IRSTI 37.27.21 https://doi.org/10.26577/JGEM.2023.v70.i3.08

T. Tillakarim[1,*], N. Serikbay[1],
D. Rakishev[1,2], S. Sairov[1]

[1] RSE «Kazhydromet», Kazakhstan, Astana
[2] L.N. Gumilyov Eurasian National University, Kazakhstan, Astana
*e-mail: tillakarim_t@meteo.kz

MODELING RIVER RUNOFF OF LITERAL TRIBUTARIES OF THE BUKTYRMA RESERVOIR WITH USING HBV MODEL

The article presents the results of applying the HBV-light model for 6 mountain rivers flowing into the Buktyrma reservoir: Buktyrma, Ulken Boken, Naryn, Kurshim, Turgysyn, Kalzhyr. Research work carried out the simulation of the flow of mountain river basins with a catchment area varying within 758-12423 km^2. The parameters of the models were calibrated using the GAP optimization algorithm for the periods 1978-2017. The calibration period according to the recommendations for river basins were 5 years, with the exception of the Turgysyn and Kalzhyr river basins, where hydrological stations were opened in 2012 and 2007, respectively. For modeling the runoff as input hydrological and meteorological data were used data from the observation network of the RSE "Kazhydromet". It should be noted that, due to the sparse network of meteorological stations, for Turgysyn, Kurshim, Ulken Boken, Naryn river basins as input data were used meteorological data from stations not located in the catchment areas of rivers. As a result of model calibration, the optimal parameters for each river are obtained. Several widely used criteria were used to evaluate the effectiveness of the model: NSW, PBIAS, RSR and R^2. The results of calculations of these criteria correspond to a "very good" and "good" assessment of the performance rating: the Nash-Sutcliffe criterion varying between 0.84 – 0.92, the RSR ranges 0.32-0.45, the PBIAS -14.3 % to +18.2 %. According to the simulation results, it was revealed that the model for all the rivers under consideration reproduces the dates well the beginning, duration of the spring flood period and the maximum water consumption for this period. Given the sparse network of meteorological stations and the overregulation of some river basins, the using of the HBV-light model showed good results of modeling runoff for mountain rivers of Kazakhstan for calibration period. Also, the model was validated for 2018-2020 period. Validation results on performance criteria indicators for the Buktyrma and Ulken Boken river basins showed a "very good" replication result, while for the remaining 4 river basins the results were unsatisfactory, which was a consequence of management activities on the flow of river basins.

Key words: water discharge, calibration parameters, model validation, Ertis water basin, digital elevation model.

Т. Тілләкәрім[1*], Н. Серікбай[1], Д. Ракишев[1,2], С. Саиров[1]

[1] «Қазгидромет» РМК, Қазақстан, Астана қ.
[2] Л.Н. Гумилев атындағы Еуразия ұлттық университеті
*e-mail: tillakarim_t@meteo.kz

Бұқтырма су қоймасының бүйір салалары өзендерінің ағындысын HBV моделін қолдана отырып модельдеу

Мақалада Бұқтырма су қоймасына құятын Бұқтырма, Үлкен Бөкен, Нарын, Күршім, Тұрғысын, Қалжыр тау өзендері үшін HBV-light моделін қолдану нәтижелері берілген. Зерттеу жұмысында қарастырылып отырған өзендердің су жинау алабы – 758 – 12423 км^2. 1978–2017 жылдар аралығында GAP optimization алгоритмін қолдана отырып, модель параметрлерін калибрлеу жүргізілді. Нұсқаулыққа сәйкес калибрлеу кезеңі, гидрологиялық бекеттер тиісінше 2012 және 2007 жылдары ашылған Тұрғысын және Қалжыр өзендерін қоспағанда, 5 жылды құрады. Ағындыны модельдеу үшін кіріс гидрологиялық және метеорологиялық деректері ретінде "Қазгидромет" РМК бақылау желісінің деректері пайдаланылды. Метеорологиялық станциялардың сирек желісіне байланысты, Тұрғысын, Күршім, Үлкен Бөкен, Нарын өзендерінің рологилық станцияның болмауымен, аталған өзендердің су алаптары аумағында орналаспаған станциялардың деректері пайдаланылды. Модельді калибрлеу нәтижесінде әр өзен үшін оңтайлы параметрлер алынды. Модельдің тиімділігін бағалау үшін бірнеше кеңінен қолданылатын критерийлер: NSE, PBIAS, RSR және R^2 есептелді. Осы критерийлерді есептеу нәтижелері "өте жақсы" және "жақсы" өнімділік рейтингіне сәйкес келгендігі анықталды, яғни NSE 0,84 – 0,92, RSR 0,32 – 0,45 аралығында, PBIAS 14,3 %-дан +18,2 %-ға дейін өзгерді. Модельдеу нәтижелеріне сәйкес, қарастырылып отырған барлық өзендердің моделі көктемгі су тасқынының басталу күндерін, кезеңнің ұзақтығын және осы кезеңдегі судың максималды өтімін жақсы үлгілейтіндігі анықталды. Метеорологиялық станциялардың сирек желісін және кейбір өзенде шаруашылық әрекеттердің болуын ескере отырып, Қазақстанның таулы өзендері ағындысын калибрлеу кезеңінде HBV-light моделі өзен ағындысын модельдеудің жақсы нәтижелерін көрсетті. Сондай-ақ жұмыста 2018-2020 жылдар үшін модельді тәуелсіз кезеңде тексеру жұмысы жүргізілді. Нәтижесінде, Бұқтырма және Үлкен Бөкен өзендерінің алаптары үшін тиімділік критерийлерінің көрсеткіштері бойынша «өте жақсы», ал қалған 4 өзен алабы үшін «қанағаттанарлықсыз» нәтижеге сәйкес болды, бұл өзен алаптарының ағынындағы шаруашылық қызметтің салдары үлкен екендігін көрсетті

