

## **Risk Assessment and Risk management of accumulation of chemical pollution in seasonal snow and glaciers and their transportation by waterways**

Parviz Normatov, Abulqosim Muminov, Inom Normatov, Abdullo Sadykov  
Institute of Water problems, Hydropower and Ecology of the AS Republic of  
Tajikistan

**Abstract.** We detected an increase in heavier isotopic composition ( $\delta^2\text{H}$ ,  $\delta^{18}\text{O}$ ) in waters of the Zeravshan River and its tributaries from upstream to the downstream. The change is associated with the evaporation process. The exchanges of groundwater and surface waters in Muksu river basin was observed. Groundwater of the Muksu River Basin (a tributary of the Vakhsh River) nourish the River Muksu in dry periods.

### **1. Introduction**

First, it is important to note the issue of the water quality in transboundary rivers and their tributaries. Zeravshan River crosses the border of The Republic of Tajikistan some 28-30 km below the city of Penjikent and flows through the territory of The Republic of Uzbekistan. Total length of Zeravshan River is 877 km out of which 303 km flows through the territory of The Republic of Tajikistan. The problem of water quality in transboundary river basins, in the Zeravshan River basin in particular, 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. Therefore, there is no uniform standard for assessing the degree of anthropogenic load on geoenvironmental systems (e.g., maximum permissible concentration). The problem of water quality of the Zeravshan river is mostly associated with the pollution of the river by wastewater from the Anzob ore-concentrating facility (AOCF) - the mining enterprise for extraction and enrichment of mercury-antimony ores of the Dzidzikurut deposit. Groll et al (2015), Kerimov et al. (2011), Kholmirezova et al. (2012), Normatov et al. (2003, 2005a, 2005b, 2010, 2012, 2013, 2014a) .

Vakhsh River is the main river of the Republic of Tajikistan that merges with the Pyanj River to form Amu Darya – the largest river in Central Asia. Potential energy resources of Vakhsh amount to 28.6 Million kWt·h (250 Million kWt·h/year of electricity). Development of the hydropower potential of the Vakhsh River involves construction of planned future, and currently operating number of large and medium size reservoirs and hydropower stations (HPS) Normatov et al. (2014, 2014a, 2015, 2016), Normatov (2015).

Common problems of the reservoirs of the HPS are the issues of sedimentation and changes in the chemical composition of water caused by reducing the useful volume, corrosion of metal structures, as well as the extent of vital activity of living organisms in the reservoirs.

The aim of this work is to study the chemical and isotopic composition of Zeravshan and Vakhsh rivers and their tributaries in general, and assessment of sources of pollution in these rivers basin in particular.

## 2. Study Site and Methodology

We focused in our study on the transboundary Zeravshan and Vakhsh rivers, their main tributaries and main glaciers of the Zeravshan River Basin. Sampling of water from Zeravshan River and its tributaries were used by the scheme (Fig. 1) developed in Groll et al. (2015). The chemical analyses of waters were carried out by methods described in Normatov et al. (2010).

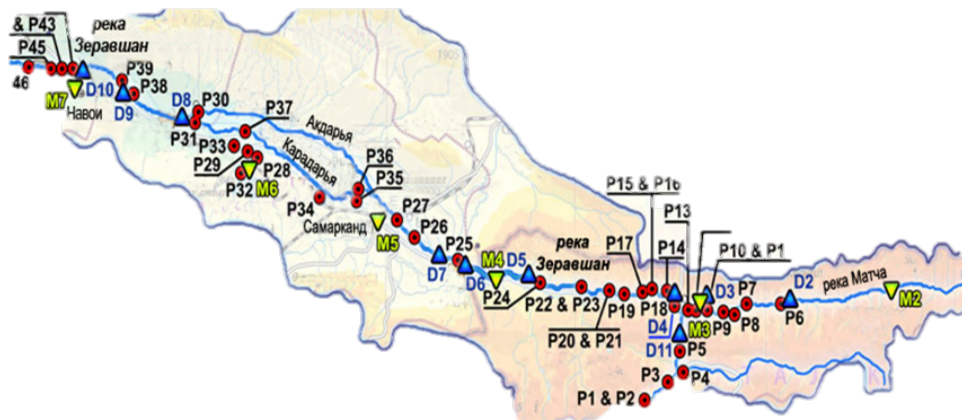


Figure 1. Scheme of sampling of water from Zeravshan River and its tributaries

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 were performed on Wavelength-Scanned Cavity Ringdown Spectroscopy (WS-CRDS). The characteristic chemical composition for each river was identified by sampling of the tributaries to the confluence with the main river and with other tributaries.

## 3. Result and Discussion

The results of chemical analyses of the Zeravshan River are presented on Fig. 5 show that the concentrations of cations and anions of the water of Zeravshan River above, and below the Anzob ore-concentrating facility (AOCF) wastewater dams are insignificant and do not exceed their MPC. It is obvious that the Zeravshan River is not polluted by wastewater of the AOCF.

