, Maimak, Kara-Bura; Issyk-Kul oblast –Akulen village, Chirak, Shalba; Naryn oblast –Cholpon village, Kochkorka; Osh and Jalal-Abad oblast are subjected to underflooding. Tens of settlements are located in vicinity to large reservoirs: Andijan, Papan, Naiman, Tortgul, Bazarkorgon and others are underflooded due to water infiltration from irrigation systems, excessive watering, and drainage system faults.

3.3.5. Transport

The current condition of the road net in Kyrgyzstan can be characterized as follows. The total length of the road network accounts for about 23 thousand kilometers including 10 thousand kilometers of state roads. The heaviest load is on the state roads paved over the full length (half of pavement is major). Bishkek – Balykchi – Naryn – Torugart, Bishkek – Osh, ring-road Balykchi – Kara-Kol – Balykchi and Osh-Khorog road can be listed among them. Roads linking district and oblast, industrial and agricultural centers are paved by 90% of the full length. All regions of the country are saturated with a net of local roads which are of significant importance for the development of agriculture, even if 90% of them are unpaved. The road net in Kyrgyzstan features high density - some 76.4

km per 1000 km^2; and 4.3 km per 1000 persons. Basic defects of road quality include discordance of design features to existing traffic flow, insufficient capacity of paving exposed to the destructive environmental processes. This leads to accelerated road deterioration and road accidents. The length of public railroads in Kyrgyzstan is 372 km (MTC KR, 2012). The railroads Bishkek - Bystrovka –Balykchi and partly Djalal-Abad - Kok-Jangak were constructed under the most difficult geologic conditions.

The construction of a road network is a strong technological factor which disturbs the natural balance of a mountain slope due to both slope undercutting in its, as a rule, lower part and knife edge loosening, and increase in block jointing as a result of drilling and blasting operations and consequent decompaction of uncovered sections of blocks. During use of railroads and highways (passage of railway vehicles or heavy haulers) growth and proliferation of cracks occurs due to regular vibration of blocks. All these factors lead to a decrease in slope stability and the formation of landslides and rockfalls on unstable and dislocated sections.

Sections on the country's main route - Bishkek-Osh road where exogenous geological hazards occur and develop are as follows: 166-170, 243, 396-426, 454 km, near Kok-Bel pass, Kambarata-2 hydropower site, and Tashkumyr hydropower site. Moreover, landslide-prone sections are common on the following roads: Kok-Jangak – Markai, Suzak-Changyr – Tash, Terek-Suu – Alaiku, east slope of Chiyrchyk pass, Kemin - Shabdan, and in Mailuu-Suu where a landslide blocked the road linking south and central part of the town in April 1999. Rockfalls and landslides pose a threat to the Bishkek-Balykchi railroad at sections eastward Jil-Aryk v., near Kyz-Kuio, and southward river Konorchek. Landslide prone sections are located on the railroad between the village Bagysh and the town of Kok-Jangak. Presently, rehabilitation of Bishkek-Osh road (including tunnels) involving foreign donors is in progress in Kyrgyzstan, along with other projects such as construction of a new road Cholpon-Ata – Almaty, bypass roads in the southern part of the country, railroad Balykchi - Kara-Keche. Also design of new transport communications including the interstate route Andijan-Jajal-Abad-Kashgar is under way.

In connection with this it is important to take into account the existing experience as well as design and construction defects of existing transport communications (MTC KR, 2012). Such defects include the following:

- mistakes during site investigation in terms of both quality depth, and scope (coverage of adjacent mountain areas);
- mistakes during design stage – no provision has been made for protective structures at avalanche-, landslide-, rockfall-prone areas; or they are not available in sufficient quantity;
- during construction stage – site investigation recommendations are not followed in terms of priority and terms of construction works, breakdown in process including blasting operations;
- during usage – no activity constructed to maintain structures to protect roads from natural hazards.