Түйін сөздер: өзеннің шығыны, калибрлеу параметрлері, модельді тексеру, Ертіс су шаруашылығы алабы, сандық жер бедері үлгісі.

Т. Тілләкәрім[1*], Н. Серікбай[1], Д. Ракишев[1,2], С. Саиров[1]

[1] РГП «Казгидромет», Казахстана, г. Астана

[2] Евразийский университет имени Л.Н. Гумилева, Казахстана, г. Астана

*e-mail: tillakarim_t@meteo.kz

Моделирование стока боковых притоков рек в Бухтырминское водохранилище с применением модели HBV

В статье приведены результаты применения модели HBV-light для 6 горных рек, впадающих в Бухтырминское водохранилище: Бухтырма, Улкен Бокен, Нарын, Куршим, Тургысын, Калжыр. В работе было выполнено моделирование стока горных рек с площадью водосбора варьирующиеся в пределах 758 - 12423 км^2. За 1978-2017 гг. периоды была произведена калибровка параметров моделей, используя алгоритм GAP optimization, из которого были выбраны периоды с наилучшими параметрами. Период калибровки, согласно рекомендациям, составляло 5 лет, за исключением рек Тургысын и Калжыр, где гидрологические посты были открыты в 2012 и 2007, соответственно. Для моделирования стока в качестве входных гидрологических и метеорологических данных использованы данные наблюдательной сети РГП «Казгидромет». Необходимо отметить, что, ввиду редкой сети метеорологических станций, для бассейнов рек Тургысын, Куршим, Улкен Бокен, Нарын использованы метеоданные станции, не расположенные на территории водосборов рек. Для оценки эффективности модели использованы несколько широко применяемые критерий: эффективность NSE, PBIAS, RSR и R^2. Результаты расчетов этих критериев в период калибровки модели соответствует «очень хорошей» и «хорошей» оценке рейтинга производительности: критерий NSE составило 0,84 – 0,92, RSR колеблется от 0,32 до 0,45, PBIAS от -14,3 % до +18,2 %. Согласно результатам моделирования выявлено что, модель для рассматриваемых рек хорошо воспроизводит даты начала, продолжительности периода половодья и максимальные расходы воды. Учитывая редкую сеть метеорологических станции и зарегулированность некоторых рек применение модели HBV-light показало хорошие результаты моделирования стока для горных рек Казахстана. Также в работе проведена валидация модели за 2018-2020 гг. период. Результаты валидации по показателям критериев эффективности для бассейнов рек Бухтырма и Улкен Бокен показали «очень хороший» результат воспроизведения, в то время как для остальных 4 бассейнов рек результаты оказались неудовлетворительными, которое явилось следствием хозяйственной деятельности на сток речных бассейнов.

Ключевые слова: расход воды, калибровочные параметры, валидация модели, Ертисский водохозяйственный бассейна, цифровая модель рельефа.

Introduction

Hydrological modeling currently has become one of the important elements used in the planning and managing of water supply and monitoring systems, as well as in the provision river forecasts and warnings. The basic principle of hydrological modeling is the ability to reproduce and predict the behavior of water bodies or systems using a model (WMO, 2012: 320). For the water sector, they are an important tool for predicting the impact of climate change on runoff, water resources and flooding at the local, regional and global levels (Huang, 2019).

Hydrological models represent a simplified description of the hydrological system of the real world, and their level of complexity largely depends on the structure of the model and their goals (Fleiscmann et.al., 2018: 943-959).

More detailed overview of the developed runoff models and some of the most well-known hydrological models are discussed in the works of (Singh, 1995: 1144; Peel, 2020: 1-15). Development of hydrological modeling began in the 1960s with the introduction of the first models such as SSARR and the Stanford Watershed model. Also, earlier developed models include: Canadian model UBC, Danish model NAM, Japanese model TANK, Swiss-American model SRM, US National Meteorological Service River forecasting system based on Sacramento watershed model, GR4J models and Swedish HBV model. Then, starting from the 90s of the last century, were appeared following later models such as British TOPMODEL model, Chinese Xinanjiang model, Danish MIKE-SHE model, Italian and American VIC model (Seibert, Bergström, 2021: 1-28).

