Chapter 9

Monitoring of Meteorological, Hydrological Conditions and Water Quality of the Main Tributaries of the Transboundary Amu Darya River

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Additional information is available at the end of the chapter

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Abstract

The results of monitoring of meteorological, hydrological parameters and hydrochemistry of the main tributaries of the transboundary Amu Darya River, the Vakhsh, Zeravshan and Pyanj rivers are presented. The influence of climate change on the meteorological characteristics of river basins has been observed. The need for coordination of Central Asian countries in the implementation of integrated water resources management is suggested. It is pointed out that the lack of a developed network of hydrometeorological observation points and a low level of information exchange among the countries of the region often leads to the emergence of scientifically unjustified scenarios and forecasts of climatic and hydrological processes in the region. The creation of a single regional center for cryosphere and hydrometeorological observations for continuous monitoring of processes occurring with water objects in the region is proposed.

Keywords: transboundary, Central Asia, Amu Darya, Zeravshan River, Vakhsh River, isotope hydrology

1. Introduction

Water resources in the Aral Sea Basin, whose territory belongs to five states, are mostly used for irrigation and hydropower engineering. These water users require river runoff to be regulated with different regimes. The aim of the hydropower engineering is the largest power production and, accordingly, the utilization of the major portion of rivers annual runoff in winter, the coldest season of the year. Irrigation requires the largest water volume to be available in the summer, during the vegetation period. River runoff regulation is exercised by large reservoirs which, along with hydropower stations, are operated as part of complex purpose hydroschemes. The largest hydropower stations have been constructed in the republics of the runoff formation zone in the upper reaches of the Amu Darya and Syr Darya rivers—in Kyrgyzstan and Tajikistan, while the major land areas to be irrigated are concentrated in the republics in the lower reaches of the rivers—Kazakhstan, Turkmenistan, and Uzbekistan. The problems of water resources use and the appropriate river runoff regulation were solved in the USSR by administrative command methods based on nationwide interests [1]. The situation has radically changed after the collapse of the Soviet Union and the formation of five independent states in Central Asia. The conflict of interests between hydropower engineering and irrigated farming has become evident and acquired transnational significance. What are the causes of the present-day conflict between irrigation and power engineering in the region? The first cause is the excessive development of irrigated farming in the region in the 1960s–1990s, resulting in a strict demand for practically complete regulation of river runoff, both seasonal and over-years, and its complete consumption for irrigated farming [2, 3].

There is no doubt that the main water arteries of Central Asia (CA)—the Amu Darya and Syr Darya—are important in the life of the regional population, in the survivability components of the biosphere and are a key factor in the development of two important areas—hydropower and agriculture. The diversity values of rivers' water flow have specific requirements for finding a balanced mechanism for their use excluding drain pollution and ecological imbalance. Such a multifunctional approach to sustainable use and protection of water resources is achieved by the implementation of integrated water resources management.

Transboundary water arteries make special demands for expansion and joint efforts for the development of regional standards and norms for the use of water resources, as enshrined in interstate agreements. Implementation of the interstate agreements aspects on various points of joint use of water resources is largely determined by the level of observation, measurement of meteorological, hydrological parameters, water quality and condition of water bodies and the efficiency of their use.

The Amu Darya is a Transboundary river of Central Asia and flows through four countries (Afghanistan, Tajikistan, Uzbekistan, and Turkmenistan) and is characterized by a length of 2400 km, the basin area of 534,739 km^2. The main tributaries to the Amu Darya are Vakhsh, Pyanj and Zeravshan rivers.

In the 1990s, the area of irrigated land in the region rose to 9.0 million hectares. A sharp increase was observed in the energy sector. The total installed capacity of all power plants in the region reached by the mid-1990s of the twentieth century to 40 million kWt. Unfortunately, all these impressive results led to the same great negative consequences. The intensity of the disturbance processes of ecological balance in the region has sharply increased, especially in the Aral Sea and the Aral Sea zone, the salinization of lands and their desertification have increased and the quality of water has worsened in almost all sources. At the same time, by the 1970s, the water resources of the Syr Darya River Basin were almost completely depleted. This led to the frequency of water deficit, for example, in 2010, the water deficit in the region was 21.3 km^3/year and turned into a global environmental problem in the region [4, 5]. The second cause is the severance of economic ties between Central Asian countries after the collapse of

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the Soviet Union. In the Soviet period, irrigated farming was a priority in the use of water resources. At the same time, the hydropower engineering that was operated in the regime was unfavorable for the national interests of the countries in the upper reaches of the rivers.

What are the ways to resolve this problem? Paradoxically as it may be, a radical solution of the conflict between irrigation and hydropower engineering will be their joint rapid development with the construction of new large HPPs with large-volume reservoirs, rather than the restriction or subordination of one of them. In the case of hydropower engineering, this implies the production of economic and clean power. As for irrigation, this implies an increase in the depth of long-term regulation of runoff and water availability for the areas already developed, as well as the potential for the development of new areas. The availability of several hydropower stations with reservoirs will allow the contradictions between hydropower engineering and irrigation to be resolved. Nowadays, the conflict between them arises because there is only one large hydropower facility with a reservoir in the basin of each of the major rivers in the region: the Toktogul HPP in Kyrgyzstan on the Syr Darya and the Nurek HPP in Tajikistan on the Vakhsh River. A single large hydroelectric complex on a river cannot exercise runoff regulation in two regimes simultaneously—irrigation and power ones. The construction of one large hydroelectric complex on each of the two rivers will radically change the situation. In this case, the upstream reservoir will operate in a purely power regime, while the downstream reservoir with the same volume will be able to re-regulate the runoff and even restore its natural regime. Moreover, it will be able to ensure runoff regulation in the interests of irrigation. The availability of more than two hydroelectric complexes with reservoirs will allow the situation to be improved even farther.

Water relations between Central Asia republics during the Soviet Union time were regulated by "Complex Use and Protection of Water Resources Schemes" in Amu Darya and Syr Darya Basins.

The main purpose of working out basin "Schemes" was to define real volumes situated within the Amu Darya and Syr Darya basins and available water resources for using. It also provided their fair allocation among region republics, meeting all the water users' interests. It should be noticed that a number of important aspects were not considered and included in "Schemes," for the situation has greatly changed after 1980 (years of the last "Schemes" specification and completion of hydraulic range composition). Mainly, it concerns the ecologic acquirements and sanitarian clears thrown into rivers and channels. Overusing basin water in irrigational lands planned as maximum use by "Scheme" resulted in exhausting water resources and new problems: (1) deterioration of ecological condition, sometimes leading to ecological disaster in river lowlands of Aral Basin, (2) great pollution of river water with pesticides, herbicides, other harmful elements and increase of water mineralization [1].

The Zeravshan River is one of the transboundary tributaries of the Amu Darya River that is formed in Tajikistan and that flows into Uzbekistan. The average flow of the Zeravshan River is about 5.0 km^3 with an average annual flow of 158 m^3/sec [6, 7, 8].

The meteorological and hydrological monitoring of the Zeravshan River Basin conditions in the territory of the Republic of Tajikistan is conducted at four meteorological stations and the Dupuly hydrological station. The total area of the glaciers in the Zeravshan River Basin is 437.9 km^2. The Zeravshan glacier is the largest among the 632 glaciers with a length of 27.8 km and an area of

132.6 km^2. According to the Agency of Hydrometeorology of the Republic of Tajikistan, there have been significant changes of geometric dimensions and mass loss of Zeravshan glacier during the period 1927–1991. The glacier retreated 88–94 m/year for the period 1991–2001 and its area decreased by 700,000 m^2 and it is expected to decrease by 30–35% by 2050 [6, 9]. The next section provides an analysis of the Zeravshan River Basin meteorological condition.

The problem of the water quality change and development of mechanisms of its control is still actual and concerns not only the separately taken country of Central Asia (CA) but also all the states of the region. Nowadays one of the most polluted rivers of Central Asia is Zeravshan River. The capacity of this water is changed under the influence of collector drainage water of irrigating basin zone and wastewater of Samarqand, Kattakurgan, Navoi, and Bukhara cities. Mineralization of water exceeds from origin to estuary: from 0.27–0.30 to 1.5–1.6 g/l. The most exceed of maximum permissible concentration (MPC) among heavy metals is observed in Cr and Zn. Moreover, in Zeravshan River high amounts of antimony was found and its phenol pollution composes 3–7.5 MPC [1]. The problem of water quality in transboundary river basins, in particular in the Zeravshan River Basin, is compounded by the fact that up to now there is no network sharing of information regarding the quality of the waterways between the neighboring states of Central Asia. Herewith, a uniform standard for assessing of the anthropogenic load degree on geoenvironmental systems (maximum permissible concentration) is not developed. The problem of water quality of the Zeravshan River is mostly associated with its pollution by wastewater of the Anzob mountain-concentrating combine—the mining enterprise for extraction and enrichment of mercury-antimony ores of the Dzidzikurut deposit [10–18].

The Vakhsh River is the main river of the Republic of Tajikistan and one of the tributaries of the Transboundary Amu Darya River in Central Asia. It has a length of 691 km and the area of the basin is 39,160 km^2. The Vakhsh River originates when the Surkhob and Obikhingou Rivers merge at a height of 1151 m. The right inflow to the Vakhsh Rivers, the Surkhob River has a length of 81 km, and the basin covers an area of 1760 km^2 at an average altitude of 3140 m. There are 246 glaciers in the Sorbog River Basin covering a total area of 105.6 km^2. The left component of the Vakhsh, the Obikhingou River, is 196 km long by basin area of 6660 km^2 [6].

The Pyanj River is one of the tributaries of the Transboundary Amu Darya River in Central Asia by a length of 921 km and a basin area of 114,000 km^2. The average value of the water flow is about 1032 m^3/s. The total area of glaciation of the Pyanj River Basin is 3767 km^2 [19].

It is quite natural that the formation of the basic characteristics and the water quality of the main river runoff is the result of the imprint of the properties and parameters of its tributaries with prehistory meteorological conditions and the condition of its feeding sources (ice, snow-ice, rain, etc.). Therefore, the monitoring of hydrological characteristics, the study of the chemical composition of the main rivers tributaries and thus the creation of a database on the river basin meteorological conditions, hydrological parameters and degree of contamination are the pledge for preparation of the reliable information about the main river.

This chapter presents the results of many years' studies of the hydrological parameters, hydrochemical and meteorological conditions of the basins of the Vakhsh, Zeravshan and Pyanj rivers—the main tributaries of the Amu Darya.

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2. Objects and methodology

The object of study is the Vakhsh River and its tributaries—Surkhob and Obikhingou—by use of water discharge data corresponding to rivers from Hydroposts: on the Surkhob-Garm Hydropost; Obikhingou river—Tavildara-Yozgand; on the Vakhsh river—Darband for the period 1960–2012. For estimation of the meteorological conditions of the Kyzilsu, Obikhingou and Vakhsh rivers Basin, the meteorological data of the Lyakhsh, Tavildara and Garm meteorological stations were used.

The differential integral curves of average annual discharge are used to identify periods with high and low water run-off. The differential integral curve takes into account the fluctuations of the flow over relatively short periods. It is defined by summing the deviations of modular coefficients from the middle, that is, the ordinates are calculated as Σ (K−1). Thus, the ordinates of the curve at the end the cumulative sum of the annual modular coefficients gives the deviations from the long-term average (K = 1). The use of differential integral curves gives a vision of cyclical fluctuations without the effect of the boundaries displacement between the phases of the low and high duration cycles [6].