The extent of agricultural development upstream of the Zeravshan River is determined by the orographic features due to the limitation of irrigatable land. Therefore, it can be expected that the salinity of the runoff from these areas into collector-drainage system is negligible. An analysis of the histogram data (Fig. 2) of the composition of the water shows that Zeravshan River and its tributaries in the upper reaches do not experience

anthropogenic pressure, and their mineralization is mainly due to leaching of coastal mineral deposits.

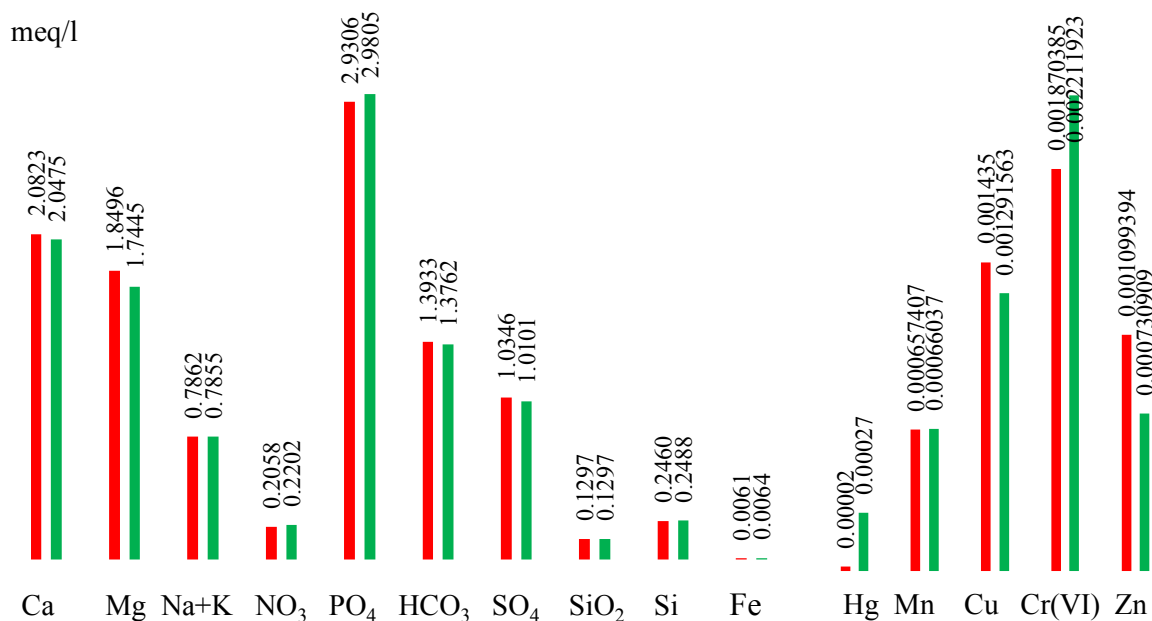


Figure 2. Results of chemical analyses of the Zeravshan River water above (■) and below (■) wastewater dams of Anzob mining plant

Glaciers are viewed as favorable natural media for accumulation of atmospheric aerosols, chemical compounds and metals from long distance transport. Such phenomenon was observed at the southern slopes of Mount Elbrus, where the content of heavy metals and distribution of heavy metals in the snow cover on the glaciers was determined by Normatov et al. (2015).

It is likely that the contaminants accumulated in snow cover and glaciers migrate in the process of melting of snow and glaciers to rivers and are distributed in river flow to long distances. The choice of snow cover as a natural indicator to air pollution is reasonable, because the snow effectively absorbs atmospheric impurities including dry dust emissions from anthropogenic sources Olsson et al. (2010).

The concentration of pollutants in the snow are due to seasonal accumulation by 2-3 orders higher than in the atmosphere. Hence, contamination assessment in snow cover requires quite simple methods and can be accomplished with a high degree of reliability Temerev et al. (2010).

Physical and chemical analyses were conducted on samples collected from seasonal snow cover on the glaciers of the Zeravshan River Basin, including Zeravshan, Rossinj, and Tro and tributaries emerging from these glaciers. The river Zeravshan one of the major rivers of Central Asia originates at a height of 2775 m. On the territory of Tajikistan, it flows about 300 km and takes more than 100 small streams and 3 large rivers Tokarev et al.(2010). The annual flow of the Zeravshan River is on average about 5.2 Bln. m<sup>3</sup>.