Unfortunately, the above-listed mistakes, economic and ecological faults, ignoring high-risk posed by mountain roads did not yet serve as a warning signal and presently take place during construction of “prestigious” roads for local authorities, such as Cholpon-Ata – Almaty, or Talas-Chonor road debouching on Bishkek - Taraz highway.

3.4. Conclusion

There is growing desire the return of man to the mountains, to their diverse natural resources. “Primary” land-utilization and livestock raising are overlaid by contemporary “secondary” types of anthropogenic activity. Among the anthropogenic activities in Kyrgyzstan that are under consideration, the most considerable impacts on the mountain environment are man-caused, associated with construction and exploitation mining and hydroelectric sites, transport and infrastructure. All these sites and constructions may cause the development of natural and man-caused hazards if project designers, builders and service engineers do not take into account the specific features of the weakly balanced mountain areas with their increased sensitivity to climate change and vulnerability to anthropogenic impacts. Natural and man-caused catastrophic events destabilize the economy of Kyrgyzstan and, in the context of budget gap, impel the government to divert a considerable part of the budget to eliminate consequences of disasters and render help to the population. In case this tendency persists in future, losses from disasters will absorb a considerable part of the economic growth thus erecting an insuperable barrier to sustainable development of Kyrgyzstan (EDD, 2011).

Thus, providing safety of the population and territories and decreasing the risk of natural and man-caused processes and disasters mainly depends on reasonable balanced location of industrial sites, scientifically established design, high-quality construction, usage, and laying up potentially dangerous sites and structures in mountains.

As the amount of disasters and associated losses steadily increases, a new approach has become topical – forecasting and preventing natural and man-caused catastrophes and technologic emergencies. A basis for this approach will be composed of the following procedures: risk assessment for human induced disasters, taking an array of preventive measures, monitoring and forecasting (Torgoev, 2000), as well as making management and engineering decisions.

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4. Monitoring landslides in Kyrgyzstan

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4.1. Abstract

The methods, instruments and results of landslide monitoring in Kyrgyzstan are presented in this paper. Monitoring together with early warning against landslide hazard is based on registration and analyses of different kinds of information, including remote sensing, geophysical investigations, geotechnical, hydrometeorological and seismic measurements.

Keywords: monitoring, Kyrgyzstan, landslides, hazards, remote sensing

4.2. Introduction

During the last 20 years an increase of landslide activity has been registered in the mountainous areas of Kyrgyzstan related to ongoing climate change. This is especially true for the southern regions of Kyrgyzstan where precipitation rate (1200 mm/a) is highest. 310 big landslides ($V \geq n*10^5$ m^3) have occurred in Kyrgyzstan between 1993 and 2010 with a death toll of 256 and direct economic losses of 2.5 million $ per year on average.

All these facts determine the need for setting up a monitoring system and monitoring mass movements in order to prevent landslide catastrophes, to provide safety for the population, to secure economics and infrastructure. Monitoring is realized by an information system of routine observations that estimates and forecasts geological environment (GE) conditions and that allows finding out a tendency (trend) of the changes of surface areas (slopes) finally affecting fresh landslide activity and reactivating dormant landslides. In order to obtain representative data on changes in the geological environment and to predict landslide processes monitoring is carried out simultaneously at three scale levels: regional, local and detailed.

Regional monitoring covers huge economic and geographic regions, comprising the territory of whole Kyrgyzstan. It gives a general understanding of landslide susceptibility, spatial and temporal variability of susceptible areas, and also provides estimations on possible damage which landslide activity can bring to the environment and large economic objects. Information obtained within the scale of regional monitoring is used for planning industrial facilities, designing economic infrastructure, and for developing complex schemes of engineering protection from hazardous mass movements.

Local monitoring includes observations in catchment areas and within areas affected by large mining agglomerations and hydro power plant (HPP) cascades. Local monitoring covers territories with areas of 10 to 100 km^2 and gives deeper insights into landslide processes within the areas of existing or planned mining activity, and within areas affected by large hydrotechnical constructions. The obtained information is used for direct or indirect risk studies, for the compilation of generalized plans for cities and industrial areas, for the development of feasibility studies, and for the design of engineering activities for protecting territories and constructions from mass movements.