The Dehavz station meteorological data for the period 1931–2011 were used as it is close to the Zeravshan glacier and Iskanderkul in the Yagnob River Basin. Water flow of the Zeravshan

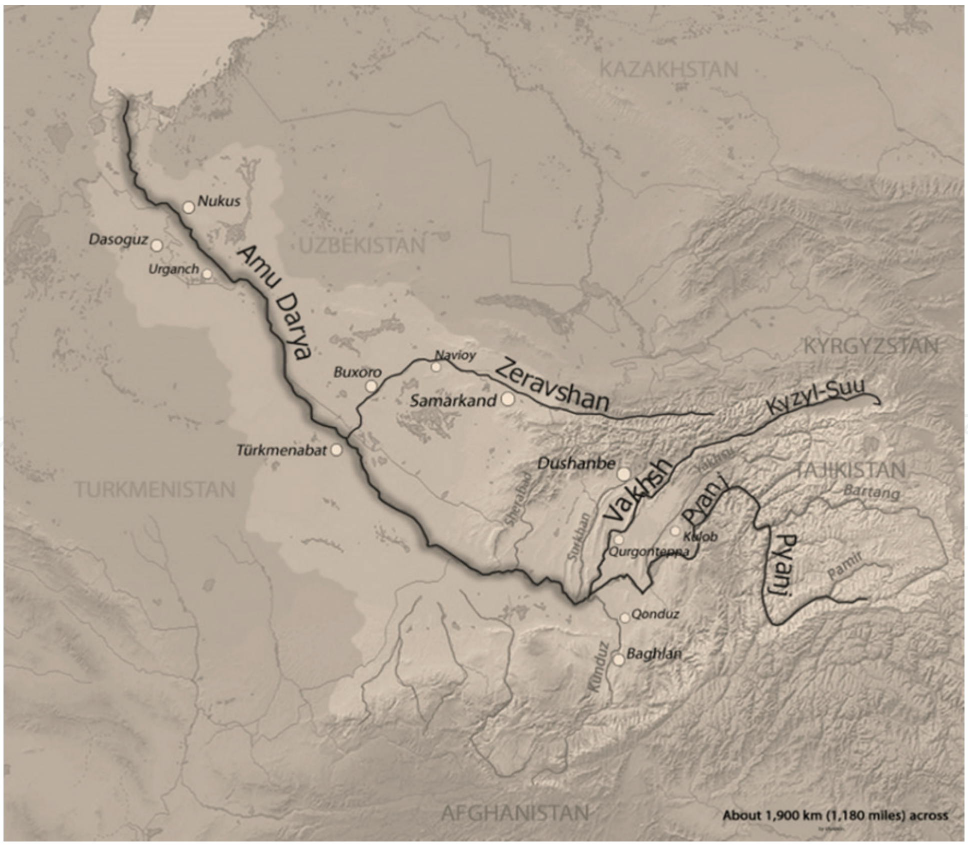


Figure 1. Amu Darya River Basin [32].

River was measured at the Dupuly Hydropost, which is the only operating station on the Zeravshan River. To determine the mean annual value of the water flow of the Zeravshan and Yagnob Rivers for the period 1931–2011, the data of the Agency for Hydrometeorology of the Republic of Tajikistan were used. Sampling of water from the Zeravshan and Vakhsh rivers and its tributaries were used by the scheme (**Figures 14** and **19**) developed in [11, 20] accordingly. The complex chemical water analyses were carried out by methods described in [9]. Sampling of water for isotopic analysis was carried out according to the methodology developed at the University of Colorado at Boulder (USA). Isotopic analysis of water was performed on Wavelength-Scanned Cavity Ringdown Spectroscopy (WS-CRDS). The individuality of each river from the point of view of chemical composition of water is compiled by sampling of the tributaries to the confluence with the main river and with other tributaries [20] (**Figure 1**).

The analysis of the meteorological conditions of the Pyanj River Basin and the dynamic change in temperature and precipitation were carried out using the date of the Agency of Hydrometeorology of the Republic of Tajikistan from the next meteorological station of the basin: Darvaz, Khorog, Dzavshangoz, Murgab and Gorbunov.

3. Meteorological and hydrological aspects

The meteorological and hydrological observations, the study of the glaciers state and the measurement of snow cover parameters are relevant at the upper reaches of Transboundary Rivers. Collection and systematization of such data is a source of forecasting the water flow of the corresponding rivers. Scientifically based and promising scheme of the main water consumer development—agriculture in the lower reaches of Transboundary Rivers is entirely determined from the degree of reliability and availability of a database on the values of the total water flow. The existence and continuous functioning of a developed network of observational and measuring stations on the watershed of the rivers is necessary in order to ensure uninterrupted and reliable information on meteorological and hydrological parameters. Taking into account the mountain orography of the Central Asian water resources formation zone, full-fledged climatic information can be provided only by a dense network of observations.

Unfortunately, the current situation of the hydrometeorological information exchange between the relevant agencies of Central Asian countries does not meet modern requirements. A low level of the information interchange causes the use of incorrect data and the emergence of a scenario of climate processes far from the real picture. Moreover, they become subject to mutual distrust and sometimes the appearance of conflict situations. It is clear that the implementation of uninterrupted hydrometeorological observations and the study of the state of water bodies located in hard-to-reach mountain areas are associated with the mobilization of huge material, financial and human resources. This plan requires a joint effort of the countries in the organization of a developed monitoring network with the extensive use of automatic stations and remote sensing methods. Of course, the existence and functioning of the regional center is necessary to coordinate the work of separate structures for integrated monitoring in the countries of Central Asia.

3.1. Vakhsh River Basin

The location of hydrological stations of the Vakhsh River Basin shown in **Figure 2**.

The increase in the volume of river flows of the Vakhsh River and its tributaries, Surkhob and Obikhingou rivers (**Figure 3**), shows that currently there is a reduction of the Tajikistan glaciations areas resulting in increased snow melt, probably due to the overall temperature increase in the region and changing precipitation patterns [6].

In the Surkhob River Basin, there are intensively melting small glaciers of the Northern slopes in the Western part of a ridge of Peter the Great. On the southern slopes of the Alay Ridge, glaciation decreases slowly as there are larger glaciers. In the Obikhingou River Basin, the largest glacier Garmo is intensively melting. During the twentieth century, it became shorter by almost 7 km, having lost more than 6.0 km^2 in area. It is currently retreating at an average speed of 9 m/year and the surface settles up to 4 m/year due to melting. Another glacier in the same basin, Skogach, retreats at a rate of 11 m annually.

Another important aspect of the hydrology of the rivers, the cyclical nature of the water flow, should also be considered. Assessing the long-term fluctuations of annual runoff and their periodicity is important. On the other hand, there are attempts to link fluctuations in water availability with various geophysical processes. The lack of a clear periodicity in long-term fluctuation of flow does not rule out the tendency to have continuously alternating high water years, called cyclical fluctuations of water flow. The length of these cycles, their sequence and

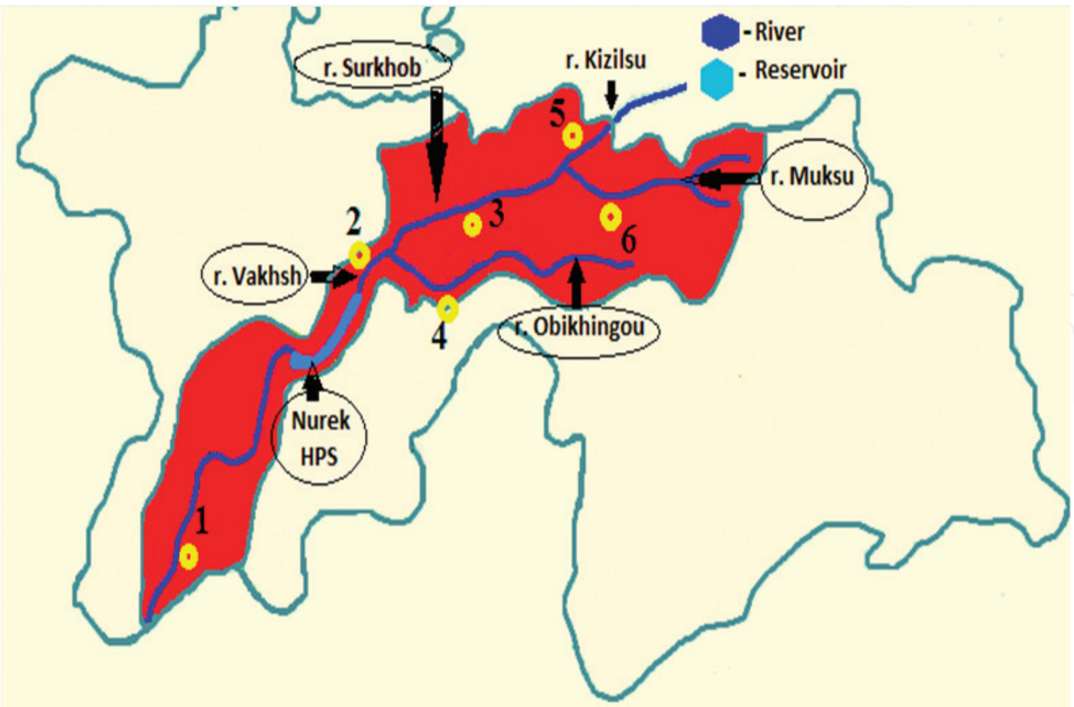


Figure 2. Vakhsh River Basin with location of hydrological stations: 1-Tiger Beam (R. Vakhsh), 2-Darband (R. Vakhsh), 3-Garm (R. Surkhob), 4-Tavildara (R. Obikhingou), 5-Dombrachi (Kizilsu), 6-Davsear (Muksu) [6].

the degree of deviation varies over a period. It is not always possible to make clear boundaries between wet and dry periods. Cyclical changes of the Vakhsh River runoff for the period 1932–2012 are shown in **Figure 4a** [6].

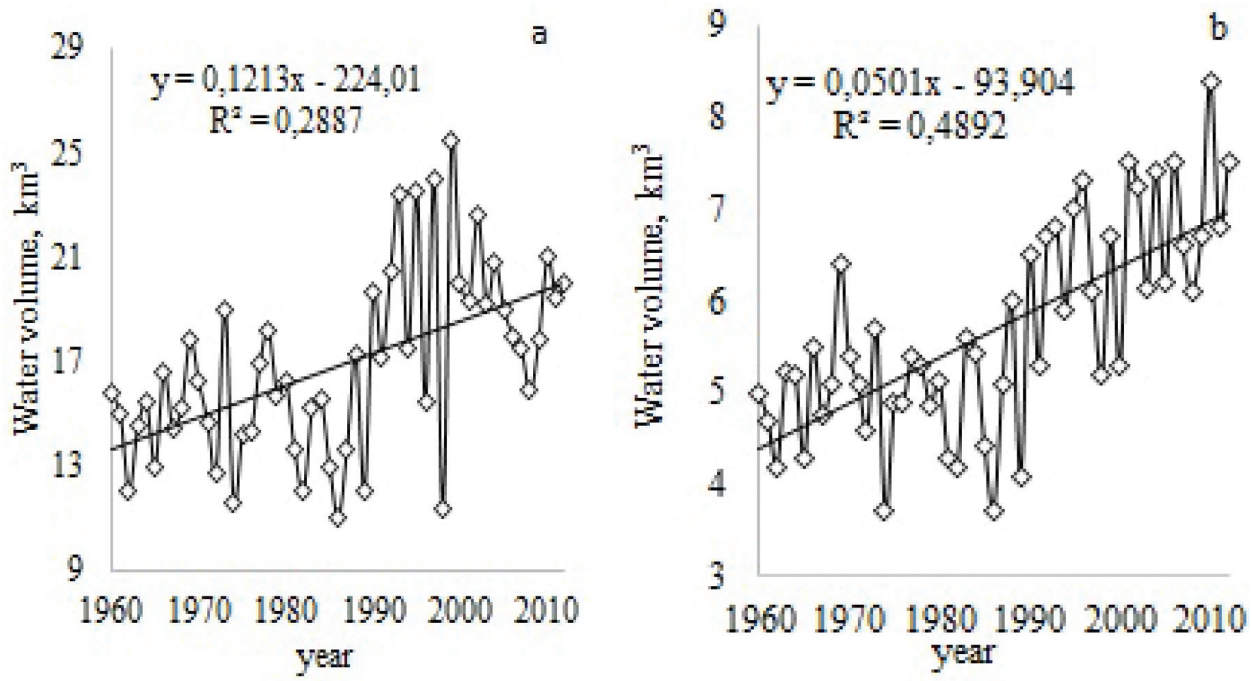
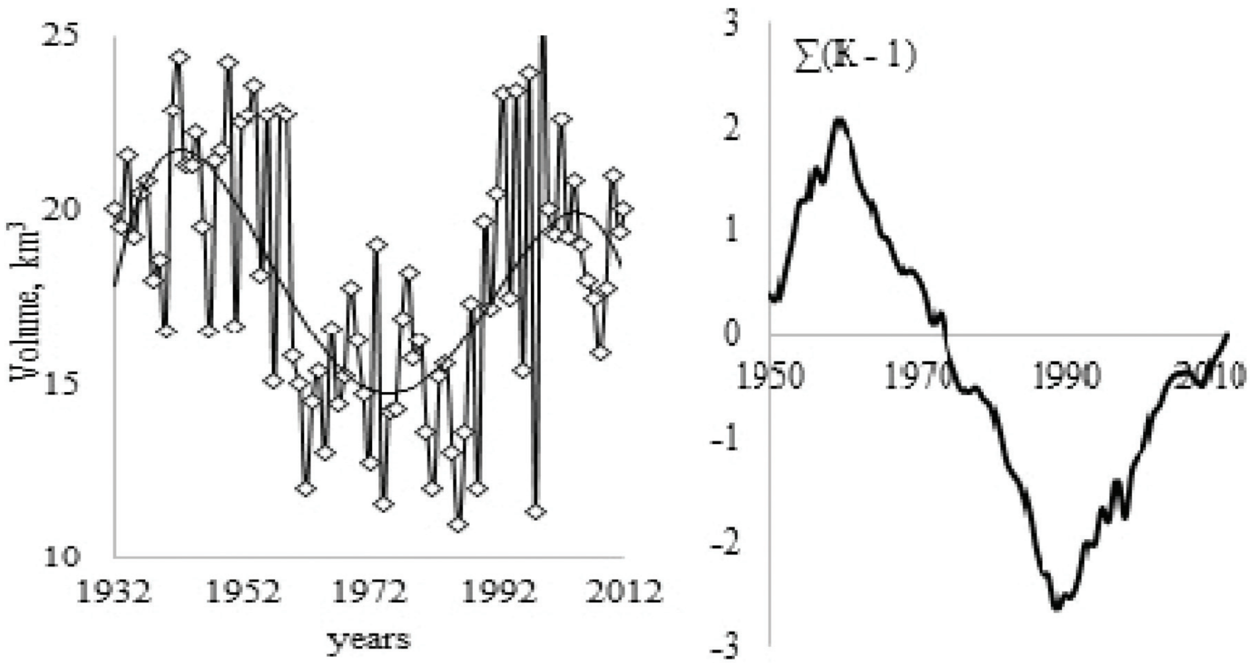