According to the Fig. 3 anions  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$ ,  $\text{Cl}^-$  and cations of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  dominate the chemical composition in seasonal snow cover on Zeravshan, Rossinj and Tro glaciers

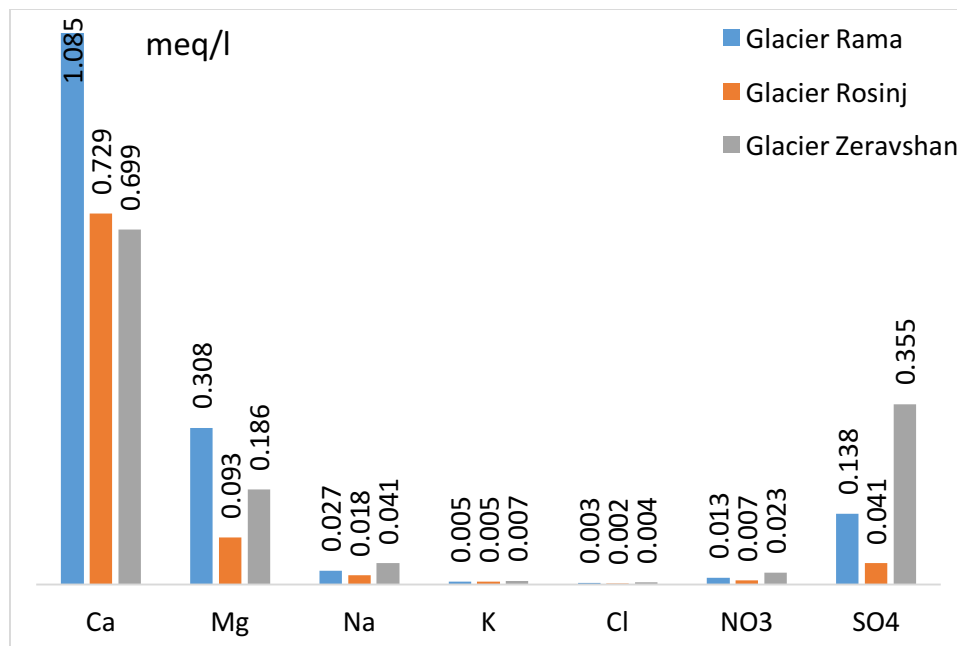


Figure 3. Chemical composition of seasonal snow on glaciers of the Zeravshan River Basin.

Oxygen and Deuterium isotopic composition and deuterium excess is considered one of the most informative indicators in hydrological and glaciological studies, particularly in the identification of regularities of the processes of ice formation, snow accumulation and the flow of aggregate mutual transformations. Figure 4 presents the results of isotopic analyses of samples of water from the tributaries of the Zeravshan River: Sabag, Yarm, Samjon, Tro, Dehavz, Dihadang, Gusn and Dashtioburdon. Sampling for isotopic analyses was 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  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ :

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

where  $R_{\text{sample}}$  and  $R_{\text{standard}}$  relations are computed for  $^2\text{H}/^1\text{H}$  and  $^{18}\text{O}/^{16}\text{O}$  in the measured samples, where the standard are the ratios in ocean water, i.e. Standard Mean Ocean Water (SMOW, Vienna, IAEA). Measurement precision was  $\pm 0.05\text{‰}$ .

It was found that the upstream tributaries of the Zeravshan River are characterized by light isotopic compositions of the oxygen and hydrogen isotopes:  $\delta^{18}\text{O}$  (-13,23 : -13,43) ‰,  $\delta^2\text{H}$  (-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 occurs in winter. In turn, the downstream tributaries of the Zeravshan River have the following isotopic composition:  $\delta^{18}\text{O}$  (-11.98 : -11.61) ‰ and  $\delta^2\text{H}$  (-78.45 : -75.80) ‰. The results indicate the existence of seasonal variations in the isotopic composition of precipitation

and their influence on the isotopic composition of the river, i.e., the change of the ratio of rainwater, meltwater from seasonal snow and groundwater.

