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Distribution of radioactive isotopes in the mountain and piedmont regions of Central Tajikistan Varzob river valley

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Abstract

The Varzob Valley in the Central Tajikistan, due to its proximity to the Gissar mountains range, acts like a funnel for the air mass transported by the southern winds. For a better understanding this local phenomenon, the gross alpha and beta as well as ^{40}K, ^{137}Cs, ^{232}Th and ^{238}U activity concentrations together with the Th/U ratio were studied. The results showed the existence of a deposition process of the airborne dust on the southern slope of Gissar Mountains. The influence of the Odjuk pegmatite outcrop on the natural radioactivity along the Varzob valley was evidenced too. At the same time, no traces of radioactive contamination from local anthropogenic sources were found.

Keywords Central Asia uranium extraction legacy · Tajikistan · Natural and anthropogenic radionuclides · Airborne radionuclides transport

Introduction

Within the Cooperative Transboundary Monitoring Data Sharing and Modeling of Water Resources in Central Asia (NAVRUZ) project [1] it was found that in some places of the Varzob gorge of Central Tajikistan, the activity concentration of the anthropogenic ^{137}Cs and natural ^{210}Pb exceeded more than four times the activity concentration reported for Central Asia [1–5]. This fact should be viewed in the context of the existence of a considerable number of tailing of former uranium mines, mainly located in the mountainous part of Tajikistan as well as in other Central Asian Republics [4–8].

To explain the presence of ^{137}Cs, a fission product, more hypothesis were formulated: (1) unauthorized discharge of small quantity of spent uranium fuel; (2) an active transfer of radioactively contaminated atmospheric dust from neighboring regions.

The first hypothesis was rejected because radiometric investigations of bottom sediments and soils collected along Varzob River tributaries and Coja Obi Garm thermal springs showed no traces of fission products [Abdushukurov, unpublished results].

Regarding the second hypothesis, it is worth mentioning that the Dosimetric Service of the Institute of Nuclear Physics in Tashkent has evidenced an increase air activity after Chernobyl accident and atmospheric Lop Nor Chinese nuclear tests and, at a lesser extent, after India and Pakistani underground tests [9]. Under these circumstances, most probable the main sources of ^{137}Cs contamination were nuclear incidents and atmospheric testings of a nuclear bombs, the air representing the principal pathway. In this regard, it was necessary to pay more attention to the physical-geographic characteristic of the involved locality.

Indeed, the Gissar (Hissar), Zeravshan and Turkestan mountain ranges, with an average height over 3500 m, and a total length of about 200 km occupy, the northern part of Tajikistan. Strictly oriented from the east to the west, they

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act like a barrier for both summer southern and northern winds, including the “Afgan” dust storm coming from the Tajikistan desert [10]. Therefor, the aerosols transported by the Afghan dust storm do not cross the Gissar ridges, the southernmost mountain range, falling almost completely on the southern mountain slopes, where they are collected and transported by the Varzob river tributaries (Fig. 1).

For a more detailed study of this phenomenon, an additional radiometric investigations were performed which results are presented and discussed in this paper.