Figure 3. The water volume change of the Surkhob (a) Obikhingou (b) rivers for the period 1960–2012 [6].



a b

Figure 4. The water volume changes of the Vakhsh River for the period 1932–2012 (a) and the differential integral curve of the Vakhsh River annual average water discharge (b) [6].

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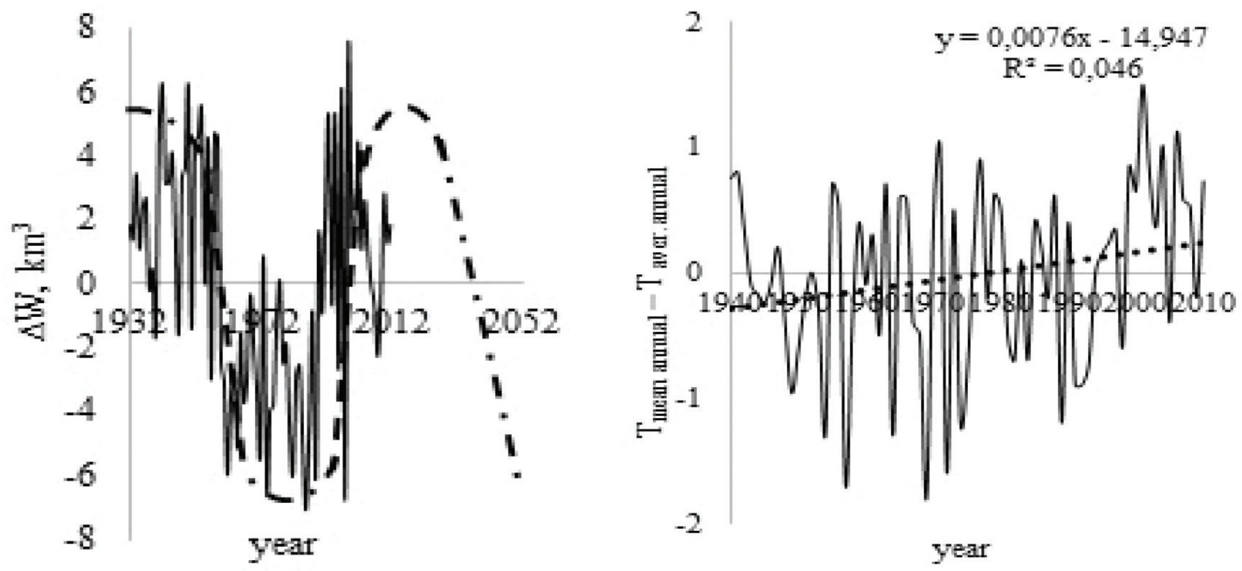
The presence of average annual water flows in the differential integral curve allows defining the periods of high and low water availability of the Vakhsh River (**Figure 4b**). It should be noted that the appearance of cyclicality in the water flow of rivers allows predicting the future scenarios of changes in the water flow of the river (**Figure 5a**) [6].

Another important factor in the water flow change is the meteorological condition of the river basins. The analysis of the date from meteorological stations shows that in the Vakhsh River Basin (including the basins of the tributaries of the river) the change in temperature has an increasing trend (**Figures 5b** and **6**). On the other hand, as it is shown in **Figure 6b, d**, atmospheric precipitation on the Kyzilsu River Basin has a decreasing trend with almost constant value on the Obikhingou River Basin.

As it was noted earlier, for the period 1960–2012, the water runoff in most of the rivers of the Vakhsh River Basin has an increasing trend. Thus, the increase in water volume and the decrease in precipitation give reason to believe that there is a continued reduction in the size of the glaciers in the Vakhsh River Basin [6].

3.2. Zeravshan River Basin

The deviation of average annual temperature at Zeravshan Glacier for the period 1931–1961 (a) and 1981–2011 (b) is presented in **Figure 7**. The period 1931–1961, as it can be seen from **Figure 7**, is characterized by low temperature and by high levels of precipitation in the form of snow. This suggests that the meteorological conditions during the period 1931–1961 were favorable for increasing the mass of the glacier [6].



a b

Figure 5. Cycle of the Vakhsh River water flow for the period 1932–2012 (a) and dynamics of the temperature change in the Vakhsh River Basin (Meteostation Garm) (b).

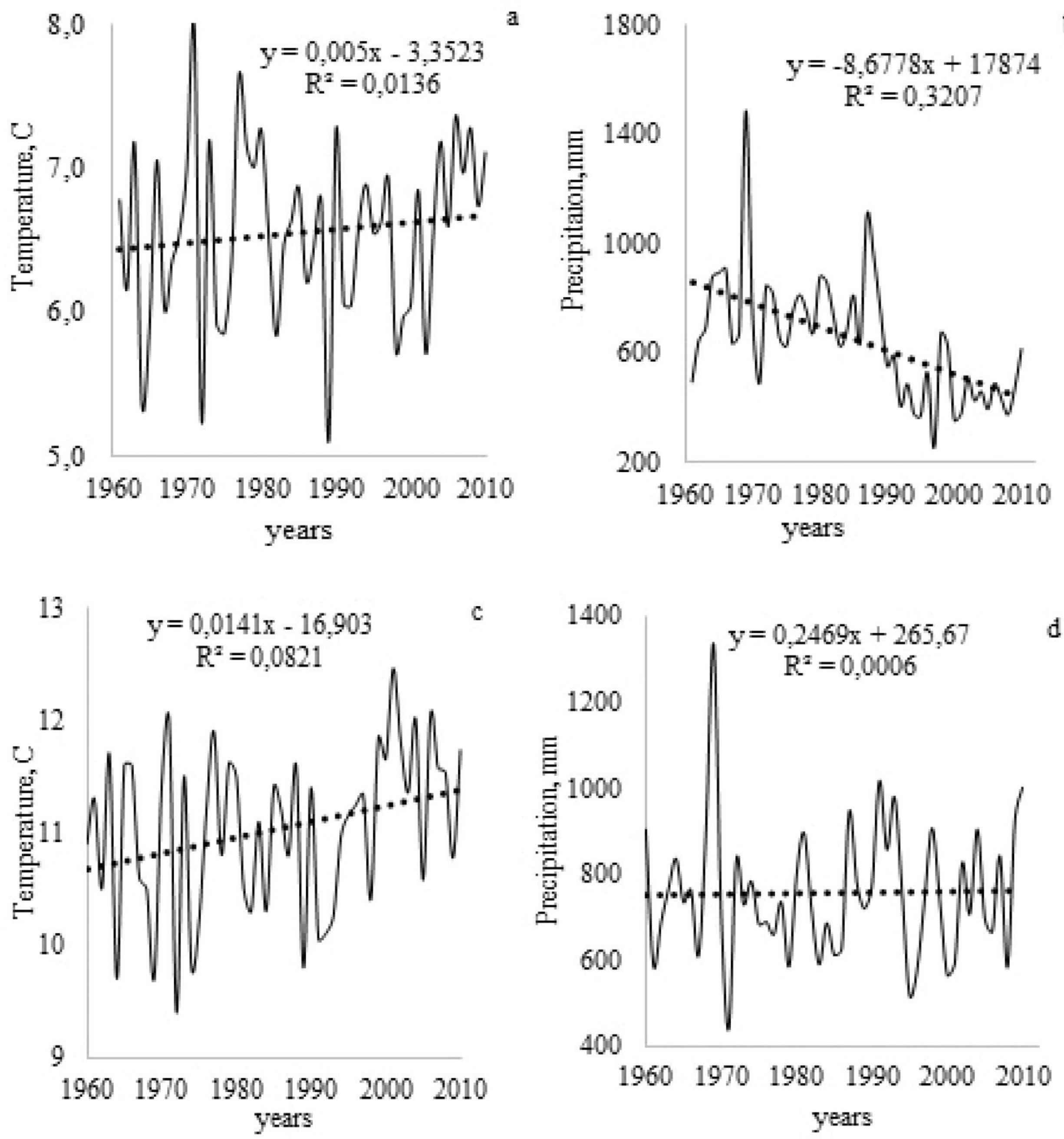


Figure 6. The average annual precipitation and temperature according to meteorological stations Lyakhsh (a, b) and Tavildara (c, d) for the period 1960–2012 [6].

The trend in temperature reversed during the period 1981–2011 compared to 1931–1961 (**Figure 7b**) and precipitation remained almost constant. The temperature change of the Yagnob River Basin for the period 1931–1961, as it is shown in **Figures 7c** and **6d**, is similar to the Zeravshan River basin and has a near-constant value. A significant increase of the temperature is appears for the period 1981–2011 [6].