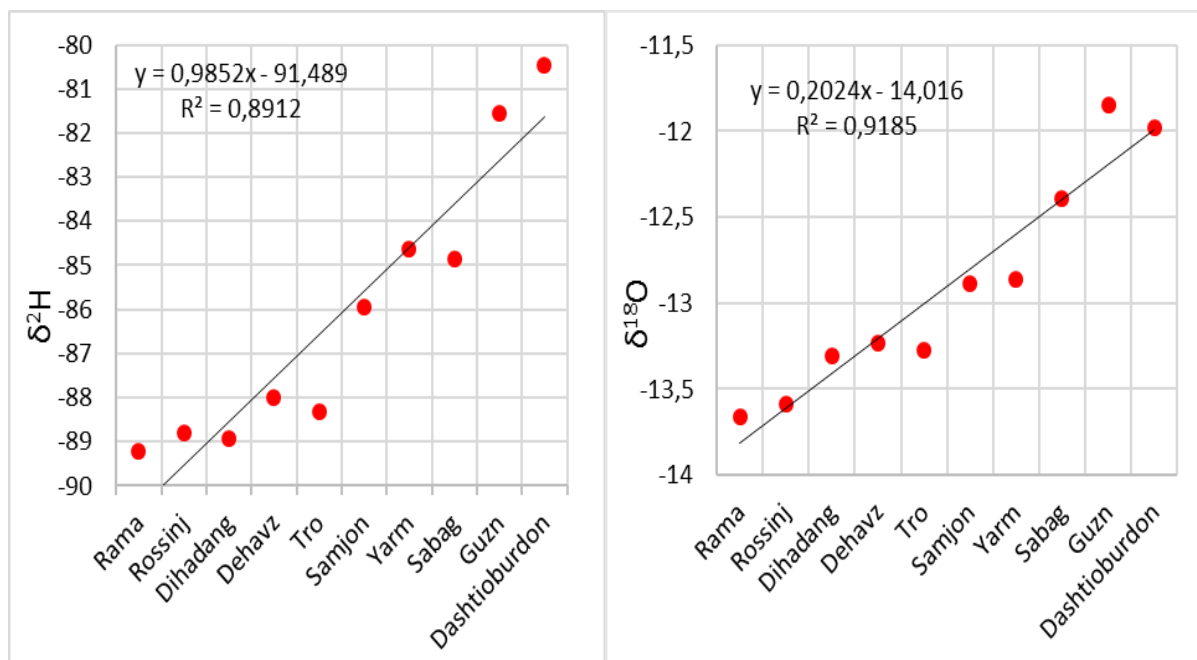


Figure 4. Results of isotope analyses of the Zeravshan river tributaries

The location of tributaries of the Zeravshan River is shown on Figure 5. Comparison of the results of isotopic analyses (Fig. 4) with their map location (Fig. 5) suggests an increase in heavier isotopes downstream. We postulate that the main factor of this increase are downstream higher temperatures and therefore the increased evaporation of water from the rivers.

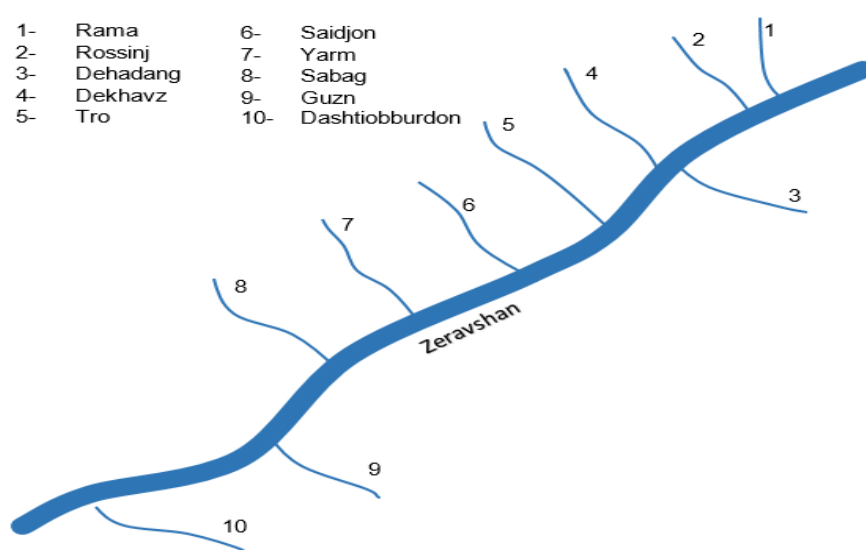


Figure 5. Schematic map of the Zeravshan River tributaries

#### 4. Hydrochemistry of the Vakhsh River and tributaries

Monitoring of water quality in transboundary rivers, identifying the sources of anthropogenic pressures and the adoption of adequate measures for their elimination through development of modern techniques is a valid tool to regulate the relationship between the components of geoecosystem. It is an important element of geoecological analysis of the problems of Central Asia as a key link in the development of bases of rational use and protection of water ecosystems.

