

Methods for assessing hydrological and geocological risks based on modelling

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Abstract. This study is intended for decision-makers in the field of water resources use (irrigation and hydropower) and for emergency prevention authorities. Another problem remains intensive technogenic pollution of the environment, including water bodies, and one of the main tasks in the conditions of technogenesis is the development of predictive models for the migration of polluting chemical elements and substances in the environment. To calculate the runoff of the river the HBV3-ETH9 hydrological model and the CMIP5 RCP4.5 and RCP8.5 climate projections were used, according to which the air temperature is expected to increase by 2.3 and 4.3 °C, respectively, in annual precipitation - by 10% of the norm. In the period 2023-2080, a gradual increase in annual runoff is expected by 9-23%, and according to the extreme scenario, by 9-36% of the norm, which is associated with intensive glacier water loss, seasonal snowmelt and rainfall. In the future, the passage of two flood peaks (in June and July) is possible. The increase in water content in April and May will contribute to increased mudflow and flood activity.

1 Introduction

The water resources of the Zeravshan River are of great importance in the water distribution of the two states of Tajikistan and Uzbekistan. The Zeravshan is formed at the confluence of two large tributaries Fandarya and Zeravshan (Matcha) and is formed on the territory of Tajikistan. Downstream, the river is completely taken apart for irrigation needs in Uzbekistan. The Fandarya River is the left component of the river. Zeravshan has a significant hydropower potential of 7482 million kWh/year with an average annual capacity of 869 MW.

On the basis of a joint statement by the two presidents of the Republic of Tajikistan and the Republic of Uzbekistan, on August 17, 2018, an agreement was signed on the construction of two joint HPPs with a total capacity of 320 MW on the Zarafshan River. First

of all, it is planned to build the Yavan HPP with an estimated cost of 282 million US dollars with a capacity of 140 MW and the generation of 700-800 million kWh of electricity, and then a HPP on the Fandarya River with an estimated cost of 270 million US dollars, a capacity of 135 MW and generation of 500–600 million kWh of electricity [1].

Climate change associated with global warming, which has been growing rapidly since the mid-1970s, is leading to changes in the flow of rivers in Central Asia [2]. First of all, it leads to the degradation of glaciation in the mountainous regions of Central Asia, a change in the area of glaciers and, accordingly, the glacial feeding of rivers. All studies on climate change in the mountains of Central Asia show that the course of warming here, although reflecting global climate warming, is of a significant regional character.

The researchers present data indicating: 1) a stronger warming in a number of mountain ranges of the Earth compared to flat regions, 2) the presence of areas where warming decreases or remains unchanged in height [3].

The authors of the paper assessed the inter-annual and intra-annual dynamics of water resources in the high-mountain basin of the Fandarya River for the current period and in the future for decades to come. The aim of this study is to assess the impact of climate change on the flow of the Fandarya River using HBV-EHT hydrological modeling.

In the study of complex geocological phenomena, for example, when it comes to environmental pollution, there is always some element of uncertainty associated with the fact that with the same combination of factors that can be taken into account, the phenomenon under study can occur in one case, and not in another. happen. In mathematics, such phenomena, considered in an abstract form, regardless of their nature and specific content, are called random events. It is assumed that the implementation of a set of conditions under which an event occurs, usually denoted by such terms as test, experiment, observation, can be repeated an arbitrarily large number of times. Random are any events that occur under conditions of incomplete information about the causes that generate them and require the use of methods of probability theory and mathematical statistics for their study. Geocological indicators are obtained during tests, the results of which are influenced by a large number of factors, and therefore they can be taken as random variables. In order to have complete information about a random variable, it is necessary to know not only all its possible values, but also the probabilities corresponding to them, or the distribution law. In this work, the authors, using the example of Chusovaya River, assessed the dependence of the content of a pollutant element in the water of a given river on its content in the effluents of the enterprise, intensively entering this river and atmospheric air, into which the same pollutant element also enters as a result of emissions from the enterprise. From the atmospheric air, the pollutant element possibly migrates to the surface waters of the river, thereby polluting it. It is this migration ability of the pollutant element that was investigated by the authors in this work.