The average annual water discharge of the Zeravshan River for the periods 1931–1961 and 1981–2011 is presented in **Figure 8a** and **b**. The decreasing trend of water discharge for the

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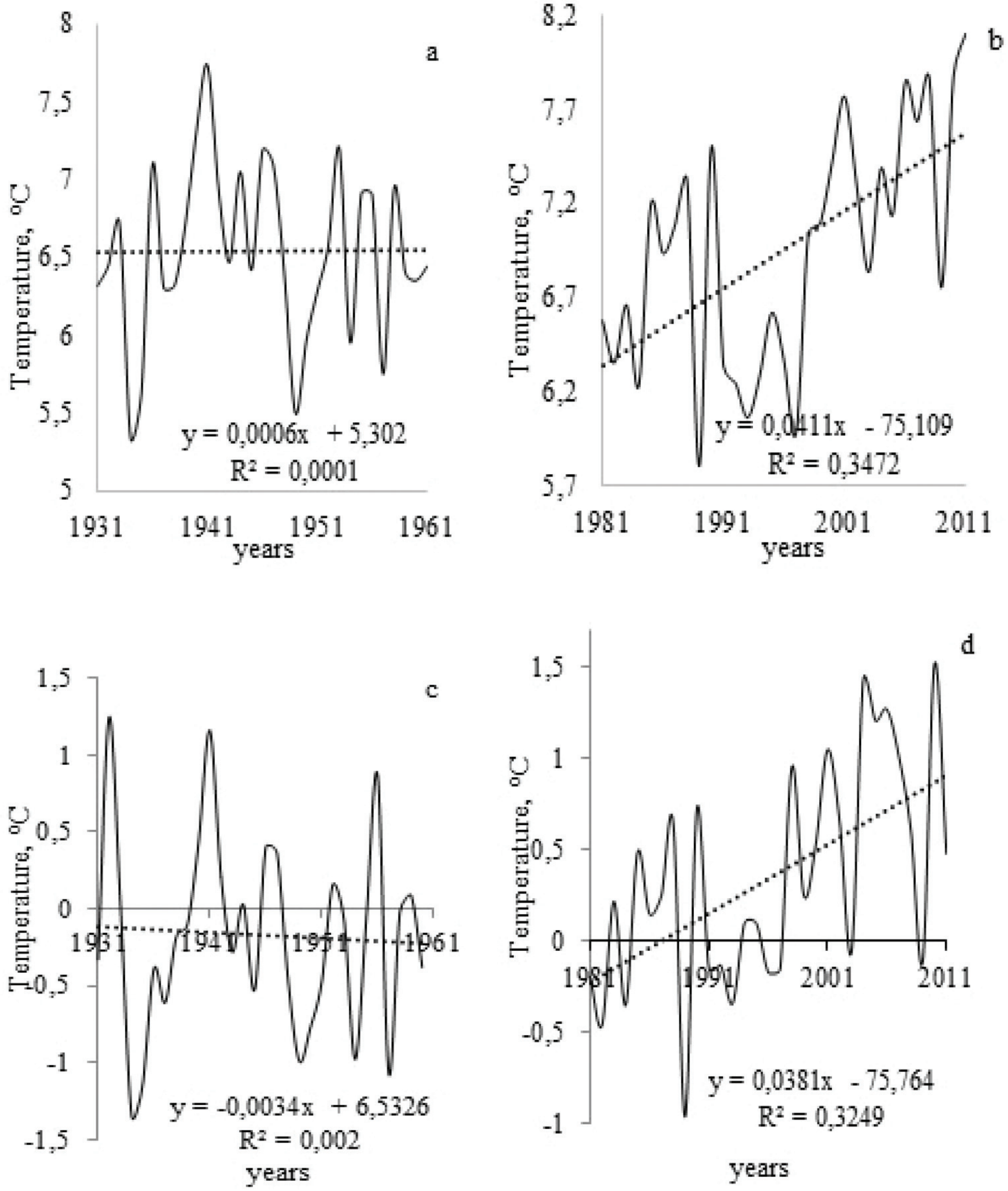

Figure 7. The average annual temperature for the periods of 1931–1961 and 1981–2011 in the area of the glacier Zeravshan (a, b) and in the Yagnob River Basin (c, d).

period 1931–1961 can be explained by the low and near-constant value of the temperature resulting in the snow accumulating and expanding the glacier rather than melting and contributing to river flow. This interpretation is supported by the fact that Yagnob River water flow has been almost constant during period 1931–1961 (**Figure 8c**). A completely different pattern in runoff is observed for the period 1981–2011 which experienced a significant increase in water discharge (**Figure 8b**) [6].

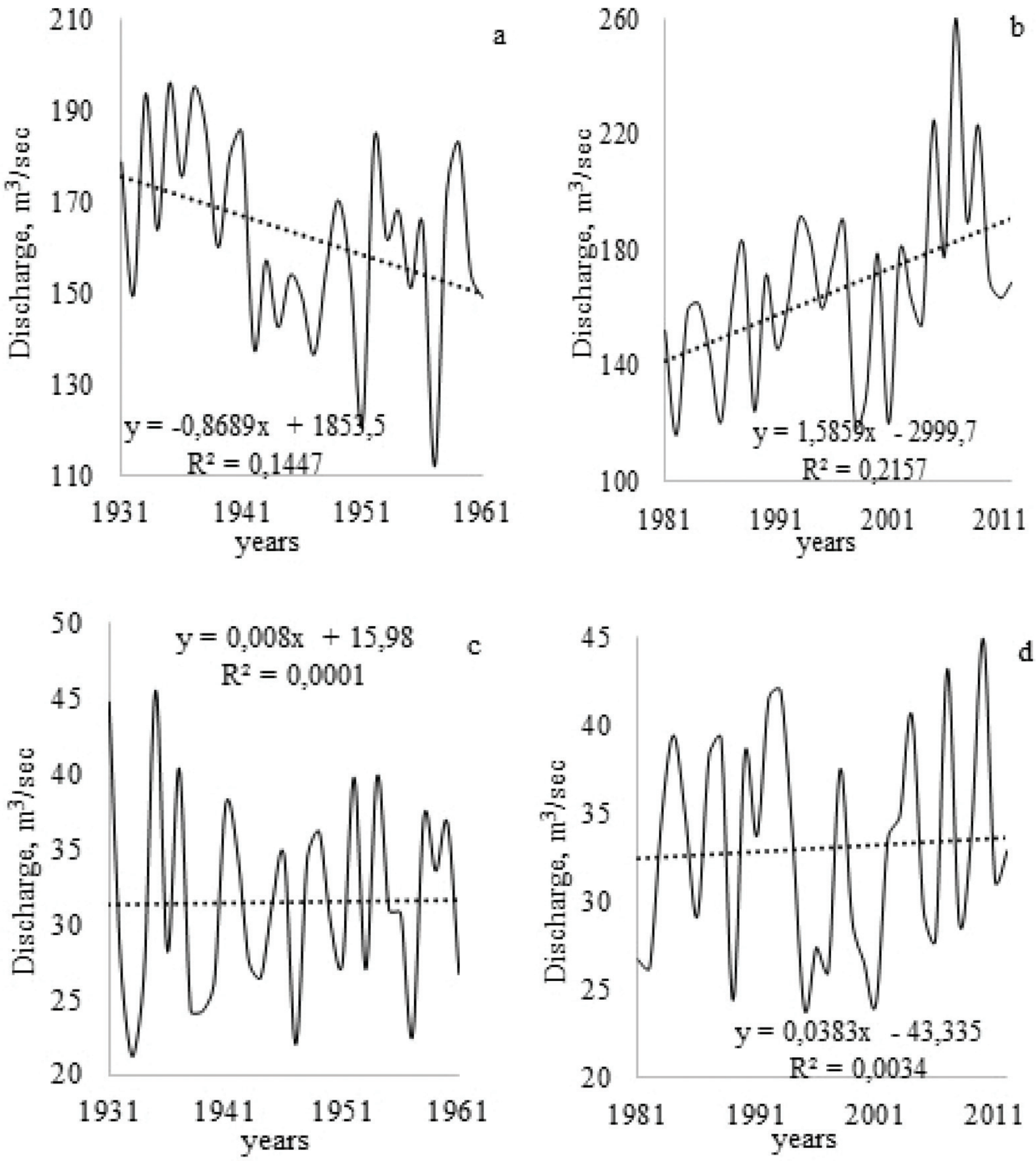

Figure 8. The water discharge value of the Zeravshan (a, b) and Yagnob (c, d) Rivers for the periods 1931–1961 and 1981–2011, respectively [6].

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The hydrographs of the Zeravshan (a) and Yagnob (b) Rivers for the periods 1931–1961 and 1981–2011 is shown in **Figure 9** that demonstrate that for the Zeravshan and Yagnob Rivers water discharge is the maximum in July and June, respectively [6].

The period 1981–2011 for the Zeravshan River (**Figure 9a**) is characterized by a flow reduction compared to the period 1931–1961. According to the estimated data, the mean annual runoff for the period 1981–2011 is 5.36 km^3 compared to 6.08 km^3 of the period 1931–1961, that is a decrease of the mean annual runoff by 12%. The mean annual flow of the Yagnob River for the periods 1931–1961 and 1981–2011 are 1.02 and 1.04 km^3 respectively, an increase of no more than 2% [6].

Impact of climate change on the water flow was calculated for Zeravshan River based on the deviation of annual runoff from the mean (**Figure 9**) [6]:

$$\Delta Q = Q_i – Q_o$$

where, Q_i is total water flows for *ith* year and Q_o is the mean annual water flow for the period 1931–2011.

The trends in the flow of the Zeravshan River for the periods 1931–2011(a), 1931–1961 and 1981–2011 are shown in **Figure 10b** and **c** [6].

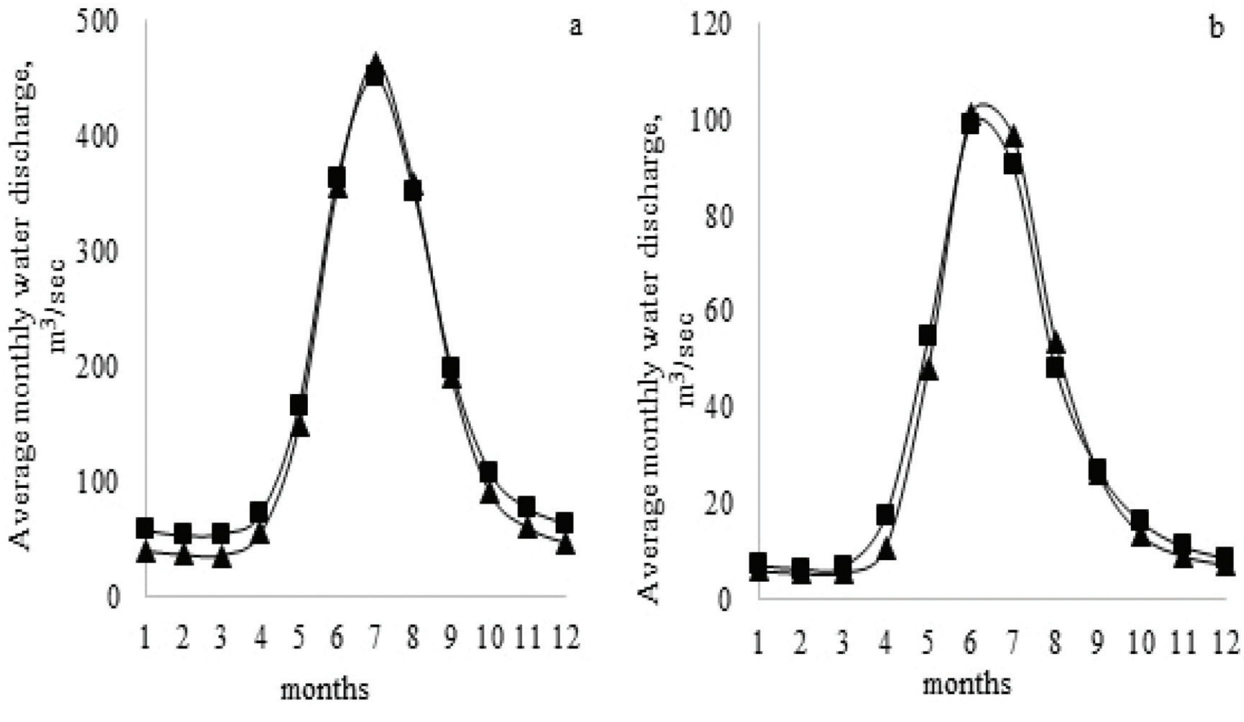

Figure 9. The hydrograph of the Zeravshan (a) and Yagnob (b) Rivers for the periods 1931–1961 (▲) and 1981–2011 (■) [15].