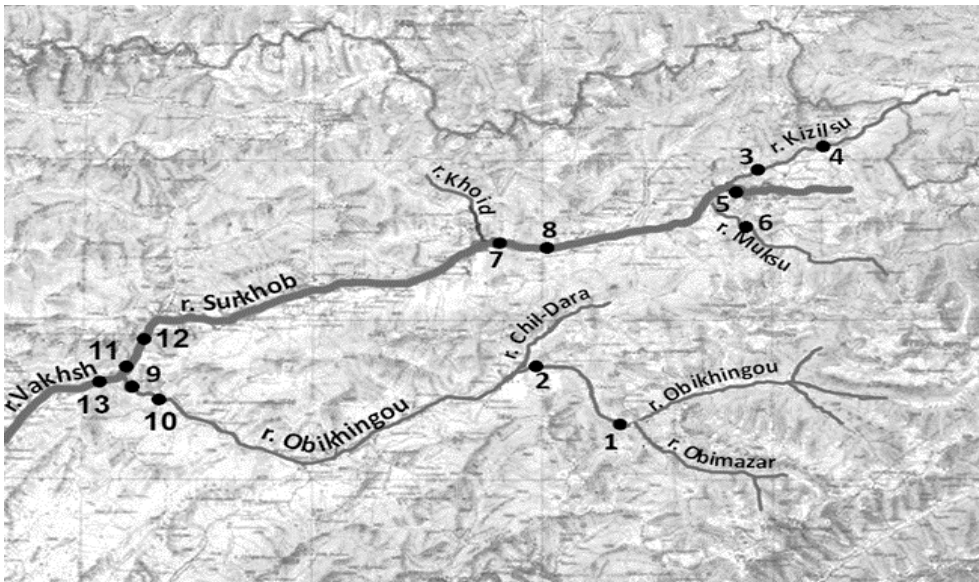


Figure 6. Scheme of sampling of water from the Vakhsh River and its tributaries

Chemical composition of the water of the Vakhsh River and its tributaries was studied by carrying sampling and analyzing water collected at the points shown on Figure 6. The distribution of the sampling points allows to evaluate the chemical composition of each minor and major tributary and their individual contribution to the chemical composition of the main river flow. Chemical analysis of river water and groundwater of the river basin are presented on Figure 7 (a and b respectively).

The content of the chemical elements of the Vakhsh River shown on the Figure 7 and Figure 8 indicate that they do not exceed established maximum permissible concentration for any of the analyzed components. This suggests that formation of chemical composition of the Vakhsh River water and its tributaries is mainly due to natural leaching of mineral rocks.

The results of isotopic analysis of the Vakhsh River and their tributaries are presented on Figure 9.

Interpretation of the results of isotopic analysis of the Vakhsh River and its tributaries requires understanding of the state of glaciation in Vakhsh River Basin. There are intensively melting several small glaciers on the northern slopes in the western part of the Peter the Great Ridge in the Surkhob River Basin. On the southern slopes of the Alay Ridge, glaciation recedes slower as there are larger glaciers. In the Obikhingou River Basin, the largest glacier Garmo is intensively melting. During the XX century, it became shorter by almost 7 km, having lost more than 6.0 km<sup>2</sup> 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.

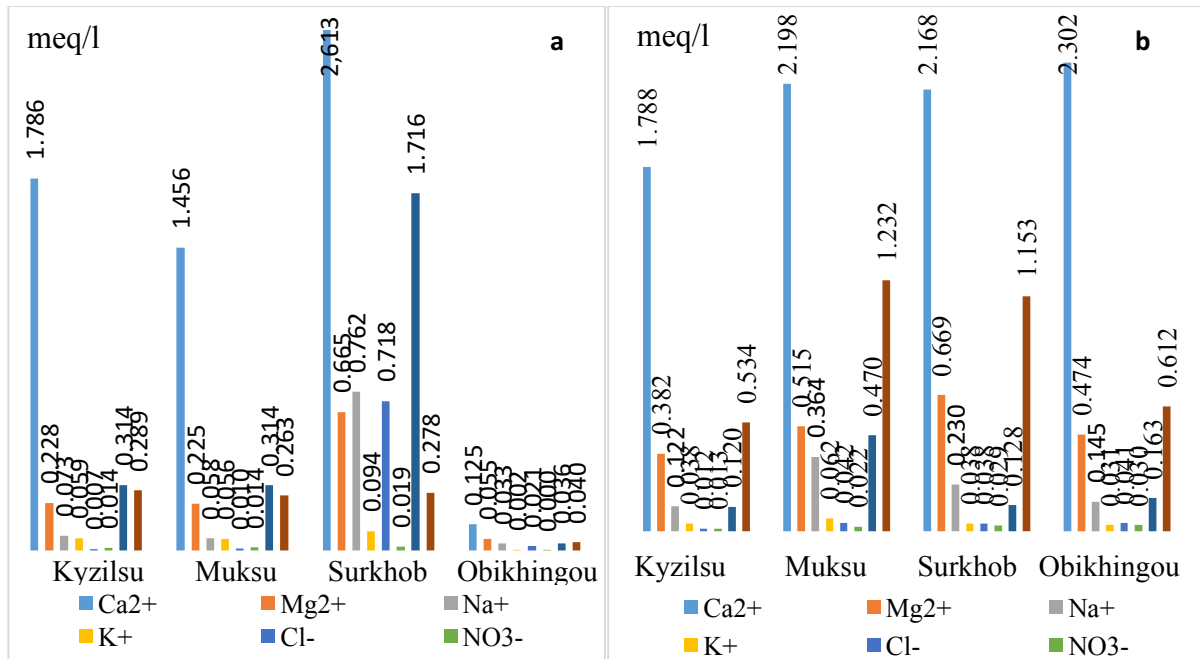


Fig.7. The results of chemical analysis of the waters of the tributaries of the Vakhsh river (a) and groundwater basins of these rivers (b)