2 Materials and methods

The Fandarya River flows in the Pamir-Alai Mountains (the territory of Tajikistan), bounded by the square of the coordinate grid 39°11'21" - 39°22'56" N. sh. and 68°32'17" - 68°32'59" E. and has a basin area of 3207 km², a river length of 24.5 km, and an average annual water discharge of 61.4 m³/s (Fig. 1). The flood on the Fandarya River begins in late April and ends in mid-October [4]. The intra-annual runoff of the Fandarya River is characterized by significant variability, flood peaks are observed in June and in some years can be observed in July, fluctuations in runoff during the months of seasonal snowmelt (March-June) are 27-52%, during the months of glacial melt (July-August) - 38-63% of the annual runoff [5]. In this study, the authors used the Tajhydromet data on the average daily water consumption at the gauging station of the river. Fandarya - Pete (hydropost height 1586 m.a.s.l.) and average daily air temperatures, and the amount of precipitation per day according to the Pejkent

weather station (weather station height 1015 m.a.s.l.) for the modern period from 2000 to 2019 years (Fig. 1). The Penjikent meteorological station is located in the Fandarya river basin and has a close dependence of meteorological parameters with the river flow [6]. For hydrological modelling, the mass balance data of the Abramov Glacier [6] for 2008-2017 and the vector layers of the modern glaciation area according to the Randolph Glacier Inventory 6.0 data were used. According to calculations made in ArcGIS using Randolph Glacier Inventory 6.0 data, the area of glaciation in the Fandarya river basin is 6% of the basin area.

The hydrological model HBV-EHT was used to calculate the runoff of the Fandarya River for future periods. The runoff-precipitation model HBV3-ETH9 used by the authors to calculate the runoff of high-altitude rivers is an improved HBV model that allows calculating the daily runoff hydrograph based on meteorological and hydrological data from land-based observations [7, 8, 9]. The HBV3-ETH9 model has a simple non-deterministic structure and to work it does not require a large set of meteorological parameters. For the catchment area Fandarya in the digital elevation model SRTM (resolution 90 meters at the equator) in the ArcGIS program was divided into altitudinal zones every 200 meters, the exposure of the slopes was determined, and the shape files of the modern glaciation of the basin were prepared. Calibration and validation (verification) of the HBV3-ETH9 model for the river basin. Fandarya was carried out using continuous series of hydrological and meteorological data for 4-5 years, which include low-water, high-water and average water years. The results of the calibration and validation of the model were evaluated by the correlation coefficient R^2 , which should be more than 0.60 and tend to 1.00. The optimization process for the HBV3-ETH9 hydrological model for the river basin was carried out in accordance with the user guide [10]. Parameter ranges for model optimization were taken from previous studies prepared for the highland rivers of Central Asia [11]. The calculations were made in the MATLAB 2016a program.

To calculate changes in meteorological parameters for the future, an analysis of climate projections was carried out using global climate models of the general circulation of the atmosphere and ocean (AGCM) CMIP, available on the portal of the Earth System Grid Federation platform (<https://esgf.llnl.gov>), combined into an ensemble. To reduce to a single latitude-longitude grid, a statistical method was used, the results of which are presented on the NASA NEX platform (National Aeronautics and Space Administration, NASA Earth Exchange, <https://cds.nccs.nasa.gov>). The adjustment was made in accordance with the BCSD method [12]. To reduce the uncertainty of climate forecasts, an ensemble approach was used using the results of 25 models, which shows the highest success in reproducing average climatic characteristics when compared with observational data. Using a multi-model approach - using forecasts from several models (ensemble) allows you to average the data and reduce the constant error of the model [13, 14, 15]. The calculations were prepared for two scenarios of representative greenhouse gas concentration trajectories: RCP4.5 and RCP8.5 (in English RCP4.5 and RCP8.5). The scenario index characterizes the magnitude of the anthropogenic radiative forcing achieved in 2100, namely: RCP4.5 – stabilization scenario, according to which the radiative forcing will stabilize by 2100 at approximately 4.5 W/m²; RCP8.5 is a scenario of high radiation load, in which it will continue to increase after 2100. According to this scenario, concentrations will stabilize only by 2250; in this case, the concentration of CO₂ will be about 2000 ppm, which is about 7 times higher than its pre-industrial level.

As an object of study, when developing predictive models for the migration activity of polluting elements, the Chusovaya River, located in the Middle Urals in the vicinity of Yekaterinburg, Sverdlovsk Region (RF). This water body is under intense technogenic impact from the processing plant located here, which processes copper pyrite ores. The main pollutant of the Chusovaya River is copper.