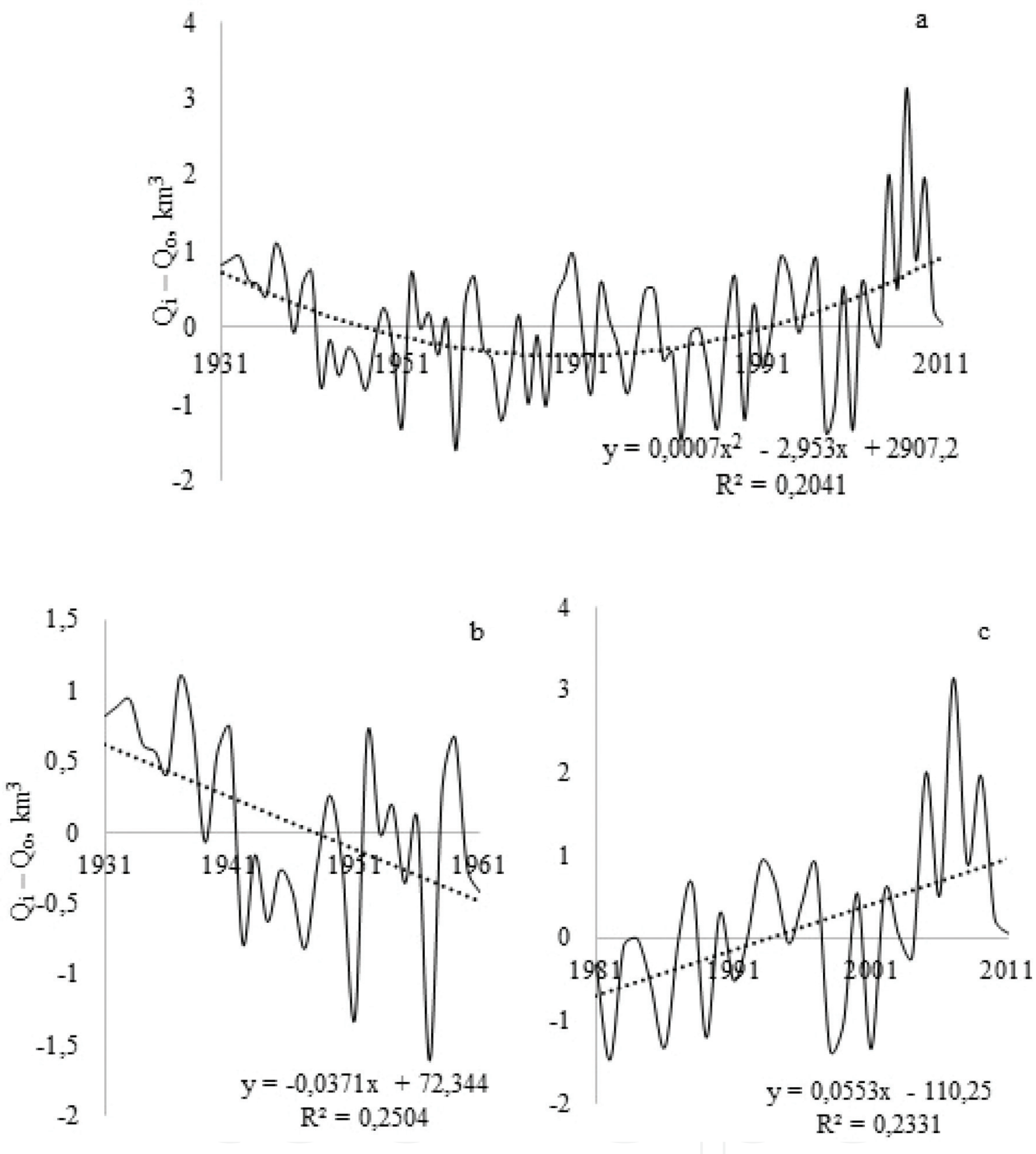

Figure 10. The actual water content of the Zeravshan River (a) for the period 1931–2011(a) and for the periods 1931–1961 (b) and 1981–2011 (c) [6].

A comparison of the Zeravshan glacier meteorological conditions for the periods 1931–1961 and 1981–2011 shows a changing trend in temperature. If the period 1931–1961 was characterized by almost constant temperature, significant increases were observed for the period 1981–2011(**Figure 7**). A similar situation was evident in the Yagnob River Basin. The reduction of water flow in the Zeravshan River for the period 1931–1961 changed to a significant decrease during the period 1981–2011 from 6.08 to 5.36 km^3 [6] (**Figure 11**).

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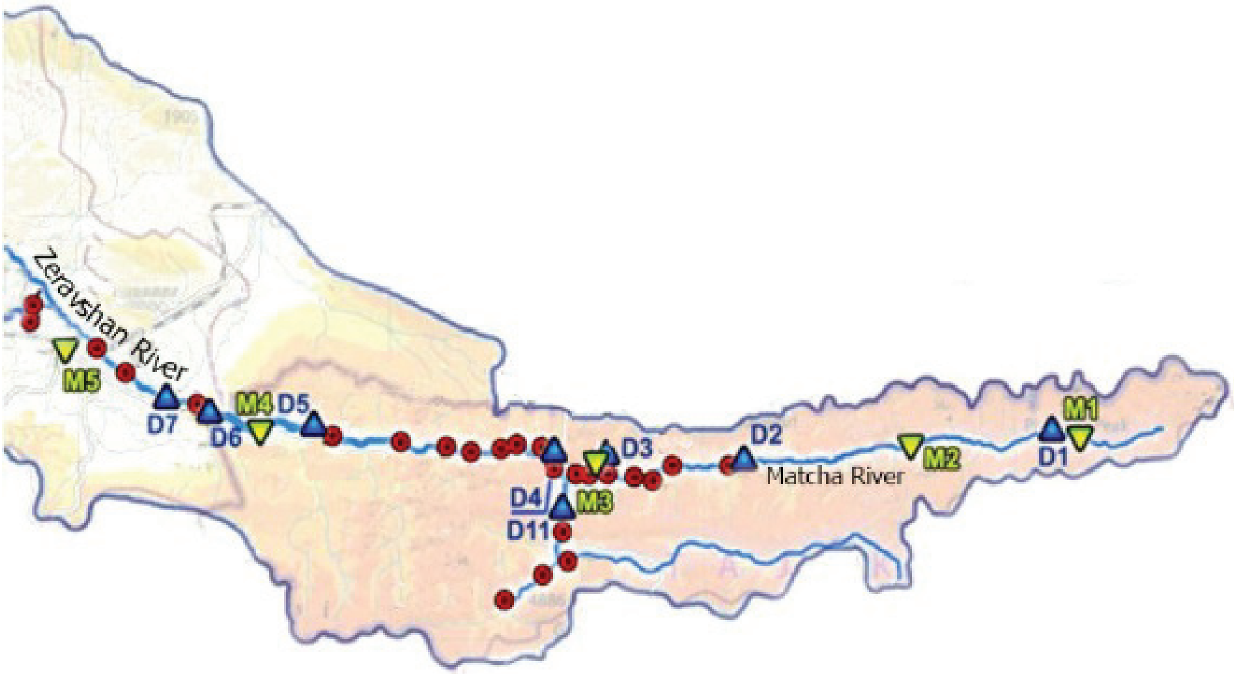

Figure 11. Water sampling side of the Zeravshan River and its tributaries [10, 11].

4. Hydrochemical and ecological aspects

Water quality has become a global issue. Every day, millions of tons of inadequately treated sewage and industrial and agricultural wastes are poured into the world's waters. Every year, lakes, rivers and deltas take in the equivalent of the weight of the entire human population—nearly 7 billion people—in the form of pollution. Every year, more people die from the consequences of unsafe water than from all forms of violence, including war—and the greatest impacts are on children under the age of five [21].

From the international level to watershed and community levels, laws on protecting and improving water quality should be adopted and adequately enforced, model pollution-prevention policies disseminated and guidelines developed for ecosystem water quality. Standard methods to characterize in-stream water quality, international guidelines for ecosystem water quality and priority areas for remediation need to be addressed globally [21, 22].

4.1. Zeravshan River Basin

The results of chemical analyses of the Zeravshan River are presented in **Figure 12** which shows that the difference of the chemical content values of cations and anions of the Zeravshan river water before and after the Anzob mountain-concentrating combine (AMCC) wastewater dams is insignificant and does not exceed their maximum permissible concentration (MPC). It is obvious that the Zeravshan River is not polluted by wastewater of the AMCC [10].

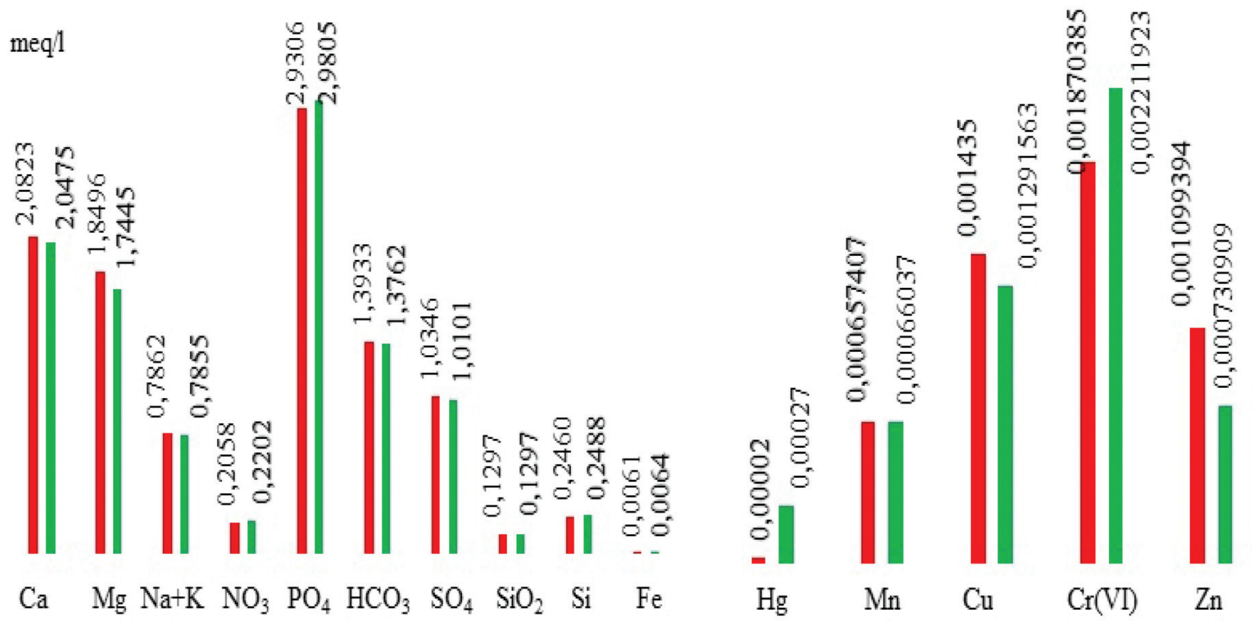

Figure 12. Results of chemical analyses of the Zeravshan River waters up to (■) and after (■) wastewater dams of Anzob mining plant [10].

The orographic feature due to the limitation of underdeveloped irrigated land determines the agriculture level on upstream of the Zeravshan River. Therefore, it can be expected that the runoff flow of collector-drainage water with high salinity to the river is negligible. An analysis of the histogram data (**Figure 12**) of the water composition shows that the Zeravshan river and its tributaries do not experience anthropogenic pressure in the upper reaches, and their mineralization is mainly due to the flushing of water coastal mineral deposits.

A similar phenomenon is observed while analyzing the content of heavy metals and distribution of heavy metals in the snow cover on the glaciers on the southern slope of Mount Elbrus due to their transport to long distances in the form of microparticles by an airflow [23]. Apparently accumulated contaminants in the snow cover and glacier during the melting process reach the river and spread out over long distances.

The choice of snow cover as a natural indicator to air pollution is actual because the snow effectively absorbs impurities from the atmosphere and deposits dry dust emissions from anthropogenic sources [24]. The concentration of pollutants in the snow is 2–3 orders higher than in the atmosphere. This allows measurement of the content by quite simple methods with a high degree of reliability [25]. In order to have information about the chemical composition formed from glaciers' water flow in the formation zone, a complex of physical and chemical analyses of seasonal snow on the glaciers of the Zeravshan, Rossinj and Tro of the Zeravshan River Basin and tributaries of the Zeravshan River emerging from these glaciers was conducted. The river Zeravshan, one of the major rivers of Central Asia, originates at a height of 2775 m. The annual flow of the Zeravshan River is on average about 5.2 Bln. m^3.

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According to **Figure 13**, in seasonal snow on the Zeravshan, Rossinj and Rama glaciers a domination in anions SO_4^{2-}, NO_3^-, Cl^- and cations Ca^{2+} and Mg^{2+} is observed.

The isotopic composition (δ^2H, $\delta^{18}O$) and deuterium excess is an informative indicator for hydrological and glaciological researches.

The isotopic analyses of water samples from the tributaries of the Zeravshan River: Sabag, Yarm, Samjon, Tro, Dehavz, Dihadang, Gusn and Dashtioburdon. Were carried out according to the methodology developed at the University of Colorado in Boulder. Analysis was performed on Wavelength-Scanned Cavity Ringdown Spectroscopy (WS-CRDS) and the isotopic composition of hydrogen and oxygen expressed in relative terms δ^2H and $\delta^{18}O$ [20]:

$$\delta = \left[\left(R_{sample}/R_{standard}\right) - 1\right]\cdot 1000‰$$

where R_{sample} and $R_{standard}$ relations 2H/1H and $^{18}O/^{16}O$ in the measured sample and the standard.