4.3. Methods

4.3.1. Remote sensing

Aerospace methods, in particular remote sensing (RS), are widely used in regional and local monitoring in mountainous areas that are not easily accessible. Figure 4.1 presents the results of RS application for investigating the progress of landslide activity in Mailuu-Suu mining area based on aerial images (1984, 1996) and applying Quickbird high-resolution, panchromatic imagery (2002 and 2008). These images were treated (geometric corrections and registration) using ENVI and ArcGIS software. Detailed monitoring is a technique commonly related to a particular landslide or a portion of an unstable slope, escarpment. Information gathered during detailed monitoring is used for prognosis and early warning against landslide failure, for planning of risk reduction measures and for prevention of emergency situations. Ground-based investigation methods (geotechnical and geophysical methods) play the most important role during detailed monitoring.

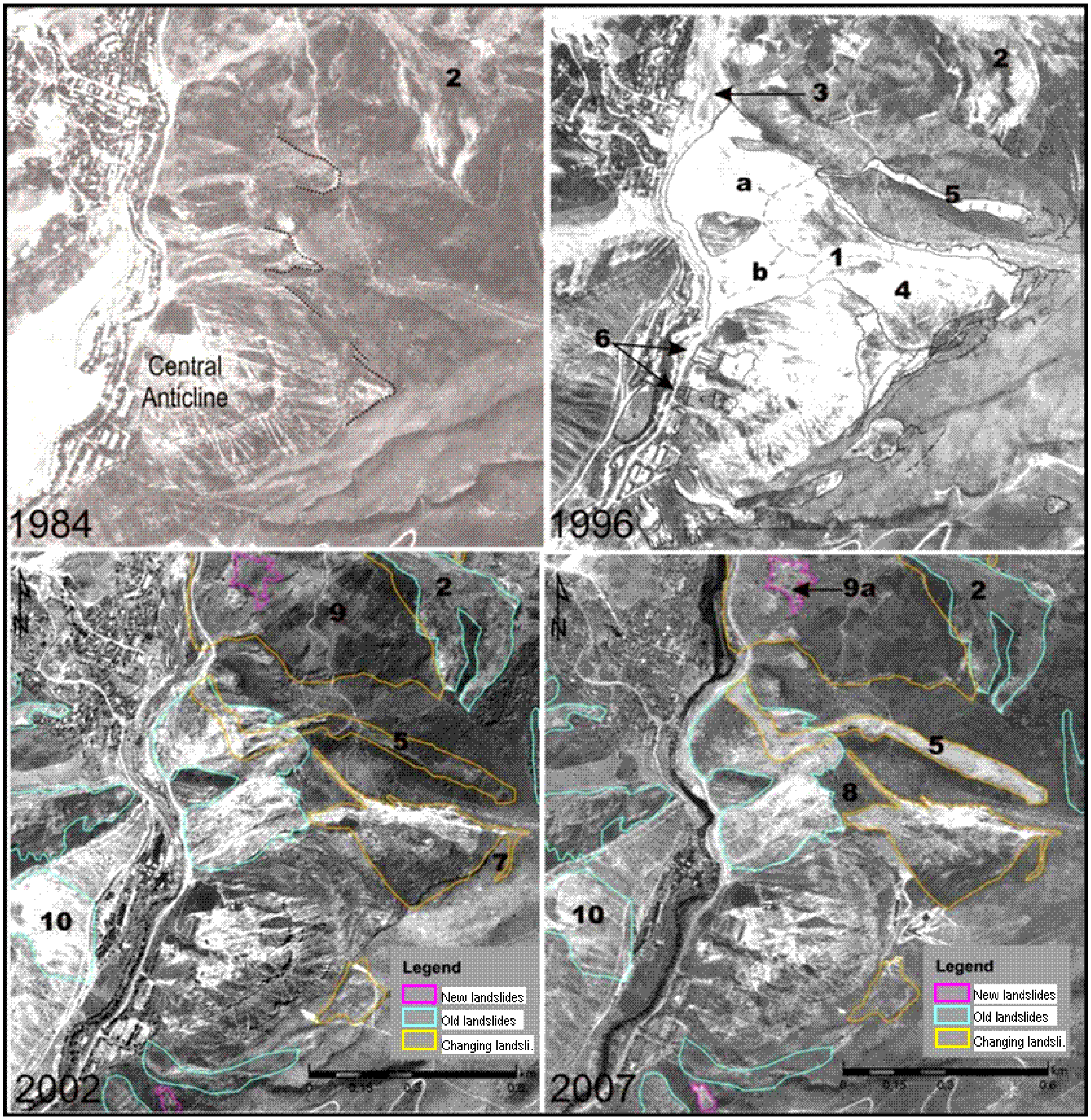

Figure 4.1 *Evolution of landslide susceptibility in the vicinity of the central anticline in Mailuu-Suu based on multi-temporal aerial and satellite imagery. Landslides: 1, 4 – "Tektonik"; 2 - "Koi-Tash" (east); 5 - "Koi-Tash" (upper); 10 - "Izolith". Meaning of polygon colors in the legend: the purple color is new landslides, the light blue color is old landslides, and the orange color is changing landslides*

These methods also include specialized recurring observations like GPS measurements and real-time automated systems equipped with different sensors (extensometers, inclinometers, piezometers, geophones, rain gauges) together with landslide failure early warning equipment. Detailed monitoring is a technique commonly related to a particular landslide or a portion of an unstable slope, escarpment (Figure 4.2).