3 Results

The calibration of the HBV3-ETH9 model for the Fandarya river basin showed good compatibility of the simulated and observed runoff for the calibration period of 2008-2012 and for the validation period of 2013-2017, the correlation coefficients R^2 were 0.94 and 90 (Fig. 1).

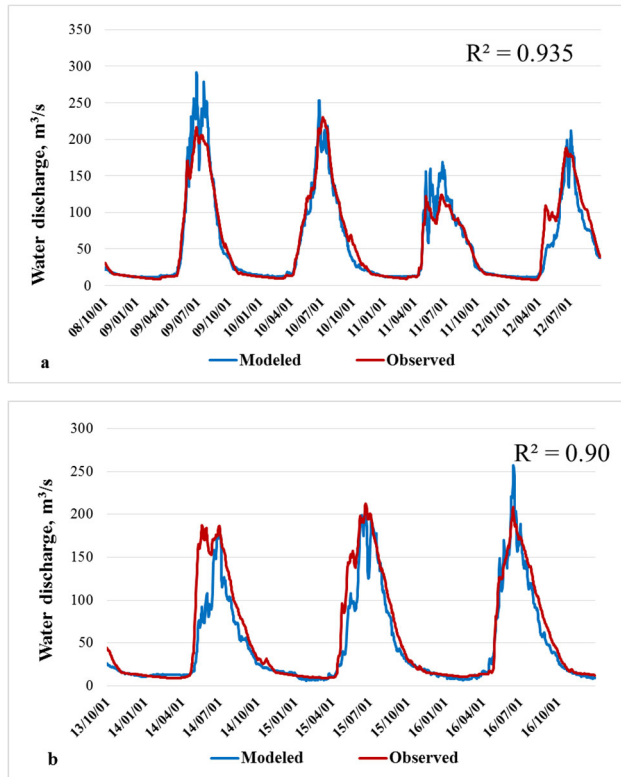


Fig.1. Calibration (a) and validation (b) results of the HBV-EHT model for the Fandarya river basin. Source: compiled by the author.

Climate projections calculated for the Penjikent weather station using the “bias correction” method show an increase in air temperature by 2080 according to the CMIP5 RCP4.5 scenarios by 2.3 °C and will be 13.5-15.7 °C, according to the CMIP5 RCP8.5 scenario by 4.3 °C and will be 14.0-17.6 °C. The average annual precipitation under the CMIP5 RCP4.5 scenario ranges from 600 to 660 mm per year or 98-109% of the values for 2006-2018. and under the CMIP5 RCP8.5 scenario from 608-668 mm or 101-110% of the values for 2006-2019. Previous studies of the intra-annual runoff dynamics of the Fandarya River showed that its formation is significantly influenced by precipitation during the warm period, followed by the accumulation of precipitation during the cold period and the observed air temperature anomalies [7]. Calculations made using hydrological modelling based on climate projections CMIP5 RCP4.5 and CMIP5 RCP8.5 show that by 2080 the average annual water discharge will gradually increase and will amount to 109-123% and 108-136% of the values for the period 2000-136%. 2019 (Fig. 2, Table 1).