The standard is ocean water (SMOW, Vienna, IAEA). Measurement precision was ±0.05‰. At the isotopic analyses it was found that the upstream tributaries of the Zeravshan river

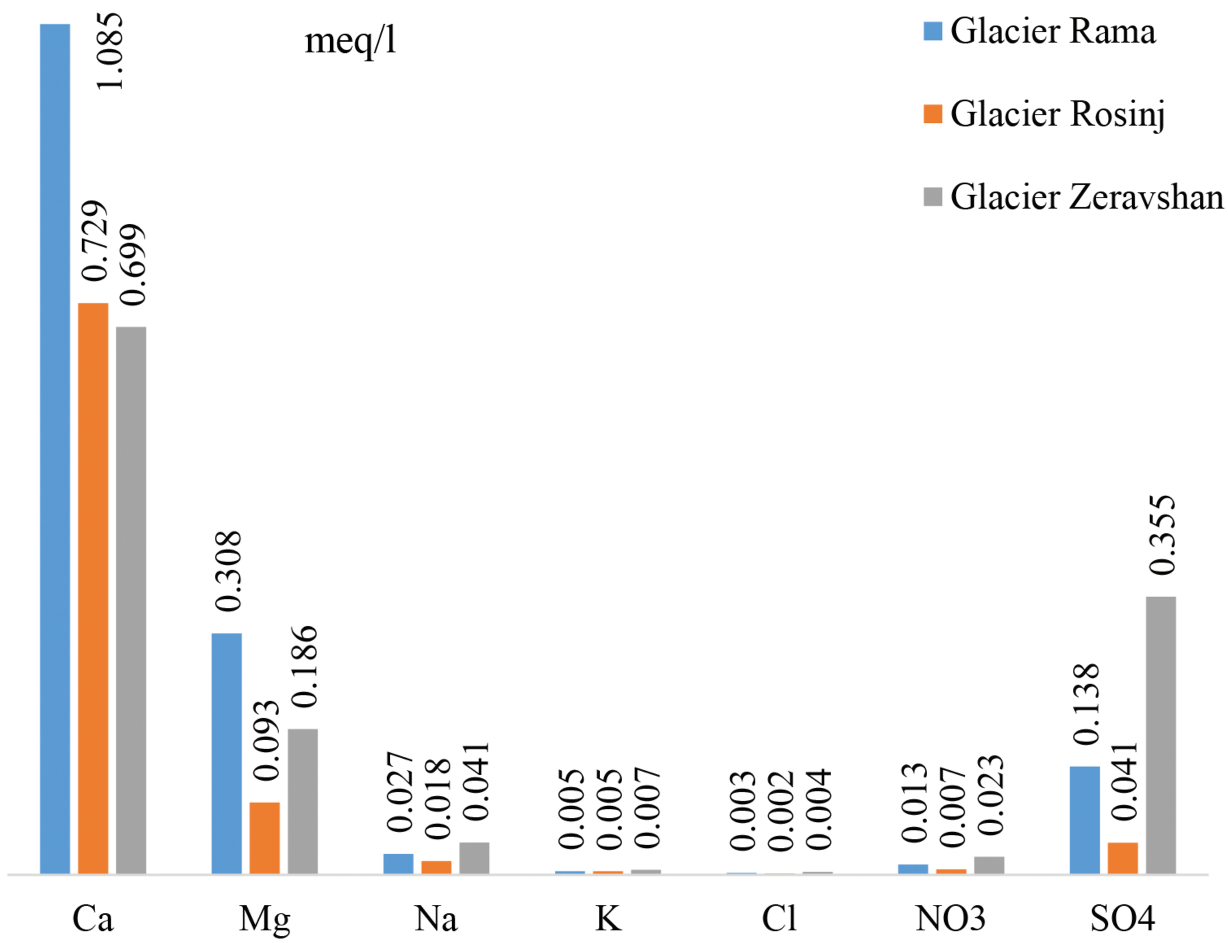

Figure 13. Chemical composition of seasonal snow on glaciers of the Zeravshan River Basin.

are characterized by light isotopic compositions of the oxygen and hydrogen isotopes: $\delta^{18}O$ (−13.23: −13.43) ‰, $\delta^{2}H$ (−88.92: −88.32) ‰ and deuterium excess 16.92—19.21. This suggests that the observed fractionation is a result of the freezing and the accumulation that occurs in winter. In turn, the downstream tributaries of the Zeravshan river have the following isotopic composition: $\delta^{18}O$ (−11. 98: −11.61) ‰ and $\delta^{2}H$ (−78.45: −75.80) ‰. The obtained results indicated the existence of seasonal variations in the isotopic composition of precipitation and their influence on the isotopic composition of the river, in other words, the change of the ratio of rainwater, meltwater from seasonal snow and underground waters [10].

The location of tributaries of the Zeravshan River is shown in **Figures 14** and **15**. The comparison of the isotopic analyses results (**Figure 14**) with the scheme of location of the Zeravshan tributaries shows that as you move from the upstream to the downstream is the weighting of the isotopic composition of water of the relevant tributaries of the Zeravshan River. The main factor of this process is to increase the temperature and therefore the evaporation of water from the rivers [10].

Currently the Zeravshan River irrigates about 551 Th. ha agricultural lands (13% of the total area of irrigated lands of Uzbekistan). One of the most important indicators of the Zeravshan River in the downstream is the salinity that often reaches maximum values of up to 3.0 MPC. This trend continued during the entire annual cycle [26, 27]. The main source of pollution of the river Zeravshan on the territory of Uzbekistan is agricultural drainage water from irrigated lands [26, 28, 29].

A degree of mineralization was determined by measuring the electroconductivity of the water. The values of the electroconductivity of water in different parts of the flow of the Zeravshan river and drainage channels on the territory of the Republic of Uzbekistan shows the extreme values in the collectors and canals that indicate high degree of soil salinity (**Figure 16**).

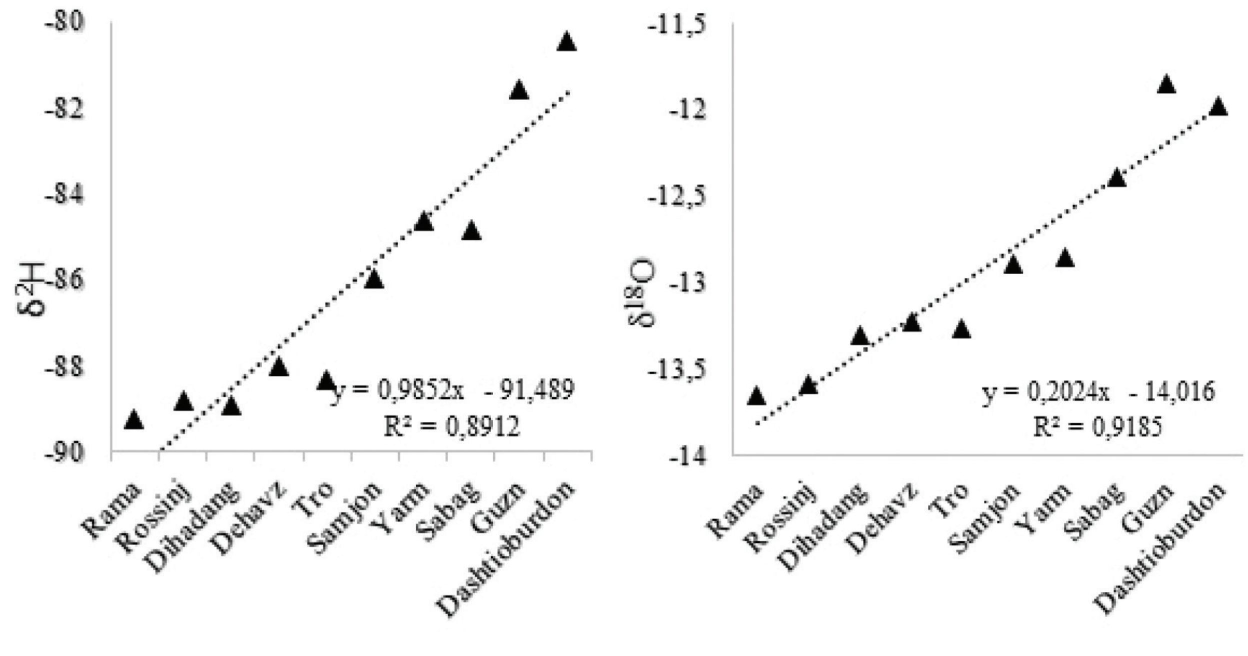

Figure 14. The values of hydrogen $\delta^{2}H$ and oxygen $\delta 1^{8}O$ isotopes for the Zeravshan River tributaries.

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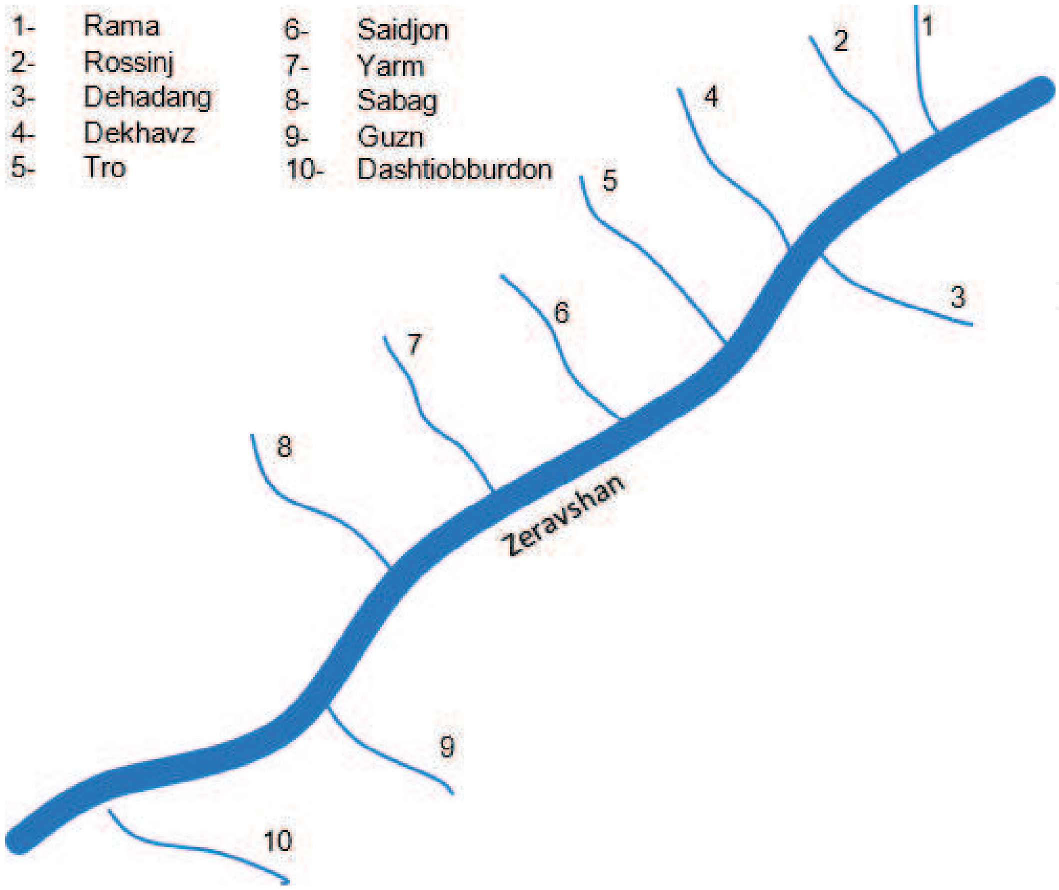

Figure 15. Scheme of the Zeravshan River tributaries location [10].

The change of the concentration of NO_3- along the entire length of the Zeravshan River with the exception of collectors and canals in the downstream of the river shown in **Figure 17**.

Point 13 in **Figures 16** and **17** corresponds to the section of the river on the border of Tajikistan with Uzbekistan. As can be seen in **Figure 16**, electroconductivity of water on the territory of Tajikistan is characterized by a minimum value 240 μS/cm and after crossing the border there is a sharp increase in electroconductivity of water. The results indicate that mineralization of the Zeravshan river water mainly occurs in a downstream of the river on the territory of Uzbekistan.

4.2. Vakhsh River Basin

Monitoring of the Transboundary rivers water quality, identifying sources of anthropogenic pressure and taking adequate measures to eliminate them by the development of modern methods are effective tool for regulating the relationship between the components of the geoecosystem [10]. The chemical composition of the Vakhsh River and its tributaries have been studied by sampling the waters at the points indicated in the scheme (**Figure 18**).