In 1980-1990, mathematical models of runoff formation were developed on the territory of the Commonwealth of Independent States (CIS), which served as a methodological basis for hydrological forecasting. The Hydrometeorological Centre of the Russian Federation and the Far East Hydrometeorological Scientific Research Institute (HMSRI) have made a significant contribution to the development of the modeling of the flow of lowland rivers, and the Central Asian and Kazakh National Hydrometeorological Institute (NIGMI) for mountainous areas. On the territory of Kazakhstan for modeling the runoff of mountain rivers were developed a conceptual dynamic model for the formation of a common runoff - KDMFOS-76 B (Golubtsov, 2010: 20). This water-balance model makes it possible to model the hydrograph of mountain river runoff by daily time intervals, and can also be used for short-term, medium- and long-term hydrological forecasting and assessment of water resources.

Conceptual models with a system of equations based on different concepts of description of physical processes of formation of flow have been most developed and disseminated (WMO, 2012: 320). One of the most widely used and well-known is the Swedish concept model, HBV.

The HBV model has been widely applied in many areas, such as weir design (WMO, 2003: 1174; Bergström et.al., 2001:), water resource assessment, nutrient stock assessment (SNA, 1995) and climate change studies (Forero-Ortiz, 2020: 1779). The model is also used for national hydrological mapping, for example in Norway (Berglöv, 2009: 10) and Sweden (Valent, 2012: 35-43). This conceptual hydrological model was first developed in 1973, then revised to HBV-6 and HBV-96 in 1992 and 1997, respectively. Since then, many variants of the model have been published, and even more variants can be found at various institutes (Jansen, 2021: 1-31).

For the territory of Kazakhstan, the HBV-light model has found application in works (Galaeva, 2013: 108-114; Shivareva, 2015: 66-72; Kishkimbaeva, 2015: 141-144; Choduraev, 2016: 43-46; Bolatova et al., 2018: 110-124; Bolatova et al., 2019: 26-43). These works are considered the possibilities of using the HBV model for modeling the runoff of mountain rivers in Kazakhstan. The obtained results indicate good reproducibility of runoff for the territory of Kazakhstan.

In order to simulate the flow of the studied area, the article considers the possibility of applying the model HBV-light (Seibert, 2012: 3315–3325).

Materials and methods

The objects of study are 5 left-bank and 1 right-bank mountain rivers of the Ertis River basin, flowing into the Buktyrma reservoir: Buktyrma, Kurshim, Ulken Naryn, Ulken Boken, Kalzhyr, Turgysyn (Table 1, Fig. 1).

The territory of most of the left bank of the Upper Ertis, as well as the flat Right-bank Ertis, belong to areas of pronounced insufficient moisture. Surface runoff in the catchment areas of rivers with a flat and low-mountain-hilly relief in this part of the territory is formed almost exclusively due to thawed snow waters. Rainfall only slightly supplements the snow supply during the flood period. In summer, the lack of air humidity and the dryness of the soil are so great that rainfall is almost completely spent on wetting the top layer of soil and evaporation and is of no practical importance in the formation of runoff. Precipitation during the autumn period determines the degree of moisture content in watersheds and has only a regulating effect on spring runoff. The duration of the spring and spring-summer floods depends on the average height, area, topography, and peculiarities of climatic and hydrogeological conditions.

Precipitation, snowmelt, and glaciers also play an important role in the formation of river flow, since the rivers are fed mixed: in the upper reaches it is predominantly mountain-snow and glacial, in the lower reaches it is snow and soil.