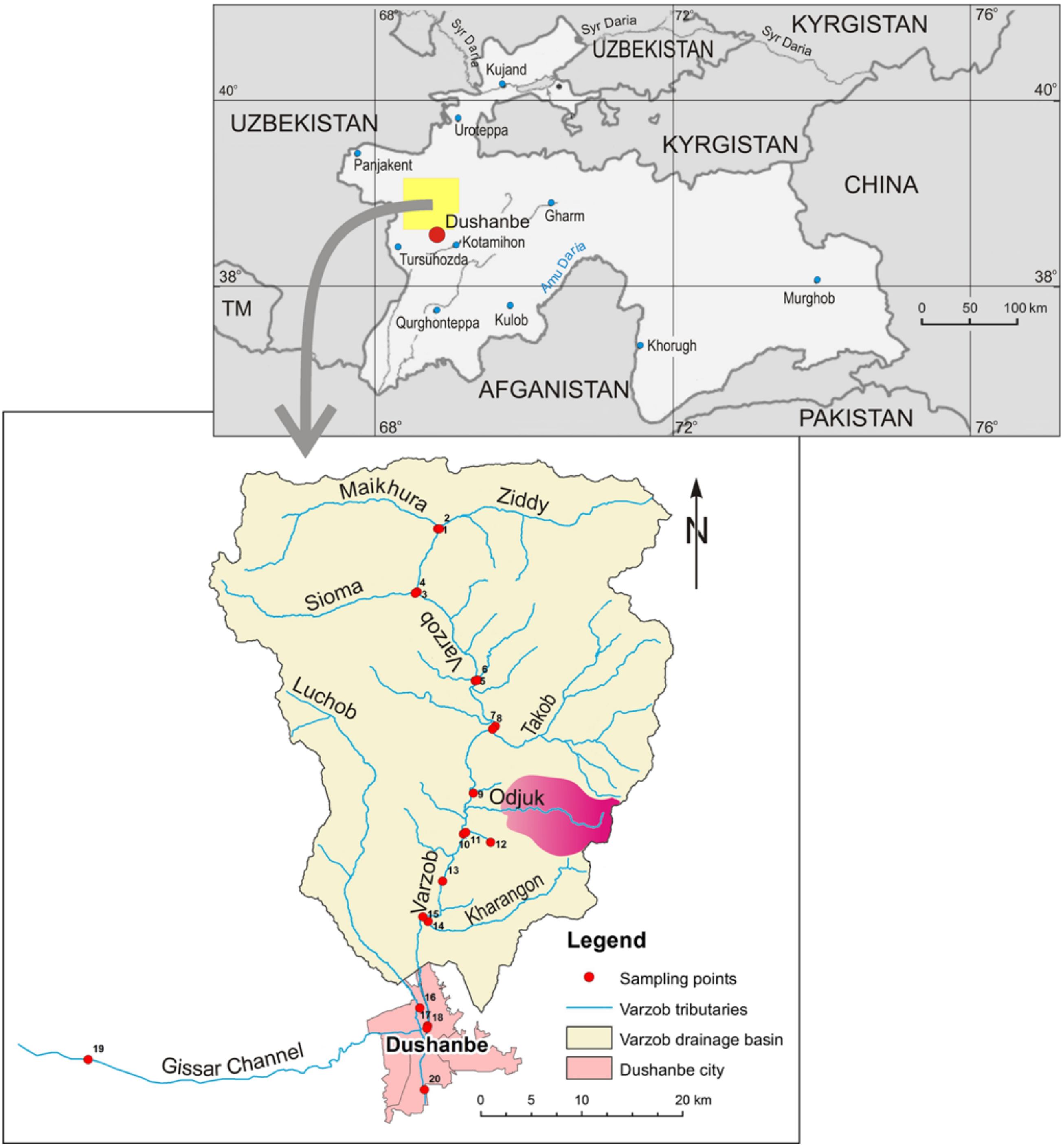

Fig. 1 The position of sampling points along the Varzob river valley as well as the location of the Odjuk pegmatite outcrop. The inset illustrated the investigated area with respect to the general map of Tajikistan. TM stands for Turkmenistan

Experimental

Varzob river drainage basin

The drainage basin of the Varzob river belongs to the South-Gissar structural-formation of the Central Tajikistan (Southern Tien-Shan). The basin covers a multi-phases Gissar batholith, with different granites of Middle carboniferous—Early-Permian to Middle Carboniferous age. In some places, these formations are ruptured by early-Mesozoic dikes of lamprophyres and explosion tubes with alkaline basalts [11].

The southern part of the Varzob valley, located in the Tadjik depression, consists of an accumulation of coastal-marine, terrigenous and chemogenics, sometimes coal-bearing, salt-bearings and gypsiferous sediments of Mesozoic-Cenozoic age. All of them were significantly deformed during the collision of Indo-Asian plate systems. The Pamir and Southern Tien-Shan mountains, which frame the depression, supplied an impressive amount of detritic material resulting from the erosion of the bordering high-mountain structures [12, 13]. Two Varzob river tributaries—Odjuk and Obi Chappa cross the large Odjuk pegmatitic field, which content of Rare Earth Elements accessories minerals such as samarskite, monazite or gadolinite could explain the presence of the Th and U in the water and bottom sediments of Varzob river [14].

It should be noted that, during the Soviet Union period, the main activity in the Varzob river gorge was related to the mining and processing industries, so a significant amount of tailing material was brought into river. Beside this, the southern Tajikistan, due to its desertic/semi-desertic character, is frequently exposed to the dust storms known as "Afghan" which northward circulation is stopped by the Gissar ridge [14].