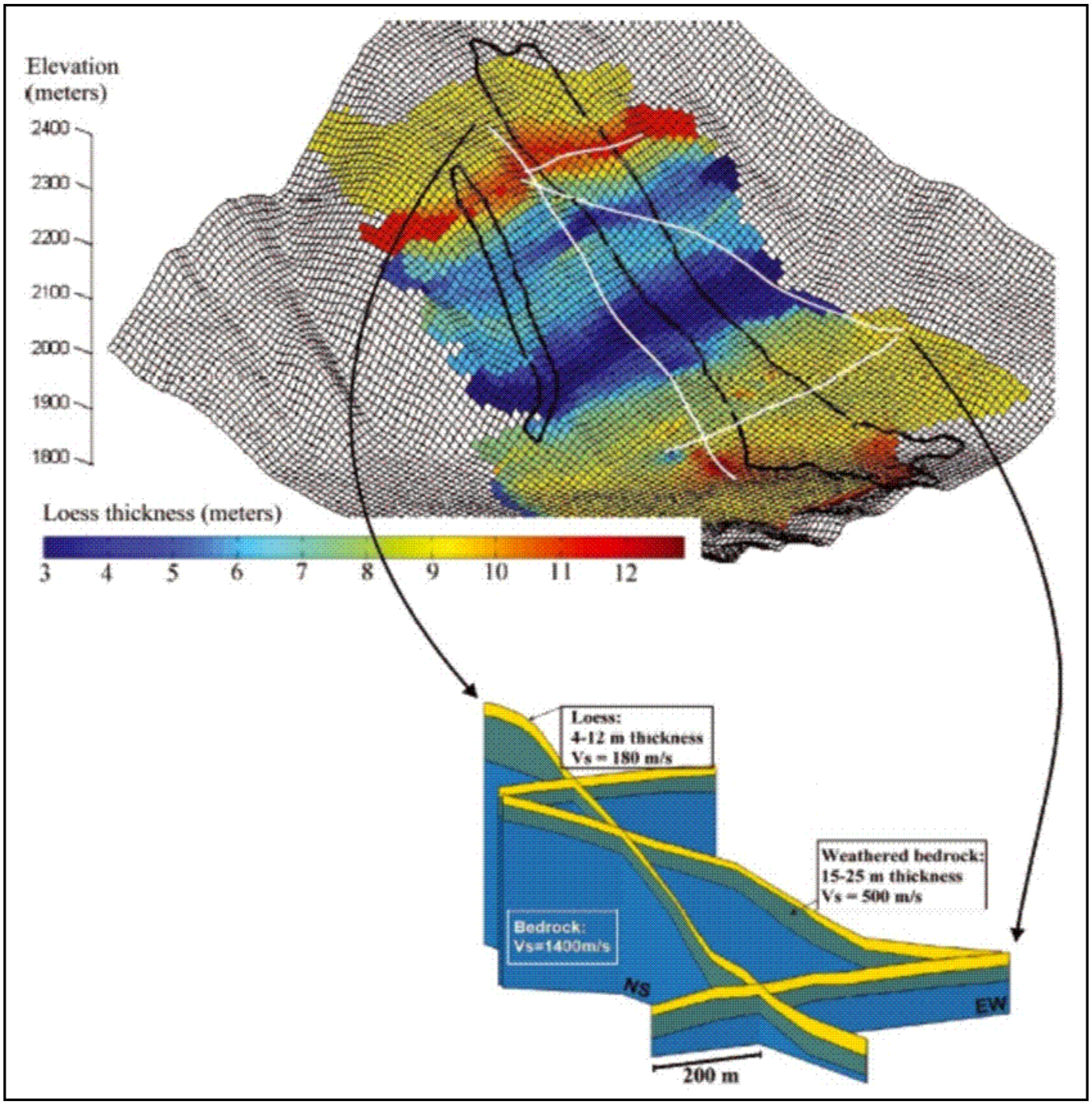

Figure 4.2 *The results of geophysical investigations (electric and seismic) of "Kainama" landslide. Black polygons mark the two landslide areas; white lines show the geophysical profiles – represented by a 3D geological-geophysical model of unstable slopes*.

The geophysical profiles – represented by a 3D geological-geophysical model of unstable slopes were derived using 2D Geophysical Inversion Software for Resistivity and Induced Polarization data (Res2DINV) software. Information gathered during detailed monitoring is used for prognosis and early warning against landslide failure, for planning of risk reduction measures and for prevention of emergency situations. Ground-based investigation methods (geotechnical and geophysical methods) play the most important role during detailed monitoring.

4.3.2. Landslides monitoring equipment

The set of devices and equipment developed and used in the Scientific Engineering Center (SCE) “Geopribor” includes: landslide deformation and displacement registrator; portable digital geotester with in-situ and radiochannel data transfer for registration of particular displacements; a multichannel system of landslide displacement registration with radiochannel data transfer and landslide failure early warning equipment; different kinds of piezometers, sensors and registrators of acoustic and electromagnetic emission for monitoring rockslides. Landslide displacement registrators consist of a wire extensometer of different modifications with diapason of measurements from 0 to 2000 mm and with an acceptable error of measurement of up to 0.5 mm. All sensors and equipment can be installed underground in isolated, waterproof containers to avoid unauthorized approach of people and animals.

Extensometers, the sensors used here, can be connected to a radio-transmitter with an antenna and an autonomous power supply. A frequency-modulated radio signal is transmitted with the preset intervals (for example, once per hour) from each of these monitoring units (MU). The collection and registration unit (CRU) of the automated monitoring system consists of a receiving system (antenna), a radio-receiving unit, a channel identification panel, an indication unit for registration of transmitted information on the value of displacement, and emergency-warning signalization. The maximal distance between MU and CRU can be up to 2 km. If the displacement increment exceeds some preset threshold values, sound and noise signalization will be activated on CRU, warning the operator and the people about landslide failure threat and possible emergency situations.