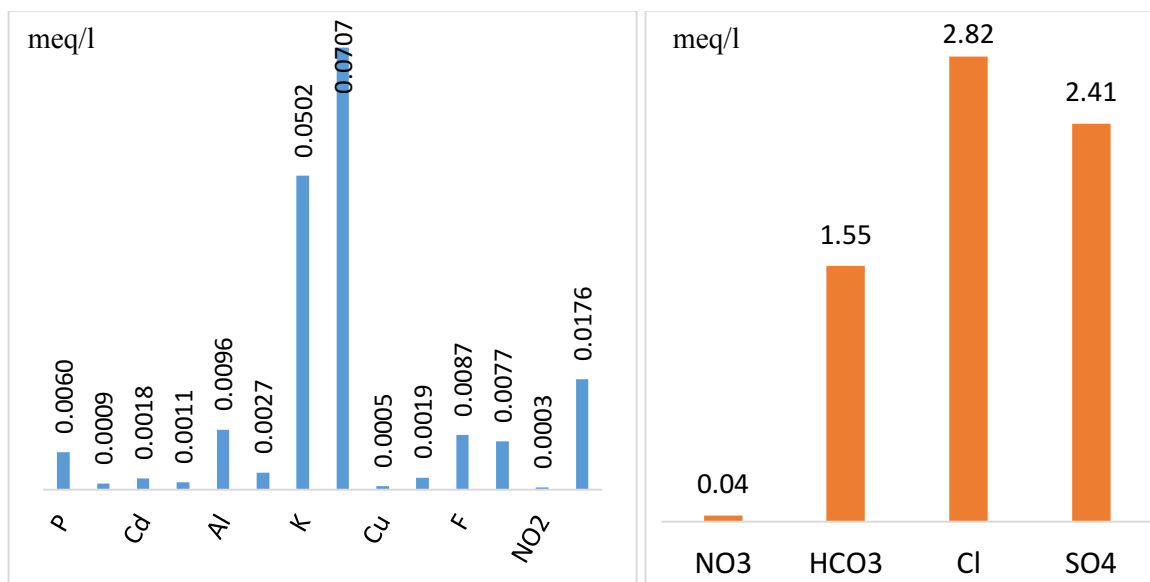


Fig.8. The results of chemical analysis of the Vakhsh river waters

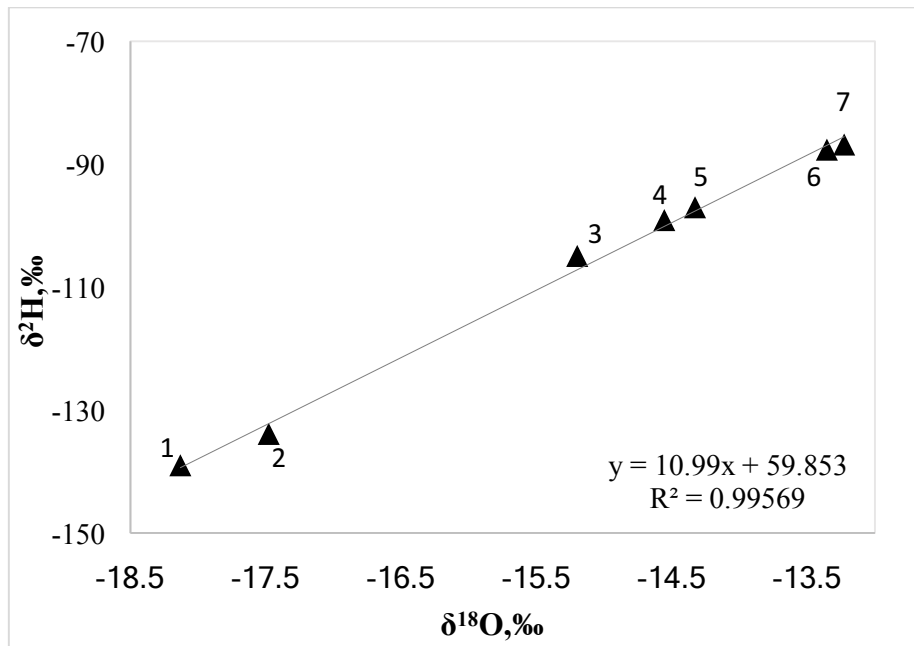


Figure 9. the Isotopic composition of water in the Vakhsh River and tributaries: 1, 2- Garmo glacier; 3 - Surkhob river; 4 – Vakhsh river; 5 –Obikhingou river; 6 – Kyzilsu river; 7 – river Muksu

In view of this pattern of recession of the mountain glaciers, it can be concluded that the rivers and Surkhob Obikhingou are fed by glacial-melt water, and assuming that precipitation mostly occurs in winter, the isotopic composition in the sampled water would be significantly lighter.