Therefore, the presence of high mountain range northern Tajikistan determines the air circulation to move northward, the Varzob valley acting, as mentioned before, like a funnel [14, 15]. In this way, Varzob river sediments are enriched in both detritic materials including the pegmatitic Odjuk field as well as aeolian one transported by winds such that "Afgan" storm [10].

Sample location

To get more information concerning the environmental radioactivity as well as to determine the most probable source of radioactive material, we have chosen 20 sampling points which covered more than 55 km of Varzob river valley from the Sioma river confluence to southern outskirts of city of Dushanbe (Fig. 1). For a better accuracy, the collecting points were as possible as equal distributed (Fig. 1 and Table 1—Supplementary material). The collecting points Tj1 to Tj23 were located in the mountain section of the Varzob valley while Tj2 to Tj48 lye on its inferior sector (Table 1—Supplementary material). To establish a possible correlation between Varzob river sediments and adjacent soils, whenever it was possible, we have collected both sediment and soil samples.

For a better description, 13 of the 20 collection points were located before the confluence with Varzob mainstream. Three other collecting points were chosen along Gissar canal to see if the canal water transports the storm dust as well as the weathering products from Gissar mountains southern slope.

In the case of soil, we have collected a 2 cm thick superficial layer, from 40 × 40 m lots and, wherever possible, at minimum 20 m off river banks. To reduce as possible as the composition fluctuation, sediments were collected for each sampling location five times along river bank at distances between 10 and 15 m. In each point we have collected about 0.5 kg of sedimentary material, kept in polyethylene bags until laboratory processing. In laboratory, large fragments of inclusions and roots were removed, the remaining material was dried, sieved through a 1 mm sieve (18 mesh), and stored for future analysis.

Sediment samples primarily consisted of sandy mud with rare pebble which were removed before processing. Soil samples, mainly sandy loam contain also vegetation fragments such as root or grass fragments, were similarly cleaned before processing. By taking into account the reduced amount of material of about 0.5 kg, no further grain distribution was performed.

More details concerning the sampling procedures are provided in [16–18].

Radiometric measurements

Alpha and beta gross activity were determined by using a modified version of RUP-1 standard radiometer [19]. The gross alpha radiation activity concentrations were determined by means of a ZnS:Ag surface counter with a superficial mass of 6–8 mg/cm^2. In the case of for beta ray, all measurements were performed by using a SBT-10 halogen filled counter provided with a muscovite window which allowed detecting beta particles with an energy higher then 100 keV. The sensitivity of the beta radiometer for 2-h measurement time was no lower than 10 Bq/kg, a convenient value for our samples. In these conditions, the measurements reproducibility was better than 90%. It is worth mentioning that both alpha and beta gross activity concentrations reflect the content of background consisting of natural ^{40}K as well as ^{232}Th and ^{238}U radioactive series radionuclides together with airborne ^{137}Cs and ^{210}Pb.

Gamma spectroscopic determination of the activity concentrations of natural ^{40}K, ^{210}Pb, ^{232}Th and ^{238}U and anthropogenic ^{137}Cs was done by using a Canberra HPGe coaxial detector with a relative efficiency of 10% and an energy resolution of 1.78 keV for the ^{60}Co 1.33 MeV line. The efficiency calibration was performed by using a reference sample consisting of river Gunt sediments collected in the vicinity of the city of Khorog (Tajikistan) which content of natural radionuclides was certified by the National Radiation laboratory of Kazakhstan and Uzbekistan as well as by the Sandia National Laboratory, USA. A second Canberra MGS-6 1030 reference sample was used to check the measurements accuracy.

Sediments as well as soils samples, processed as mentioned before, were poured into 500 cm^2 Marinelli backer. Both sample holder and HPGe detector were shielded by 5 cm lead brick box and 2 mm cadmium foil. The acquisition time was no shorter than 6 h for soil and sediments samples and of 24 h for background. Under these conditions, the total experimental uncertainty was no $>$ 7%.

Final data regarding the radionuclides distribution along the considered sector of Varzob river are reproduced in the Table 1—Supplementary material for sediments and in the Table 2—Supplementary material for soils. Moreover, for a better description of collected data, in Fig. 2 we have illustrated the distribution with the distance to Dushanbe city the gross alpha and beta as well as gamma activity concentration of natural ^{40}K, ^{232}Th and ^{238}U and anthropogenic ^{137}Cs.