The scheme of water sampling shows the respected individuality of each tributary from the point of view of chemical composition by sampling of tributaries' water up to the confluence

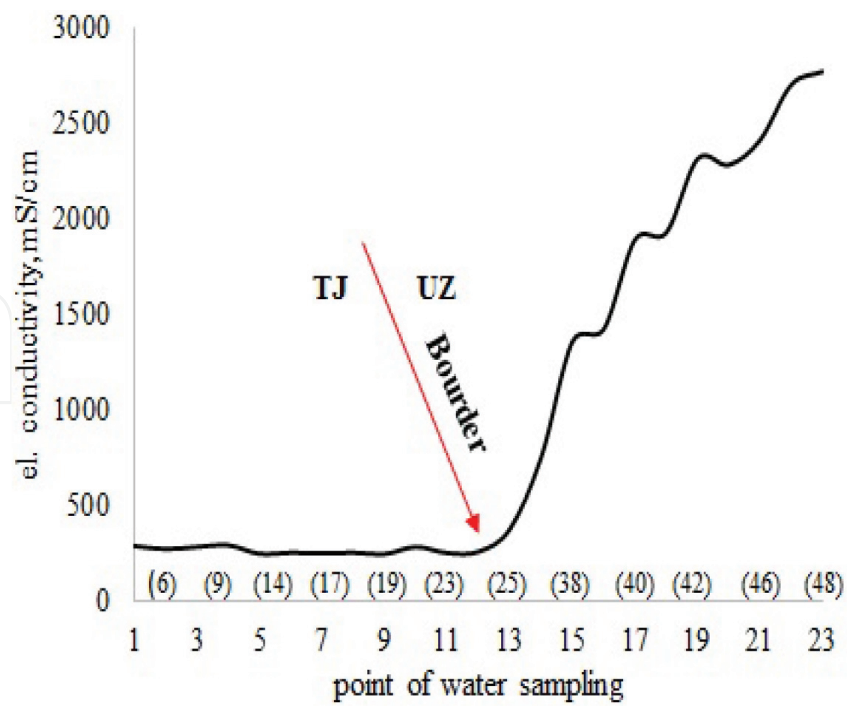

Figure 16. The electroconductivity change of the water in the upstream and downstream of the Zeravshan River *(Numbers in brackets points sampling in the diagram in* **Figure 11***).*

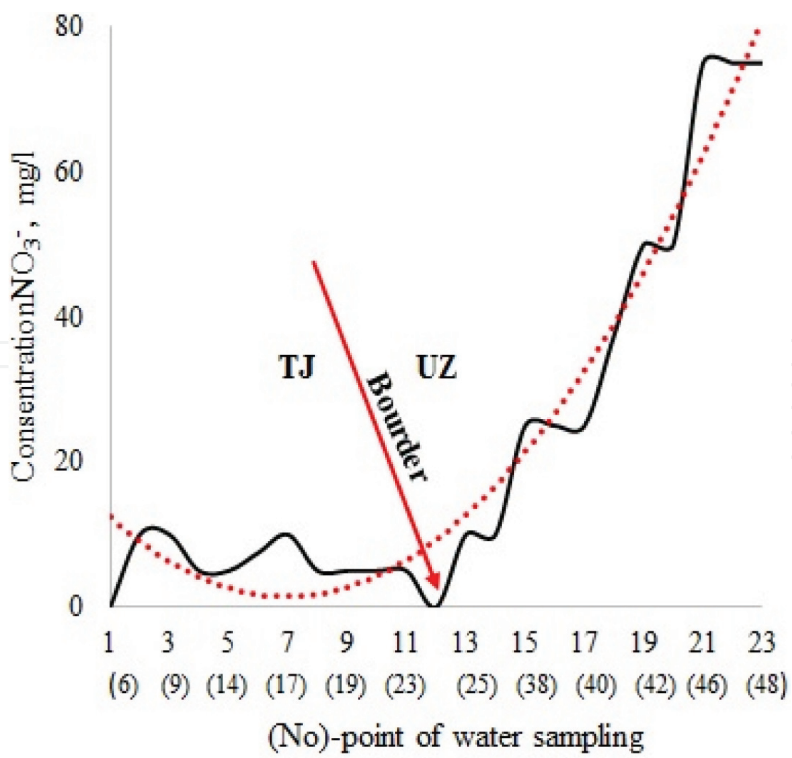

Figure 17. The NO_3- concentration along the entire length of the Zeravshan River *(Numbers in brackets points sampling in the diagram in* **Figure 11***).*

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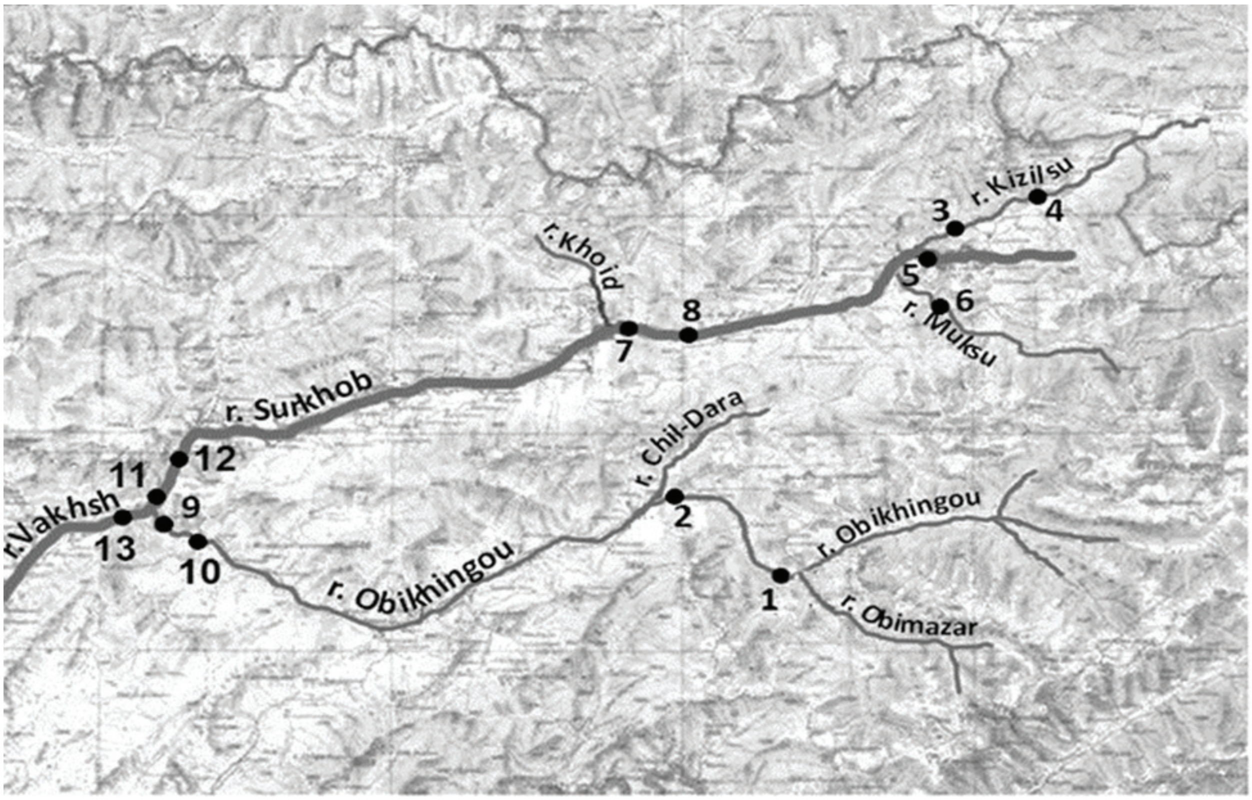

Figure 18. Scheme of sampling of water from the Vakhsh River and its tributaries [10].

with the main stream of the river and up to the junction with another tributary. We carried out chemical analysis of rivers water and groundwater of the rivers' basin, the results of which are present in **Figure 19a, b**, respectively [10].

The content of the chemical elements of the Vakhsh River is shown in **Figures 19** and **20** that indicate that they do not exceed established maximum permissible concentration. This suggests that formation of chemical composition of the Vakhsh river water is mainly due to leaching of mineral rocks [10].

The results of isotopic analysis of the Vakhsh River and their tributaries are presented in **Figure 21** [10].

For interpretation of the isotopic analysis results of the Vakhsh River and its tributaries, we analyze the state of glaciation in the river basins. In the Surkhob River Basin, there are intensively melting small glaciers of the Northern slopes in the Western part of a ridge of Peter the Great. On the southern slopes of the Alay Ridge, glaciation decreases slower as there are larger glaciers. In the Obikhingou River Basin, the largest glacier Garmo is intensively melting [10].

During the twentieth century, it became shorter by almost 7 km, having lost more than 6.0 km^2 in area. It is currently retreating at an average speed of 9 m/year, and the surface settles due to the melting of up to 4 m/year. Another glacier in the same basin, Skogach, retreats annually at 11 m [10].

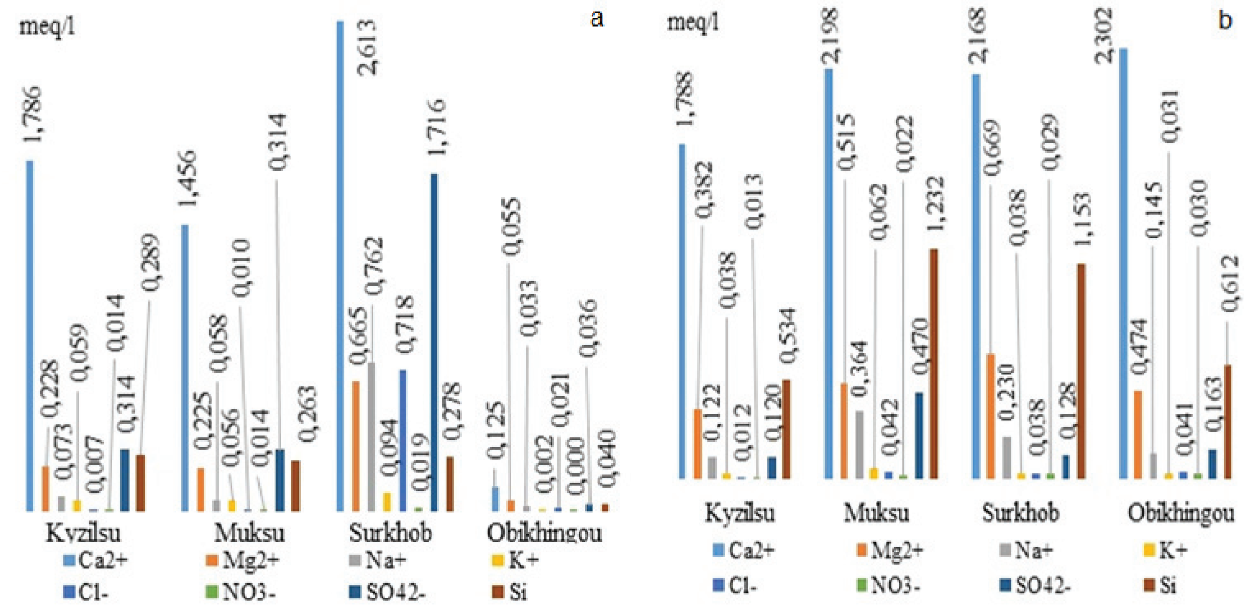

Figure 19. The results of chemical analysis of the waters and groundwaters of the Vakhsh River tributaries [10].