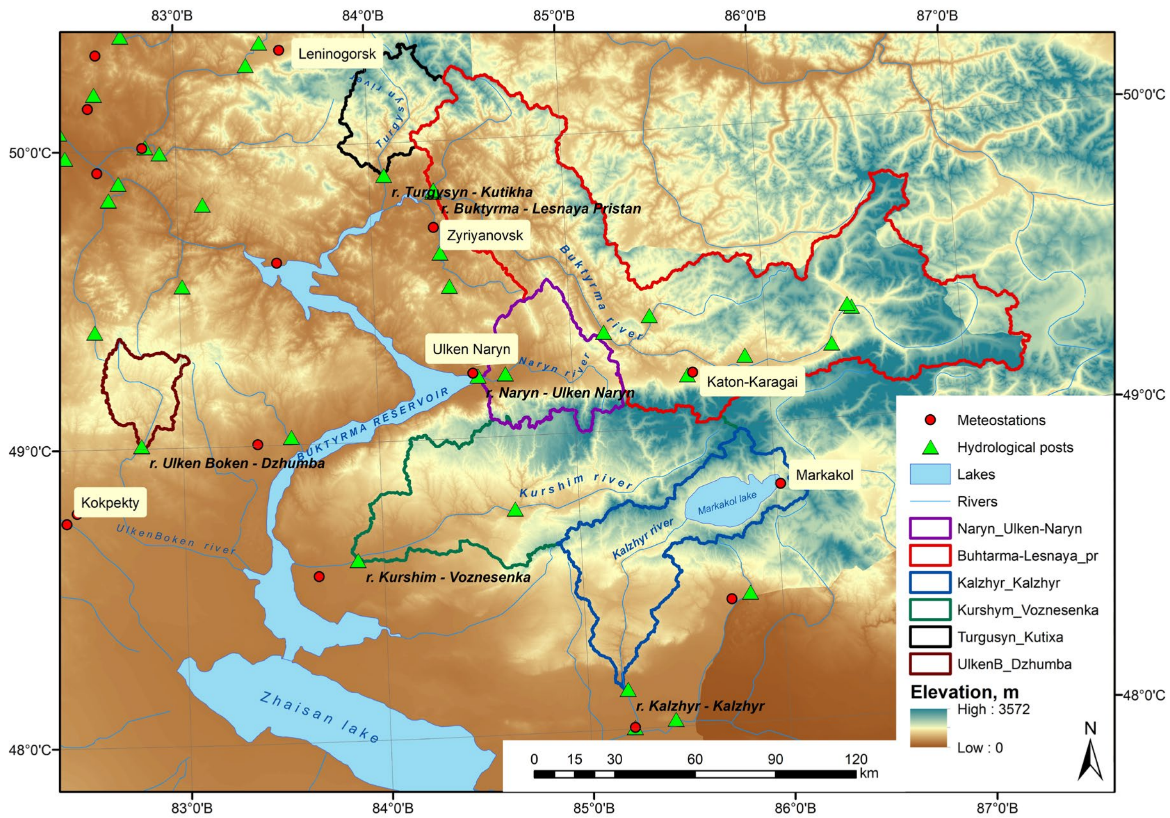

Figure 1 – Altitude map of the rivers flowing into the Buktyrma reservoir

Table 1 – General information on river catchment areas

№	River basin	Area F, km²	Altitude range H, m	Qmn, m³/s (2000-2020 yy.)
1	r. Buktyrma – s. Lesnaya Pristan	12423	432-4478	247,2
2	r. Ulken Boken – s. Dzhumba	758	696-1603	9,03
3	r. Kurshim – s. Voznesenka	5001	472-3276	72,5
4	r. Naryn - s. Ulken-Naryn	1866	392-2912	13,9
5	r. Turgysyn - s. Kutikha*	1192	319-2753	47,3
6	r. Kalzhyr – s. Kalzhyr	3150	378-3276	22,2

* data for 2008-2020.

The area of the considered mountain river basins varies from 758 km^2 (Ulken Boken river) to 12423 km^2 (Buktyrma river). The height range of mountain rivers is 319 - 4478 m. The average annual water discharge of the rivers under consideration varies within 9.03 - 247 m^3/s.

HBV model

The HBV model is a conceptual watershed model that converts precipitation, air temperature and potential evapotranspiration into either snowmelt or runoff or inflow into a reservoir, developed by Bergström (Lindström, 1992: 153-168) at the Swedish Meteorological and Hydrological Institute. The model has been modified many times and different versions exist in many countries.

The model describes the overall water balance as follows:

$$P - E - Q = \\ = \frac{d}{dt}\,(SP + SM + UZ + LZ + VL) \qquad (1)$$

where, P is precipitation, E is evapotranspiration, Q is runoff, SP is snow cover, SM is soil moisture, UZ is the upper groundwater zone, LZ is the lower groundwater zone and VL is the lake volume.

The HBV model can be viewed as a model with semi-distributed parameters; the watershed is divided into private watersheds, and the altitudinal zoning method is also used. This model includes subroutines for meteorological interpolation, calculation of snow accumulation and snowmelt, evapotranspiration, soil moisture, runoff generalization and, finally, for calculation of the transformation of water movement along rivers and through lakes.

The model simulates daily runoff using rainfall, air temperature, and evaporation as input. The precipitation simulation simulates either snow or rain depending on whether the temperature is above or below the threshold temperature, TT (^{0}C). All simulated snow precipitation is multiplied by the snowfall correction factor SFCF. Snow melt is calculated using the degree-day method:

$$\text{Melt} = \text{CFMAX} * (\text{T(t)} - \text{TT}), \qquad (2)$$

where, Melt – snowmelt; CFMAX is the degree-day factor; T(t) – average daily air temperature; TT is the threshold temperature.

Meltwater and precipitation remain in the snowpack until they exceed a certain proportion, CWH, of snow water equivalent. Liquid water inside the snow cover is refrozen according to equation (3):

$$\text{Refreezing} = \text{CFR} * \text{CFMAX} * (\text{TT} - \text{T (t)}), \qquad (3)$$

where, Refreezing - re-freezing; CFR - freezing factor; CFMAX is the degree-day factor; T(t) – average daily air temperature; TT is the threshold temperature.

Input data

The required input information for the model is precipitation (daily totals), air temperature (daily averages), evaporation, water discharge, digital elevation model, and glacial components. The Standard Model operates on the basis of monthly data on long-term averaged potential evapotranspiration, usually based on the Penman formula corrected for temperature anomalies (Bergström, 1992). But in this paper, N.I. Ivanov's formula (2) was used to calculate evaporation, since there were no input data for calculating evaporation according to the Penman formula.

$$E_0 = 0.0018 \cdot (T + 25)^2 \cdot (100 - r), \qquad (2)$$

where T is the average monthly temperature; r is the average monthly relative air humidity.