The activity concentrations of ^{232}Th and ^{238}U were determined by measuring the activity concentrations of ^{212}Bi and ^{212}Pb as well as ^{214}Bi and ^{214}Pb by supposing the existence of radioactive equilibrium within each radioactive series (Tables 1 and 2—Supplementary material).

As ^{210}Pb could be carried by the atmospheric dust too, to evidence this peculiarity, the experimental data concerning the spatial distribution of ^{210}Pb in sediments and soils are illustrated in Fig. 3.

Instrumental Neutron Activation Analysis

To check the accuracy of the gamma ray radiometric analysis, besides the specific reference samples we have used, in the case of Th and U, the Instrumental Neutron Activation Analysis (INAA). All measurements were performed at the 10 MW WWR-SM reactor of the Institute of Nuclear Physics, Tashkent, Uzbekistan. For this, aliquots of 0.2 g were carefully weighted, packed in double polyethylene packets, introduced in aluminum containers and irradiated in the reactor central channel a thermal neutrons flux density of about 10^{12} cm^{-2} s^{-1}. To monitor neutron fluence and specter at irradiation point, nichrome comparators were introduced in each aluminum container together with the reference materials SGD-1a (gabbro, Geochemistry Institute, Irkutsk), Sl-1 (Lake Sediment, IAEA), GXR-1, GXR-5 (jasper and respectively soil, US Geological Survey). The U content was determined after four days cooling time necessary for the short time radionuclides to disintegrate while in the case of the Th, the cooling time was of 30–32 days. All measurements were performed by using an Ortec P-type Coaxial HPGe Detectors. More details concerning INAA are provided in [18].

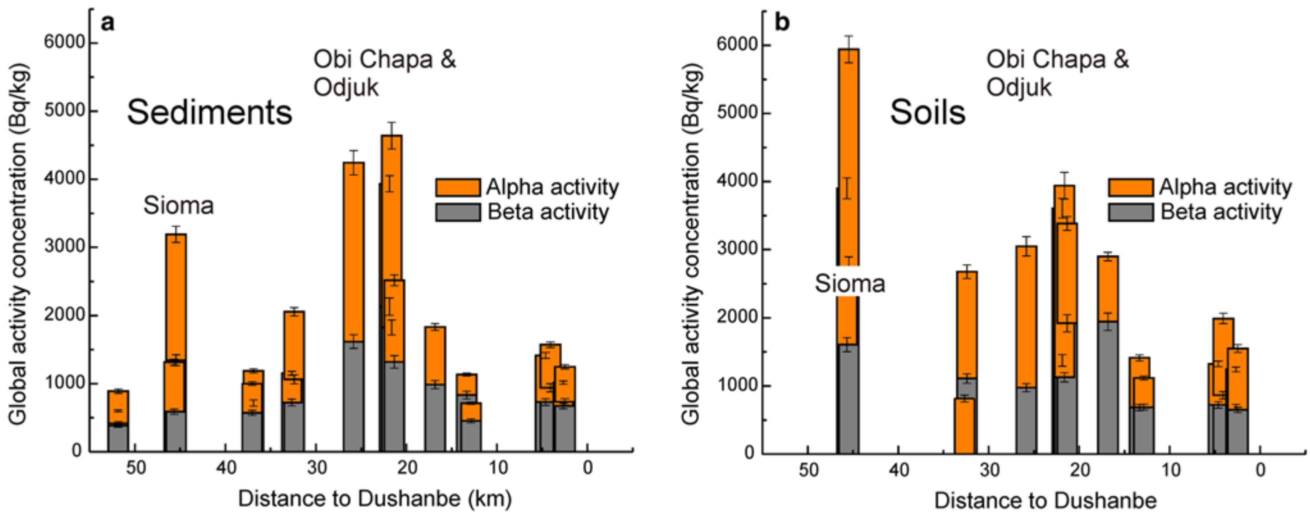

Fig. 2 The distribution of gross alpha and beta activity concentrations of sediment (**a**) and soil (**b**) samples along the Varzob valley