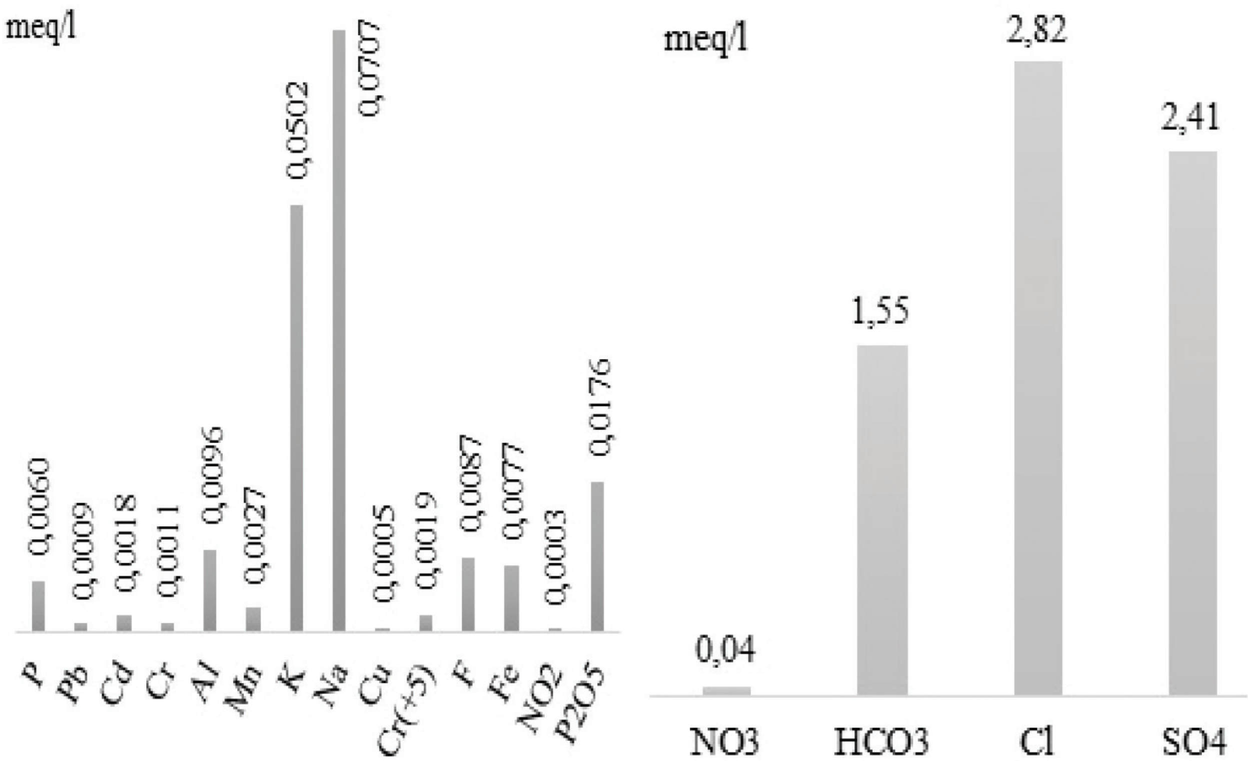

Figure 20. The results of chemical analysis of the Vakhsh River waters.

In view of this, it can be approved that the rivers and Surkhob Obikhingou are fed by glaciers [10] and it can be assumed that precipitation mostly occurs in winter and isotopic compositions are significantly lighter [20].

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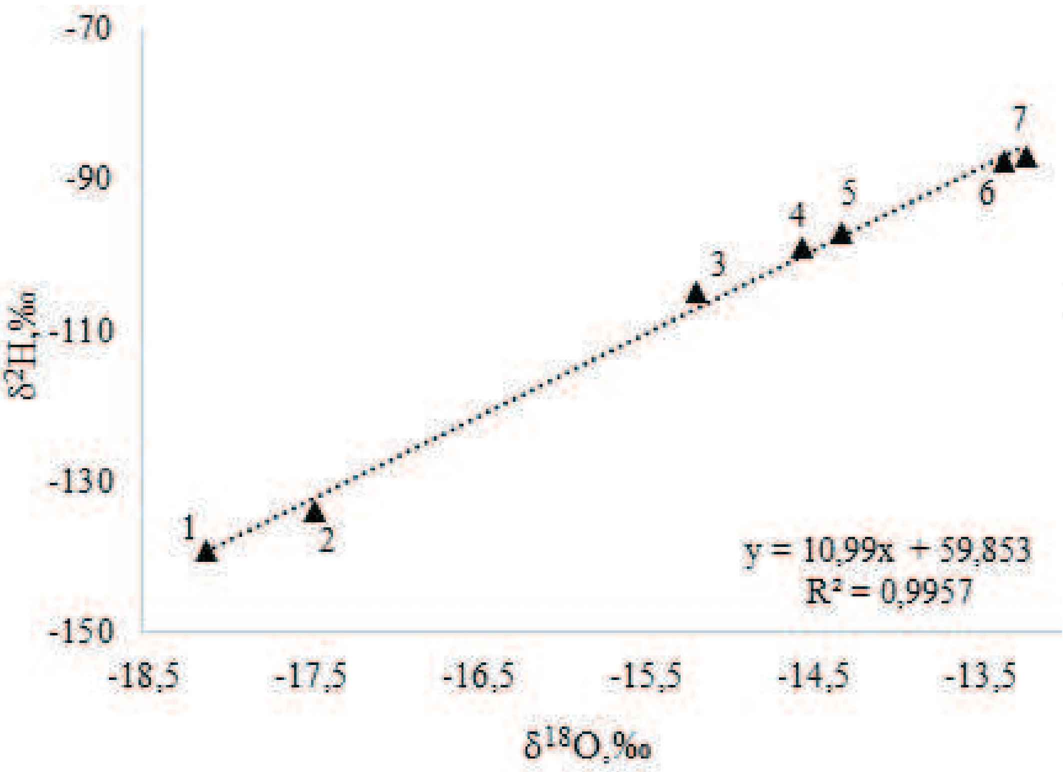

Figure 21. The isotopic composition of water in the Vakhsh River and tributaries: 1, 2: Garmo glacier; 3: Surkhob river; 4: Vakhsh river; 5: Obikhingou river; 6: Kyzilsu river; 7: river Muksu [10].

The weather and climatic conditions of the Vakhsh valley are warmer than in the valleys of its tributaries Surkhob and Obikhingou and consequently due to the evaporation process would have a heavy isotopic composition. However, the contribution of the water tributaries leads to the fact that the isotopic composition of water of the river Vakhsh becomes lighter [20].

The isotopic composition of the Kyzilsu River is characterized by values $\delta^{18}O = -13.36‰$, $\delta^2H = -87.88‰$ which is close to the values of the isotopic composition of the water areas with an average annual temperature above 0°C (**Figure 22**). It was found that the isotopic composition of the Naryn River depending on the season changes in the following range: spring ($\delta^{18}O = -13.4‰$; $\delta^2H = -96‰$) and autumn ($\delta^{18}O = -12.4‰$; $\delta^2H = -89‰$) [20, 28, 30]. Consequently, it can be concluded that to formation of water flow of the Kyzilsu River contribution of glacial runoff is small and mainly occurs due to seasonal rains [20].

Previously [20, 31], by analyses of the chemical composition of river water and groundwater in the river basins of Tajikistan, the processes of enrichment of underground water reservoirs by chemical elements of river water was suggested. Such a mechanism but in the opposite direction, that is, the conversion of reservoirs of underground waters to the source of water for the river, for example, for the Muksu River Basin, was observed.

The results of the isotope analyses of spring waters and groundwater basins of the rivers Muksu, Kizilsu, Surkhob and Obikhingou is shown in **Figure 22**. From **Figure 22**, we can see that the groundwater and spring water of the basin of the river Muksu by the values of the

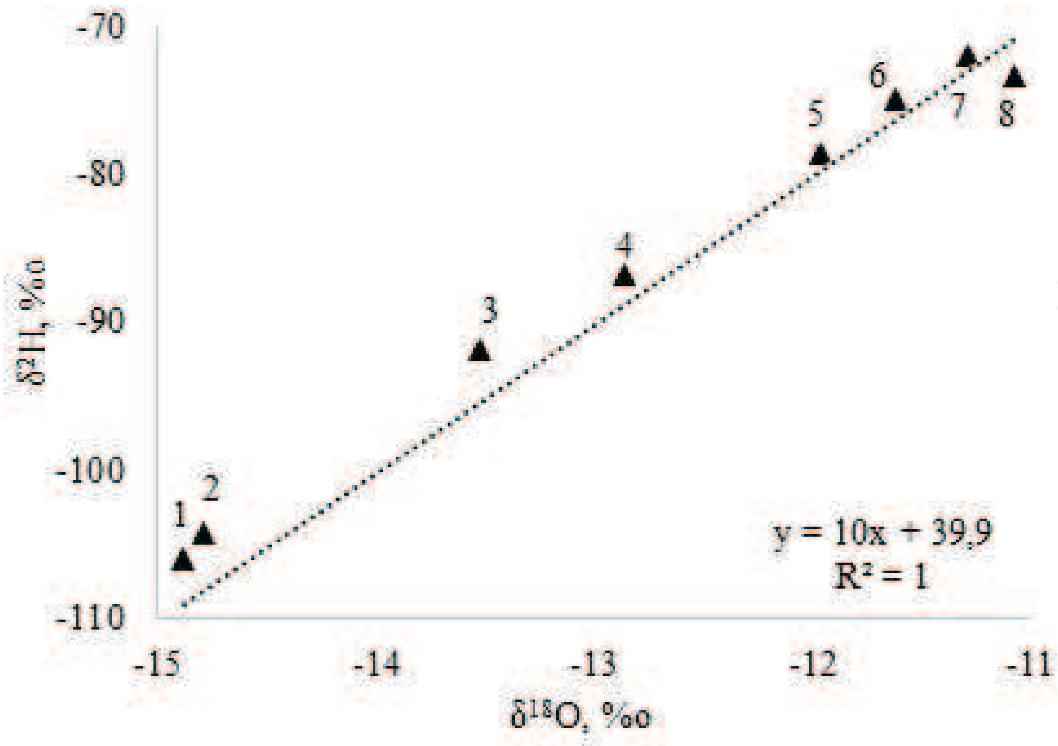

Figure 22. Isotopic analysis of spring (1, 3, 4, 5) and underground waters (2, 6, 7, 8) the basin of the rivers Muksu, Kizilsu, Surkhob, Obikhingou, accordingly [20].

isotopic composition is significantly lighter on average composition of river water and is close to the values of melted glacier water. During spring, snowmelt by the processes of infiltration, underground reservoirs are accumulated melt water and at dry periods turn to sources of runoff formation of river. Of course, it will affect the isotopic composition of river water [20].

5. Conclusion

Now the priority areas for the Central Asian countries are water and the effects of climate warming. The continued degradation of mountain glaciations, growing rate of population in the region and the problem of water supply of the population and economy branches have stimulated the search of scientific mechanisms, approaches to sustainable development at the national level and the solution to the problem of conflict-free use of water resources of transboundary river basins.

Integrated water resources management can play a key role in reducing tensions and conflicts between upstream and downstream countries of Transboundary Rivers of Central Asia on water issues, biodiversity and ecology of rivers and the rational use of water resources in the region. Certainly, the degree of implementation and effectiveness of integrated water resources management is mainly determined by the availability of reliable meteorological, hydrological and glaciological information and the degree of interchange between the countries of the region. High-level saturation of climatic information is achieved only at a continuous and consistent monitoring of climatic parameters of the region.

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The results of the monitoring of meteorological and hydrological parameters of river basins of Zeravshan, Vakhsh and Pyanj major tributaries of the Amu Darya show the individuality of each of them, demonstrating the significant influence of mountain orography on the development of climatic features. Therefore, the achievement of reliable data in such conditions is possible in the presence of a developed network of meteorological and hydrological stations in river basins.

It is demonstrated by chemical analyses that the Zeravshan River and its tributaries in the upper reaches do not experience anthropogenic pressure and their mineralization is mainly due to the flushing of coastal water mineral deposits. Chemical analysis of the Zeravshan River water samples before and after the AMCC is shown in the insignificant effect of wastewater factory on water quality. The content of heavy metals in the river does not exceed maximum permissible concentration. The existence of seasonal variations in the isotopic composition of precipitation and their influence on the isotopic composition of the Zeravshan River water is observed. The isotopic analyses show weighting of the isotopic composition at moving from the upstream to the downstream of the Zeravshan River tributaries. The main factor of this process is to increase the temperature and therefore the evaporation of water from the rivers. The content of the chemical elements of the Vakhsh River shows that they do not exceed established maximum permissible concentration. This suggests that formation of chemical composition of the Vakhsh river waters is mainly due to leaching of mineral rocks.

The results of the isotope analyses of spring waters and groundwater of the Muksu River Basin show that groundwater and spring water of the basin of the river Muksu by the values of the isotopic composition is significantly lighter when compared to river water and close to the values of melted glacier water. During spring, snowmelts at infiltration in underground reservoirs are accumulated melt water and at dry periods turn to sources of runoff formation of river. Of course, it will affect to the isotopic composition of river water.

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