For the altitudinal analysis of the basins were used three-dimensional images of the SRTM (Shuttle radar topography mission). On the basis of SRTM data with an extension of 30x30 m were prepared digital elevation models (DEM). The information obtained helped in the analysis of the relief of each basin, the classification of the area of the basins by altitudinal zones, and the identification of slopes of various exposures. In the presence of ice cover, this information was also taken into account. Ice sheet data are taken from the Global Land Ice Measurement Space-Based Land Ice Measurement database (https://www.glims.org/).

Model parameter calibration

One of the most difficult aspects of applying conceptual models is the calibration of the selected model for a specific watershed. Most model parameters are determined iteratively, either manually or automatically, based on historical input and output data series (WMO, 2012).

The procedure for calibrating model parameters is to find one optimal set of parameters for the study area. The reliability of the results of hydrological models of the watershed directly depends on this procedure. Automatic calibration on an HBV model selects the best parameters within a given range (Seibert, 2005: 32) and then runs the model using the given parameters.

For calibration, a period is used that includes both high-water and low-water hydrological years, and synchronous series of runoff and meteorological data are also needed.

In this work for modeling river runoff is used the automatic method of calibration, developed by Lindström (Lindström, 1997: 153-168), which allows the use of various criteria, if necessary, the selected parameters were changed manually. Although automatic calibration itself is not part of the model, it has important practical implications. This process requires simultaneous observations of runoff and meteorological conditions. If runoff data are not available, in some cases the parameters can be estimated from known catchment characteristics.

The model parameters are calibrated using an automatic calibration method based on the experience of a large number of manual calibrations (10,000 parameter combinations), during which the corresponding parameter values are changed until the best relationship with the observed data is obtained. The automatic calibration method for the HBV model allows to use different criteria. This process requires simultaneous observations of runoff and meteorological conditions.

The HBV model, in its simplest form, has a total of 14 free parameters. Parameter values are selected by random generation within a given range, and then, when forecasting, the model is run using the selected parameters. Typically, time series of runoff and meteorological data for 3-5 or 5-10 years are required for calibration. The calibration period should include various hydrological years, both high water and low water.

Model performance assessment methodology

The HBV model, when assessing the correspondence between the simulated runoff and the observed runoff, uses the generally accepted Nash-Sutcliffe efficiency criteria (NSE) (3) (Nash, Sutcliffe, 1970: 282-290), called in model R_{eff}:

$$R_{eff} = 1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \underline{Q_{sim}})^2}, \quad (3)$$

where Q_{obs} – water discharge measured at a hydrological station; Q_{sim} – water discharge calculated with the model.

If $R_{eff} > 0.5$, then the model reproduces well the dynamics of the modeled value. When the value of $R_{eff} = 1$, then the model calculation is recognized as fully adequate. While $R_{eff} < 0$ means the model is considered invalid.

In this paper, as an alternative estimate of the efficiency of reproduction of the model of observed data, the following statistical estimates were calculated: correlation coefficient, Percent bias (4), RMSE-observations standard deviation ratio (RSR) (5) (Moriasi, 2008: 885-900):

$$PBIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * 100}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \quad (4)$$

and RMSE-observations standard deviation ratio (RSR):

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]} \quad (5)$$

where, Y_i^{obs} – water discharge measured at a hydrological station, Y_i^{sim} – water discharge calculated with the model, Y^{mean} – average water discharge measured at a hydrological station.

Percentage Systematic Deviation (PBIAS, %) calculates the average tendency for the volume of simulated data to increase or decrease compared to the observed data. The standard deviation ratio (RSR) is one of the most commonly used error indices, calculated as the ratio of the root mean square error (RMSE) and the standard deviation of the observed data.

Efficiency is evaluated according to the criteria given in *Table 2*.

Table 2 – General assessments of the effectiveness of the recommended statistics (Moriasi et.al., 2007: 885-900)

Performance rating	RSR	NSE	PBIAS, %
Very good	0.00 <RSR <0.50	0.75 <NSE <1.00	PBIAS <±10
Good	0.50 <RSR <0.60	0.65 <NSE <0.75	±10 <PBIAS <±15
Satisfactory	0.60 <RSR <0.70	0.50 <NSE <0.65	±15 <PBIAS <±25
Not Satisfactory	RSR> 0.70	NSE <0.50	PBIAS> ±25

Results and discussion

Calibration of the HBV-light model for the river basins, which are flowing into the Buktyrma reservoir, were carried out for the period 1978-2017, with the exception of the basins of the Turgysyn and Kalzhyr rivers, since the hydrological station on the river Kalzhyr has been operating since 2012 and on the river the Turgysyn water measuring device was moved in 2007, without maintaining the continuity of a series of observations. As a result of iterative calibration of the model for the entire period, periods with the best calibration parameters were selected for each catchment area. Basically, these periods are 5 years and years of different water content.