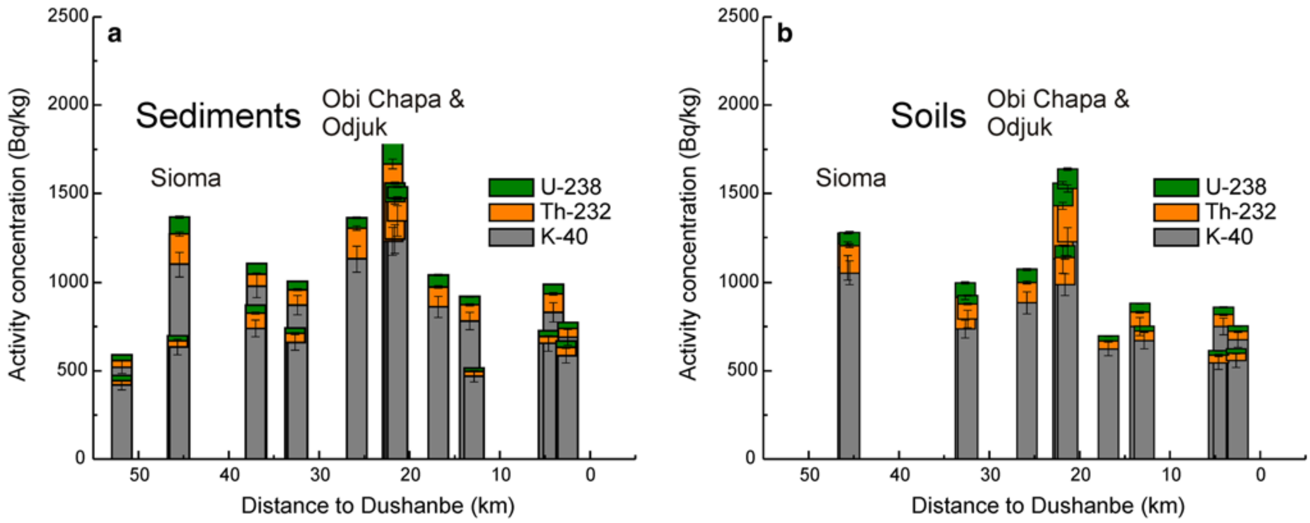

Fig. 3 The distribution of gamma ray activity concentration of natural ^{40}K, ^{238}Th and ^{238}U in sediments (**a**) and soils (**b**) along the Varzob river illustrating the influence of Ojuk pegmatite outcrop

Results and discussion

In investigating the radioactive background of the Varzob River we have interested in two issues: (1) the level of natural and anthropogenic radioactivity of Varzob river valley as a potential recreational area for the more than 680 thousands inhabitants of the municipality of Dushanbe, the capital of the Republic of Tajikistan [20]. (2) The possible origin of radionuclides by taking into account the location of Vrzob valley with respect to neighboring mountains chain as well as the influence of aeolian material transported by local winds including "Afgan" one [10, 14, 15].

Consequently, mentioned before, we have investigated the distribution of the same radionuclides as well as of the gross alpha and beta activity concentrations in both sediments and soils samples (Tables 1 and 2—Supplementary material). At a carefully analysis, the experimental data showed a relative disparity between the distribution of alpha and beta gross activity concentration in sediments and soils (Fig. 2).

In the case of sediments, as the staked diagram reproduced in Fig. 2a illustrates, both gross alpha and beta specific activities present a more or less constant activity concentration along the entire Varzob valley excepting the confluence of Sioma, Obi Chapa and Odjuk rivers. In these points, both alpha and beta activity concentrations increase more than twice, the gross alpha activity concentration appearing higher, which suggests the presence of more alpha-active radionuclides. A similar pattern we have found in the case of soils samples with the exception of Sioma collecting point. Here we have noticed a significant alpha ray activity concentration overpassing about two times the beta one, and significantly higher in soil than in sediments (Fig. 2b, Table 2—Supplementary material).

In the case of gamma ray activity concentration, with the exception of the Sioma location, the distribution of natural ^{40}K, ^{232}Th and ^{238}U in the Varzob river sediments seems very close to those found in the soils (Fig. 3, Tables 1 and 2—Supplementary material). The presence of the same maximums for Obi Chapa and Odjuk sampling points most probably can be explained by the proximity of the Ojuk pegmatite outcrop (Fig. 1). In both cases, as expected, the main contribution comes from ^{40}K, the natural radioisotope of the Potassium, on of the main major, rock forming element [21].