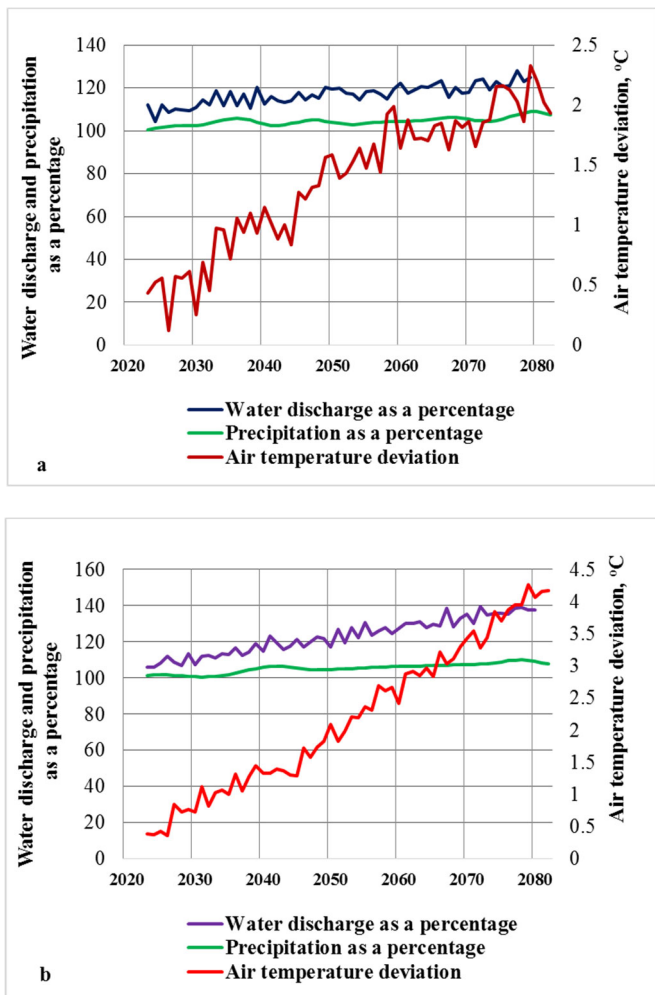


Fig. 2. Combined graph of the calculated average annual water discharges of the Fandarya River with annual air temperature and precipitation at the Penjikent weather station under the CMIP5 RCP4.5 (a) and CMIP5 RCP8.5 (b) scenarios. Source: compiled by the author.

Table 1. Change in the average annual runoff of the Fandarya River in m³/s and as a percentage of the average values for 2000-2019 according to CMIP5 scenarios. Source: compiled by the author.

Scenario name		2023-2030	2031-2040	2041-2050	2051-2060	2061-2070	2071-2080
CMIP5 RCP 4.5	in m ³ /s	58.3	61.0	61.8	62.7	63.5	65.6
	in percents	109	114	116	117	119	123
CMIP5 RCP 8.5	in m ³ /s	57.7	60.6	63.6	66.8	69.8	72.5
	in percents	108	113	119	125	131	136

According to the CMIP5 RCP4.5 and RCP8.5 scenarios, flood peaks will be observed in June, which corresponds to the current period for 2000-2017. The volume of runoff for the period May-September will increase, which is associated with increased water loss from glaciers and an increase in precipitation during the cold period and June (Fig. 3).

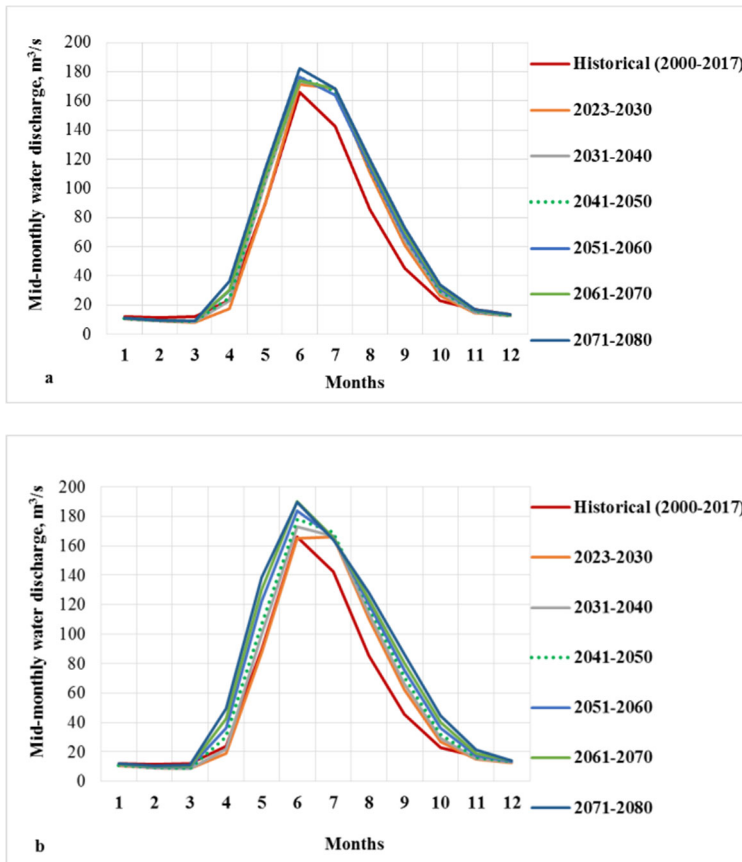


Fig.3. Calculated intra-annual runoff dynamics of the Fandarya River for the periods 2031-2080 under the CMIP5 RCP4.5 (a left) and CMIP5 RCP8.5 (b) scenarios. Source: compiled by the author.