As shown in *Fig. 1*, there are practically no weather stations in the river catchment areas. In this regard, to calibrate the model were used nearby weather stations climate data; in some basins, averaged data from two or more weather stations (*Table 4*).

As a result of calibration, the threshold temperature, which simulates precipitation in snow or rain, varies from -1.5 to +2.1 °C. Depending on the location of the river basin, the degree-day factor varies from 3.0 to 9.5 mm/°C day. It should be noted that in the left-bank tributaries this factor varies between 3.0 - 5.2 mm/°C day, and in the right-bank tributary of the river Ulken Boken is 9.5 mm/°C a day, i.e. it shows that every day in low mountainous areas snow melts more, than in high mountainous areas (*Table 3*).

The model calibration results were evaluated by several performance criteria, shown in *Table 3*. The efficiency of the model calculated by the Nash-Sutcliffe criteria, according to the general statistical performance estimates, corresponds to a “very good” estimate, which varies between 0.84 - 0.92 (*Table 4*).

The standard deviation coefficient, according to the general statistical assessments of productivity, also corresponds to a “very good” assessment, which varies between 0.29 - 0.45.

The percentage systematic deviation (PBIAS) corresponds to a “very good” productivity result on the Buktyrma and Kalzhyr rivers and a “good” productivity result on the Kurshim, Naryn, Turgysyn rivers, with the exception of the river Ulken Boken which corresponds to the "satisfactory" assessment of the flow performance.

Table 3 – *Parameters* of the HBV model, generated using calibration for mountain watersheds of rivers flowing into the Buktyrma reservoir

River basin	Station	Snow routine					Soil and evaporation				Groundwater			
		TT, °C	CFMAX, mm $°C^{-1}d^{-1}$	SFCF	CWH glac	CFR aspec	FC, mm	LP	Beta	Alpha	K_1, d^{-1}	K_2, d^{-1}	PERC, mm d^{-1}	MAXBAS, d
Buktyrma	Lesnaya Pristan	+1,1	5,2	1,2	5,8	0,2	50	1,0	1,0	5,4	8,7	0,1	1,3	2,3
Ulken Boken	Dzhumba	+2,1	9,5	1,2	3,8	0,2	50	1,0	1,0	0,1	6,1	9,9	0,3	5,4
Kurshim	Voznesenkoe	-0,4	3,0	1,5	5,0	0,2	70	1,0	5,0	0,5	6,1	0,1	2,1	2,8
Naryn	Ulken Naryn	-1,5	5,2	1,1	6,5	5,7	220	0,7	2,0	0,4	7,5	0,1	5,6	3,6
Turgysyn	Kutikha	+1,0	3,0	1,5	1,3	1,2	50	1,0	0,1	0,2	0,1	0,2	6,0	2,5
Kalzhyr	Kalzhyr	-1,5	10,0	0,6	3,5	0,2	232	0,3	1,7	0,3	0,1	4,4	3,4	2,3

The optimal value of PBIAS equal to -0.99 of the Buktyrma River indicates the accurate simulation of the flow by the model. The HBV model indicates an error in understating the flow for the Ulken Boken river (+18.22%) and Turgysyn (+14.0%) rivers, and for the Kurshim, Naryn and Kalzhyr (minus 5.3 - 14.3%) indicate an error in revaluation of the flow.

Table 4 – Watershed characteristics and river calibration results

№	River basin	Station	Meteostation	Average height of station, m a.s.l.	Calibration period	Model efficiency		
						NSE or R_{eff}	PBIAS, %	RSR
1	Buktyrma	Lesnaya Pristan	Ulken Naryn, Katon-Karagai, Leninogorsk	764	1994-1998	0,921	-0,99	0,29
2	Ulken Boken	Dzhumba	Kokpekty	510	1995-2000	0,895	18,22	0,32
3	Kurshim	Voznesenkoe	Markakol	1372	1992-1997	0,873	-12,02	0,45
4	Naryn	Ulken Naryn	Ulken Naryn, Katon-Karagai, Markakol	952	1996-2001	0,907	-14,33	0,45
5	Turgysyn	Kutikha	Zyrianovsk, Leninogorsk,	615	2009-2012	0,860	14,00	0,38
6	Kalzhyr	Kalzhyr	Katon-Karagai	1081	2015-2017	0,840	-5,34	0,40

Modeling the runoff of the Buktyrma river basin showed that the model reproduces the observed runoff well, and there is also an exact match between the start date and the duration of the spring flood period. It should be noted that the model also simulates rain floods well.

It should be noted that results of calibration model for Ulken Boken river basin are given in research paper (Bolatova et.al., 2018: 110-124). The simulation results for the Ulken Boken river basin showed that the model well reproduces the simulated runoff and the duration of the spring flood period. It should be noted that the model reproduces the runoff 1–2 days later than the observed one.

The model also reproduces well the runoff, start dates and duration of the spring flood period in the Kurshim river basin, however, there is a reassessment of the runoff in the summer, on average for the entire period, the reassessment is 53.8 m^3/s, which was revealed by the PBIAS estimate.