Moreover, the sum of the activity concentrations of thorium series isotopes correlates well with the thorium content in the samples as determined by INAA ($r^2 = 0.99$). Similar behavior we have noticed in the case of uranium series ^{214}Bi and ^{214}Pb terms whose activity concentrations well correlate uranium INAA content ($r^2 = 0.95$) (Tables 1 and 2—Supplementary material).

As mentioned before, in the case of the Sioma river collecting points, both alpha and beta activity concentrations of soil samples overpassed the sediment ones by 1.7 and 2 times respectively (Fig. 2a and b, Table 1 and 2—Supplementary material).

This peculiarity can be well explained by following the distribution of the gamma activity concentration of ^{137}Cs and ^{210}Pb. Indeed, as experimental data showed (Fig. 4, Table 2—Supplementary material), the ^{210}Pb activity concentration in the soil of Sioma river sampling point overpasses about 6.9 times those found in corresponding sediments. As ^{210}Pb is an alpha active radionuclide, its increased content could be a good explanation of the observed increases gross alpha activity. Similar remark can

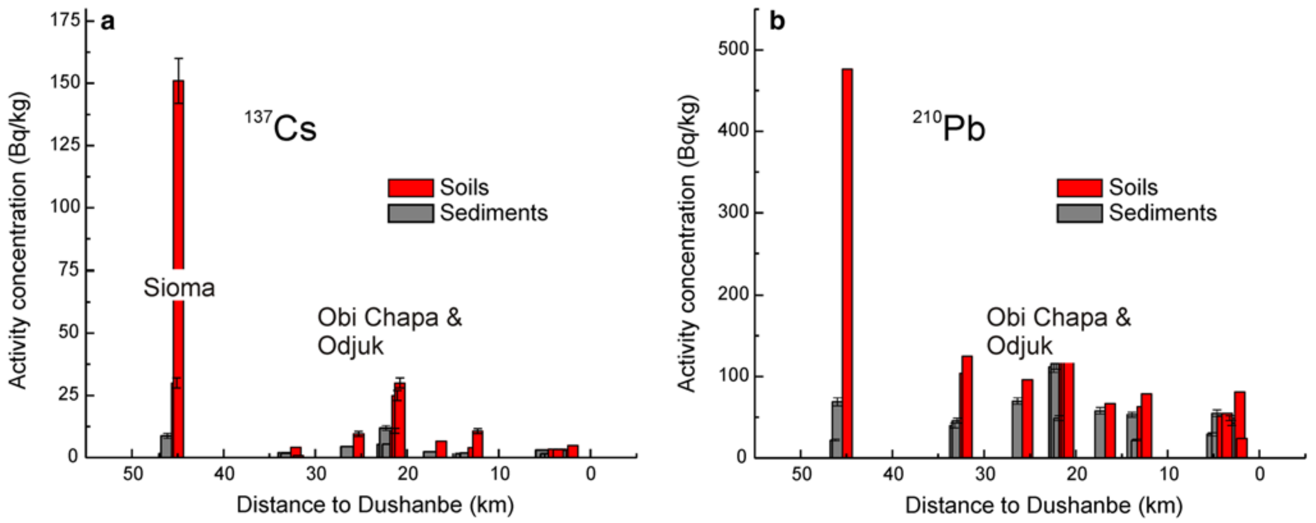

Fig. 4 The distribution of activity concentration of ^{137}Cs and ^{210}Pb in sediments (**a**) and soils (**b**) collected along the Varzob river showing a significant maximum at the confluence of Sioma river as a results of wind transported dust on the slope of Gissar Mountain range