According to the RCP 4.5 (“medium”) scenario, a gradual increase in runoff by 2080 is expected: in May, July-September by 7.7-33.5 m³/s and will amount to 118-159% of the monthly norm; in April, June and October by 3.7–12.2 m³/s or 116–145% of the monthly norm. According to the RCP 8.5 (“extreme”) scenario, a gradual increase in runoff by 2080 is expected: in May, July-September by 5.1-45.4 m³/s and will amount to 129-184% of the monthly norm; in April, June and October by 9.2–24.2 m³/s or 122–194% of the monthly norm. A decrease in runoff under the CMIP5 RCP 4.5 and RCP 8.5 scenarios is expected in March by 1.5-3.8 m³/s or 69-88% of the monthly norm.

In the area of the river basin. Chusovaya and an industrial enterprise, correlations were determined between atmospheric air, surface water, wastewater discharged into the river, according to the main pollutant of this area - copper. The calculation of the correlation coefficient showed that there is a strong relationship between the studied media (correlation coefficient 0.75), and copper intensively migrates through the media.

The concentrations of copper in the surface waters of the river were used as dependent variables. Chusovaya River flowing in the study area, and independent - in the wastewater of the enterprise discharged into the river, and the atmospheric air of the area.

For copper, direct dependences of its content in water after the release of wastewater on its content in the discharge of wastewater from the enterprise in the Chusovaya river were revealed with a significant correlation coefficient of 0.74.

4 Discussion

Previous studies of the influence of climatic factors (according to the data of 7 meteorological stations in the river basin) on the runoff dynamics of the Fandarya River for the modern period, carried out by J.B. Niyazov, confirm the studies presented in the fundamental monograph by V.L. Schultz that the flow of the Fandarya River varies significantly within the year, the peaks of floods occur both in June (the type of nutrition is snow-glacial) and in July (the type of nutrition is glacial-snow). The main sources of food for snow and ice melt depend on many climatic factors. First of all, the flow of the river depends on precipitation during the year, as well as anomalies in air temperature during the period April-June, October, January-February. From 2000 to 2017, there is an increase in air temperature during the warm period from May to October, its duration increases and, as a result, the water loss of glaciers. Precipitation for warm and cold periods also has positive trends.

By 2080, under the CMIP5 RCP 4.5 (“medium”) scenario, a gradual increase in air temperature by 2.3 °C is expected, and under the RCP 8.5 (“extreme”) scenario, by 4.3 °C from the norm, while the amount of precipitation varies from 98 to 110% of the norm, which confirms the trend observed in the modern period (2000-2017). According to climate projections, the air temperature rises by months, a slight decrease in the next 20 years is expected in March and May. Glaciation in the Fandarya basin is widely developed and such climate forecasts show that by 2080 the water content of the Fandarya River will increase by 10-25% according to the average and by 35% according to the extreme scenario. Flood peaks will be observed in June, and in July they will approach the maximum values for the year. Thus, a significant increase in water content within the year and the passage of two flood peaks can be expected.

On the surface waters of the Chusovaya is affected by discharges of the enterprise, that is, technogenic factors make a significant contribution to the formation of the ecological state of the river. This is confirmed by the high value of the correlation coefficient between the content of copper in the atmospheric air and surface waters of the Chusovaya river: correlation coefficient = 0.71

5 Conclusion

Taking into account the scenarios for changing the water resources of the Fandarya River, a gradual increase in its water content can be expected in the next 40-60 years. Mudflow and flood activity will intensify in April and May, and intensive melting of glaciers and seasonal snow will contribute to the passage of two flood peaks in July and June. In this regard, it is recommended to take timely measures to protect the bank and prevent mudflows in order to prevent and reduce the consequences of the dangers of mudflows and floods; strengthen monitoring of river flows and establish early warning systems for sudden rises in water levels and flood risk. In the future, it is necessary to build up scientific and educational potential to develop reliable scenarios for changing river flow in the context of climate change.

In geoecological studies, the following regression equations were constructed: $u_{pv} = -0.0562 + 0.2179 \cdot x_{st}$, where Cu in wastewater (x_{st}) is Cu in surface waters after discharge of wastewater (u_{pv}) and $u_{pv} = 0.0199 + 43.9997 \cdot h_{atm}$, where Cu in atmospheric air (x_{atm}) - Cu in surface water after discharge of wastewater (SW) can be used as a predictor for estimating the content of copper in surface water, knowing its concentration in wastewater or in atmospheric air.

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