The weather and climatic conditions of the Vakhsh valley are warmer than in the valleys of its high elevation tributaries Surkhob and Obikhingou and consequently due to evaporation process would have a heavy isotopic composition. However, the increasing contribution of the melt-water from the tributaries leads to the fact that the isotopic composition of water of the Vakhsh River become lighter.

The isotopic composition of the Kyzilsu River is characterized by values  $\delta^{18}\text{O} = -13.36$  ‰,  $\delta^2\text{H} = -87.88$  ‰ which is close to the values of the isotopic composition of the water in areas with an average annual temperature above 0 °C (Fig. 9). It was found that the isotopic composition of the Naryn River changes seasonally in the following range: spring ( $\delta^{18}\text{O} = -13.4$  ‰;  $\delta^2\text{H} = -96$  ‰) and autumn ( $\delta^{18}\text{O} = -12.4$  ‰;  $\delta^2\text{H} = -89$  ‰) Tokarev et al. (2010). It was assumed that there are no significant contributions of glacial water to the Naryn River. Given this assumption, it can be concluded that formation of water flow in the Kyzilsu River occurs mainly due to seasonal rains and the contribution from glacial melt-water is negligible.

Previously Vasilenko et al. (1985) suggested on the basis of chemical composition of river water and groundwater of Tajikistan, that groundwater reservoirs under the river basins are recharged from the river channels. We conclude the opposite process, i.e. groundwater contribution to the flow of Muksu River (Fig. 6).



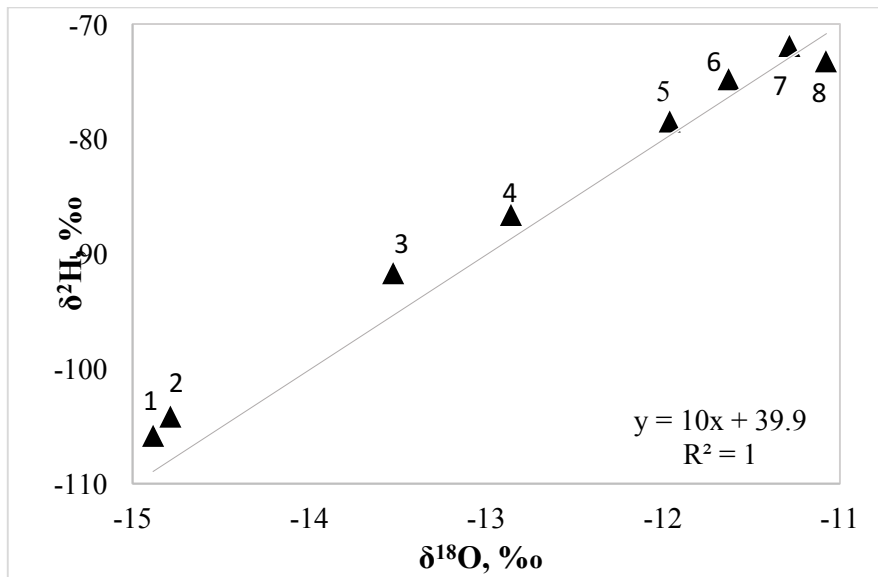


Figure 10. Isotopic analysis of spring (1, 3, 4, 5) and underground waters (2, 6, 7, 8) in the basins of rivers Muksu, Kizilsu, Surkhob, Obikhingou, respectfully.

The results of the isotope analyses of spring waters and groundwater basins of the rivers Muksu, Kizilsu, Surkhob, and Obikhingou shown on the Fig. 10. Fig.10 demonstrates that isotopic composition of groundwater and spring water in Muksu River basin are on average significantly lighter and close to the values of melted glacier water shown in Fig. 9.

## Conclusion

The research of the data for the period 1960-2012 by Agency of Hydrometeorology of The Republic of Tajikistan on the reduction of the area of glaciation in the basins of the Vakhsh River suggest that the increased water flow volume of the rivers is due to melting of small glaciers. Thus, one may conclude that the water in Vakhsh River basin is vulnerable to climate change. One may predict future flow volumes in Vakhsh River using seasonal changes in the river flow volumes.

No local anthropological sources of pollution were detected and the chemical composition of water in the investigated river basins were found to be mainly due to the natural leaching of mineral rocks.

## Acknowledgments

The authors express their appreciation to the U.S. Agency for International Development (USAID) & NSA for support of this study through the CHARIS and PEER projects.