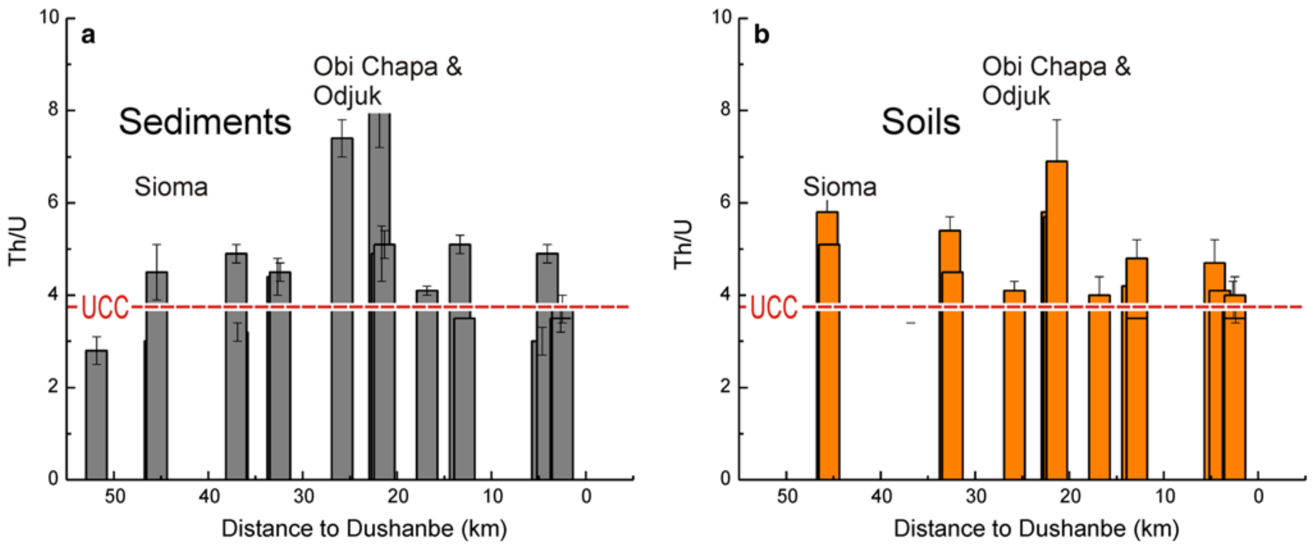

Fig. 5 The distribution of the Th/U ratio in sediments (**a**) and soils (**b**) samples collected along the Varzob river. Both distribution present a relative maximum in the vicinity of Obi Chapa and Odjuk rivers confluence due to the presence of Odjuk pegmatite field. The horizontal red line corresponds to the UCC Th/U ratio of 3.9. (Color figure online)

be made in the case of anthropogenic ^{137}Cs radionuclides, released most probably during the neighboring Chinese, Indian and Pakistan nuclear tests. In this case, its activity concentration in Sioma soils overpasses about 18 times the corresponding content in Sioma's sediments (Fig. 4, Tables 1 and 2—Supplementary material).

In the case of Sioma sampling point soils (Fig. 4b), a possible explanation for the increased activity concentrations of airborne ^{137}Cs and ^{210}Pb concerns the local disposition of Gissar range. As mentioned before, Gissar mountain range represents the first natural obstacle in the way of southern winds which can penetrate only through narrow mountain gorges, including the Varzob one. By penetrating to the gorges, the speed of airflow increase. Since the entrance to Sioma gorge is located frontal to the wind direction that allows intercepting more than 80% of all air streams.

Here, the transported dusts which falls on the Gissar and Zarafshan glaciers influence their melting so that, an important fraction of the dust particulate mater, enriched in ^{137}Cs and ^{210}Pb, is deposited in this sector of Sioma river. Further, the dust which enter river stream is transported by Vrazob river while those deposited on soil remains trapped which could be an explanation of the observed disparity between sediments and soils (Fig. 4 a and b, Tables 1 and 2—Supplementary material).

Another peculiarity of the natural radioactive elements distribution along Varzob valley regards the Th/U ratio. According to [22], in the Upper Continental crust (UCC), this ratio is equal to 3.9. In the case of Varzob valley sediments and soils, the average value of Th/U ratio is of 4.3 ± 1.4 and 4.5 ± 0.9 respectively, relatively close to the UCC value. However, at a closer examination, it can be remarked that the Th/U ratio reaches in sediments and soils of Obi Chapa and Odjul sampling point significantly higher values (Fig. 5a and b) which could be also related to the presence of the pegmatite field which weathered material can be found in local sediments and soils.

Conclusions

A complex radiometric investigation of alpha, beta and gamma specific activity concentration of sediments as well as of soils collected along the Varzob River, Central Tajikistan evidenced the existence of two sectors with increased activity concentrations: (1) one on the central sector of the valley, where two tributaries, Obi Chapa and Odjuk cross a pegmatite outcrop and (2) one on the base of the Gissar Mountains range, where due to the local relief, the dust enriched in ^{137}Cs and ^{210}Pb carried by southern winds, including the Afgan one is deposited and retained mainly by soil.

A detailed analysis of the Varzob river results showed that, within the experimental uncertainties, there are no any noticeable traces of recent local radioactive contamination or radioactive residues.

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