Modeling of the flow of the Naryn river basin showed that the model also very well reproduces the start dates, duration and maximum discharges during the spring flood. However, the runoff modeling results for 2012 showed the worst results, which may be due to the construction of a hydrotransmission system with a regulatory lock on the Naryn River 0.5 km north of the village of Zhuldyz, which was put into operation at the end of 2011. There is also an overestimation of runoff in the summer and autumn months.

According to the runoff modeling results of the Turgysyn river basin, the start date model reproduces 2 days earlier or less, also captures all “peaks” (maximum discharges) during the flood period and rain floods caused by heavy precipitation.

Difficulty in calibration arose for the Kalzhyr river, since the data were only for 2013 to 2017, of which the best result was obtained for the period 2016-2017. This difficulty was also caused by the fact that since 1950 the runoff on the Kalzhyr river has been regulated by 6 hydraulic structures, mainly water intake channels. In this regard, the flow of the river is disturbed, which led to the difficulty of calibrating the flow. However, it should be noted that the result obtained corresponds to a “good” performance result. In general, for the Kalzhyr river, the model showed good reproducibility of the start date and duration of the spring flood period, with the exception of the autumn low water period, during the calibration period.

The given graphs of the relationship (*Fig. 3*) between the observed and simulated water discharges for all the considered rivers, built with daily water discharges, indicate a close relationship, where the coefficient of determination (R^2) varies within 0.82 – 0.92.

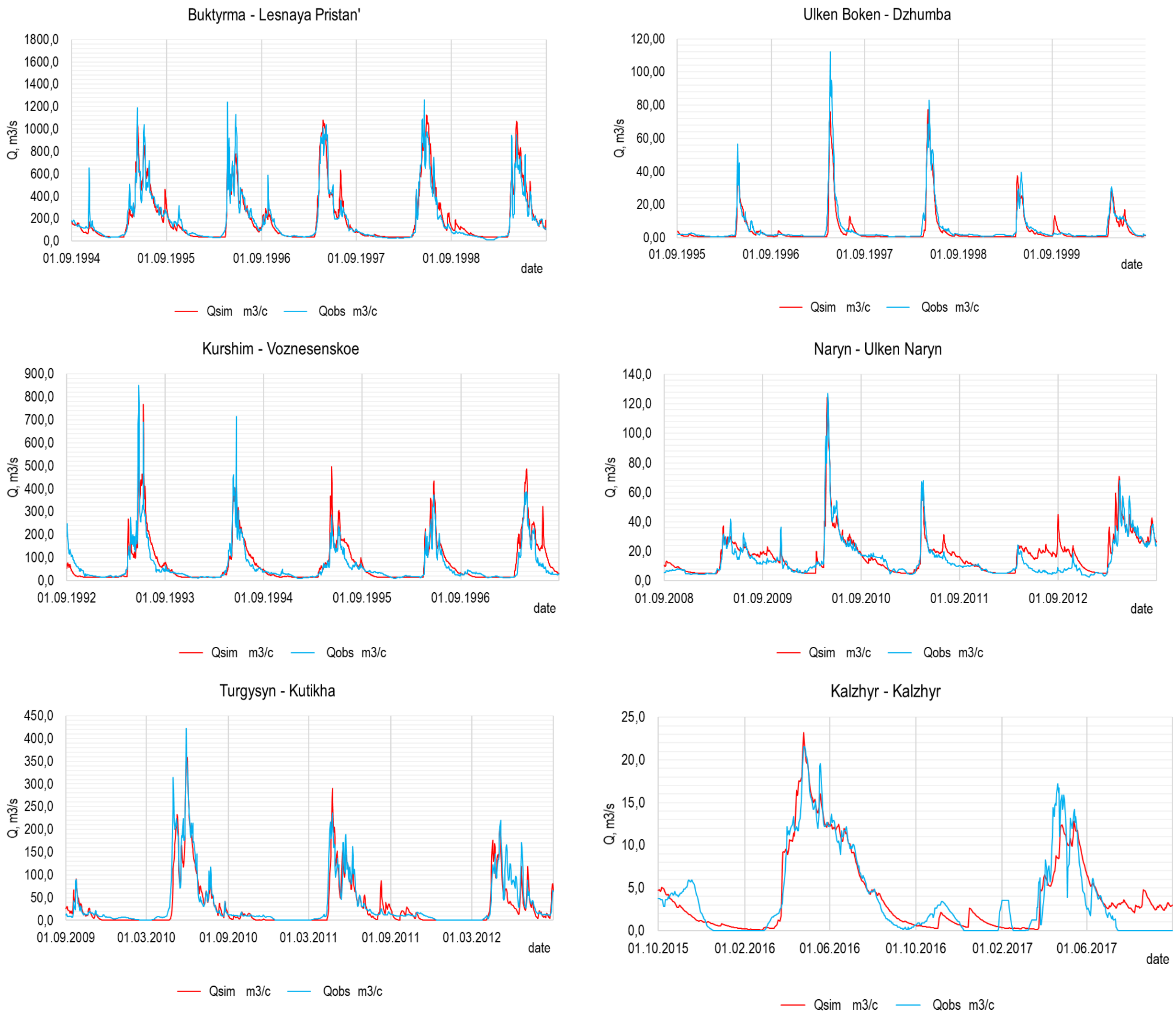

Figure 2 – Hydrograph of the results of modeling the runoff of rivers flowing into the Buktyrma reservoir