4.4. Results and discussion

Multiyear experience and utilization of monitoring equipment under field conditions of mining areas (Kok-Yangak, Mailuu-Suu, Min-Kush) and in Kambarata HPP-2 proved its effectiveness and reliability concerning landslide activity monitoring for reducing risks during emergency situations. With the help of the automated system of landslide activity monitoring, new records were collected providing practically and scientifically valuable results. The value of the automated system became especially obvious for the case of “Tektonik”, “Izolith” and “Koi-Tash” landslides (Figure 4.3), situated in the area of Mailuu-Suu city (Havenith et al., 2006). For the first time the facts such as the precursor of spasmodic movements of sensitive seismic landslides were determined directly for the 20-50 hours prior until the strong (M > 6) regional (Pamir-Hindu Kush) and local (Tien Shan) earthquake. The correlation between speed of movement with precipitation rate, air temperature, ground water level change and seismic activity in neighboring areas was also defined (Torgoev et al., 2010).

Further basic types (mechanisms) of landslide displacement were defined as a result of long-term non-interrupted or discrete monitoring of landslide movements in Kyrgyzstan. This monitoring was performed with the above-described equipment. The next types of landslide displacement leading to main failures (in a lot of cases catastrophic) are folowing:

- Irregular movements consist of slow or fast displacements of different duration alternating with long pauses (for example, “Izolith” and “Tektonik” landslides in Mailuu-Suu).

- Stick-slip movements include multi-repeated displacements of different amplitude and, as the rule, are synchronous with seismic and/or other geodynamic events (Figure 4.3). These displacements alternate with pauses of durations between several months and several years (“Upper Koi-Tash” landslide in Mailuu-Suu)

- Creep includes long-term, at the beginning slow, landslide displacements, which accelerate with time and end with slope failure (“Tuyk-Suu” landslide in Min-Kush and “Koi-Tash” landslide in Mailu-Suu).

Atmospheric precipitation data were collected from Kyrgyz Hydrometerologic Department and this data were obtained from gauging station “Massy” that is located 30 km to the South-West of the Mailuu-Suu town. The local seismic activity data (with radius of 100 km from Mailuu-Suu town) were taken from the Institute of Seismology of Kyrgyz National Academy of Science. Proscessing of statistical data was performed using StartGraf program.

The difference between the below-described landslide movements registered by monitoring is explained by different mechanisms of soil and rock deformation and also by the affection by different external factors. The factors affecting landslide movement and prognosis of its failure are seasonal (precipitation, snow melting) and geodynamic (earthquakes, explosions, vibrations) ones (Figure 4.3). From the three described models of landslide movement, the creep model (gravitational creep) is more appropriate and reliable from temporal prognosis and early warning points of view. That is due to its higher potential to predict the exact time of slope failure based on approaches developed by different authors (Fukuzono, 1990). These assumptions are based on the trend of linear change of reversal rate of brittle materials displacement over time to the tertiary stage of creep, i.e. before the collapse of the landslide.