## References

- Groll M., Ch. Opp Ch., Normatov I. et al. (2015) Water quality, potential conflicts and solutions—an upstream-downstream analysis of the transnational Zarafshan River (Tajikistan, Uzbekistan). *J. Environmental Earth Sciences*, 73(2), 743-764
- Kerimov A., Romomaeva O., Khemelevskaya I. (2011) Distribution of heavy metals in the surface layers of snow-firn thickness on the southern slope of Elbrus. *Ice and Snow*, 2 (114), 24-35 (rus).
- Kholmirezoeva M.O., Radzhabova A.S., Buranova S.A., Normatov I. (2012) Monitoring and physical-chemical studies of ground and surface water sources of Republic of Tajikistan. *Water: chemistry and ecology*, 6, 92-96.
- Normatov I. (2003) The water balance and the solution of water problems in the Central Asian region. *Proceeding UNESCO/IAHS/IWHA Symposium, 1-4 December 2003, Rome, Italy*, pp. 300-314.
- Normatov I. (2005a) Country paper on regions of Tajikistan. G- WADI Asia-Global Network for Water and Development Information in Arid and Semi-Arid Regions of Asia. *Proceeding of International G - WADI Modeling Workshop, 12-16 September 2005, Roorkee, India*.pp.123-160.
- Normatov I. (2005b) Regional experiences in solving water resources problems in Tajikistan. Book Building a New Asia. Ed: M. Singh. Kolkata, SHIPRA. pp.295-304.
- Normatov I. (2012) Maintenance of Food Security in the conditions of change of Agroclimatic Resources and working out of mechanisms of adaptation of agricultural crops to climate changes. *Proceedings of International Conference Hydrological and Ecological Responses to Climatic Change and to LUCC in Central Asia, 23-27 November 2012, Urumqi, China*. pp.170-176.
- Normatov I., Murtazaev U., Nasirov N. (2010) Creation of adaptation mechanisms: The key to more cost-effective and environment-friendly water management. *Red Book. IAHS Publ.* 338. pp. 74-76.
- Normatov I., Normatov P., Muminov A. (2014a) Modern adaptation approach of agriculture to the climate change and reservoirs impact. *Proceedings of 5<sup>th</sup> International Disaster and Risk Conference, IDRC. Davos, 12-15 October 2014, Davos, Switzerland*. pp.102- 106.
- Normatov I., Opp Ch., Normatov P. (2013) Monitoring and Analyses of impact of the industrial complexes on water quality of the Central Asian Transboundary Rivers. *Proceeding of 6<sup>th</sup> International Conference Water Resources and Environment Research. Water & Environmental DynamicsII, 3-7 June 2013, Koblenz, Germany*, pp. 212-229.
- Normatov P. (2014) Social and ecological aspects of the water resources management of the Transboundary Rivers of the Central Asia, *Red Book. IAHS Publ.*, 364, 2014, pp.441-445.
- Normatov P. (2014a) Monitoring Impact of industrial complexes on water quality and chemical analyses of seasonal snow of the Zarafshon River Basin glaciers.

*Proceeding of 16th Annual Conference of the International Association for Mathematical Geosciences, Jawaharlal Nehru University, 17-20 October 2014, New Delhi, India, pp.208-2012.*

Normatov P. (2015) Water Quality of the Zeravshan River and chemical analysis of seasonal snow on the glaciers of the Zeravshan river basin. *Vestnik Tajik National University V. 1, 1(102), 306-310.*

Normatov P., Armstrong R., Normatov I., et al (2015) Monitoring Extreme Water Factors and Studying the Anthropogenic Load of Industrial Objects on Water Quality in the Zeravshan River Basin. *Rus. J. Met & Hydrol., 40(5), 89-97.*

Normatov P., Armstrong R., Normatov I.(2016) Variations in hydrological parameters of the Zeravshan River and its tributaries depending on meteorological conditions. *Rus. J. Met & Hydrol., 41(9), 657–661.*

Normatov P., Normatov I. (2014) Quantitative estimation of Hyman intervention Rivers on quality of waters of the Transboundary Rivers of the Central Asia. *Abstracts Book of Goldschmidt, 8-13 June 2014, California, p. 1827.*

Normatov P., Frumin G. T. (2015) Comparative analysis of hydrochemical parameters upstream and downstream of the Zeravshan Transboundary River. *Proceeding Rus. State Hydromet. Univ., 39, 181-188.*

Olsson O., Gassmann M., Wegerich K. et al. (2010) Identification of the effective water availability from stream flows in Zarafshan river basin. *J. Hydrology, 390, 190-197.*

Temerev S., Indyushkin I. (2010) Chemical monitoring of snow cover in the area of influence of Barnaul. *News of Altay State University, 3-1(67), 196-203(rus).*

Tokarev I.V., Polyakov V.A., Samsonova A.A., et al. (2010) Water Isotope composition in the formation of conditions of the Toktogul reservoir water budget, [hge.spbu.ru/download/tokarpapper/isotopes.pdf](http://hge.spbu.ru/download/tokarpapper/isotopes.pdf).

Vasilenko V., Nazarov I., Fridman Sh. Monitoring of pollution of snow cover. L.: Gidrometeoizdat, 1985(rus).