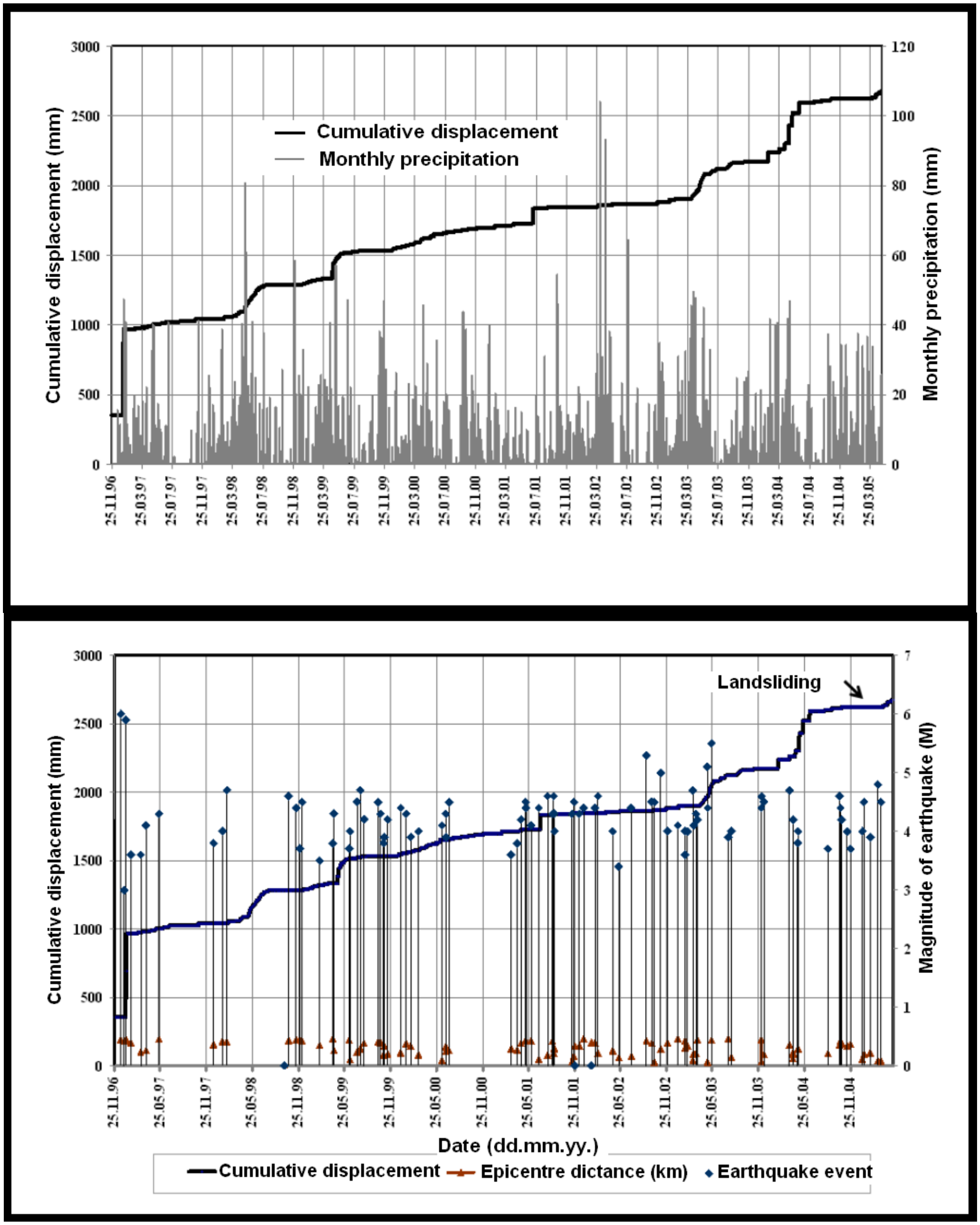

Figure 4.3 *Monitoring data of "Koi-Tash" (upper) landslide in correlation with atmospheric precipitation (gauging station "Massy") and local seismic activity (100 km radius from landslide)*

4.5. Conclusion

Monitoring of mass movements in geodynamically active mountainous regions is one of the most important stages for the prognosis and prevention of geohazards, and consequently for the population and infrastructure safety assurance. Geomonitoring allows tracking potentially hazardous exogenous geological processes and studying correlations and interconnections within them. This finally gives the possibility to make spatial and temporal prognosis of the landslide hazard on regional and local scales. Application of GIS and RS approaches for investigation of landslide activity are the main natural and technogenic influencing factors, which allow allocating the most vulnerable geological formations and investigating the dynamics of landslide development. The obtained results show that combining remote and on-the-ground geophysical methods (geotomography) for geological environments with GIS provides valuable information for example when a huge spatial extent of factors is available, or when singular landslides are to be investigated and characterized. From a practical point of view, such a complex approach, which includes analyses and post-processing of various types of information, provides a possibility of forecasting estimated synergetic landslide risks in the surrounding of waste tailings located in Mailuu-Suu and Min-Kush (Torgoev et al., 2008).

4.6. Acknowledgement

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