To assess the reproducibility of runoff volumes for the spring flood period, simulated flood volumes for the model calibration period were calculated. The flood volumes are calculated based on the dates of the beginning and end of the flood indicated in the long-term data on the regime and resources of land waters, issued by the RSE "Kazhydromet. According to the results of calculations, the average error of the model for the Buktyrma River averaged 8.0 %, for the river Ulken Boken – 15.6 %, Kurshim – 22.8 %, Naryn – 11.8 %, Turgysyn – 5.6 %, Kalzhyr – 3.5 %.

In order to check the calibration parameters of the model for an independent period, validation was carried out for the considered rivers for 2018-2020 period (*table 5*). The validation results showed that for the rivers Buktyrma and Ulken Boken, the calibrated model meets the "very good" performance rating for all criteria, recommended statistics, NSE, PBIAS and RSR. The NSE efficiency criterion is 0.87 and 0.86, respectively, for p. Buktyrma and Ulken Boken. The percentage error of the model for the period under review was 1.3 and -7.8 %, respectively, and the RSR coefficient was also 0.37 for both rivers.

For the remaining 4 rivers basins, the results for all performance criteria showed an "unsatisfactory" assessment of reproducibility.

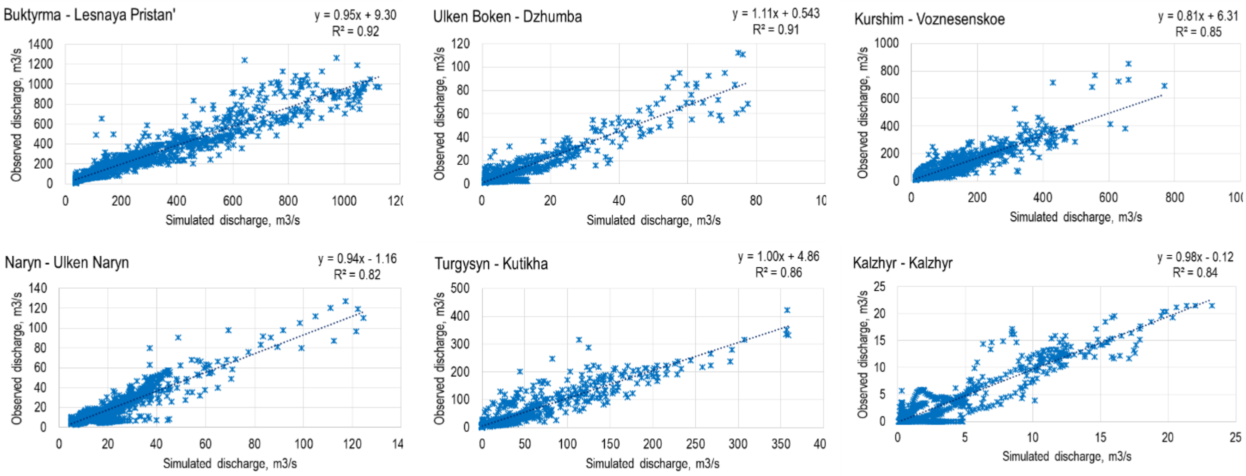

Figure 3 – Graphs of the relationship between simulated and observed data

Table 5 – Model validation results for the period 2018-2020

№	River basin	Station	Effectiveness for daily discharge			Water discharge, m³/s					
						2018		2019		2020	
			NSE	PBIAS, %	RSR	Qsim	Qobs	Qsim	Qobs	Qsim	Qobs
1	Buktyrma	Lesnaya Pristan	0,87	1,3	0,37	236	219	228	218	206	208
2	Ulken Boken	Dzhumba	0,86	-7,8	0,37	5,11	5,21	7,56	6,01	8,63	9,74
3	Kurshim	Voznesenkoe	0,12	-33,2	0,94	89,4	64,7	84,1	59,3	79,1	74,9
4	Naryn	Ulken Naryn	-0,62	-58,3	1,27	16,5	14,5	15,9	11,7	15,7	8,23
5	Turgysyn	Kutikha	0,04	-26,6	0,98	42,4	44,4	45,1	42,7	43,1	21,7
6	Kalzhyr	Kalzhyr	0,02	25,9	0,99	12,2	31,4	12,5	25,7	11,9	12,2

In the daily context, the results showed very low indicators, which can be explained with the impact of economic activity on the water regime of river basins. The validation results for the Buktyrma and Ulken Boken river basins showed «very good» results. For the Kurshim, Naryn and Turgysyn river basins the results were unsatisfactory, but a comparison of monthly and annual values of water consumption showed not bad results (*table 5*).

The Kalzhyr River, which is most susceptible to economic impacts, has shown that the influence of human activity is very great for reproducing the flow hydrograph.

Conclusions

The results of runoff modeling using the HBV-light conceptual model showed that the model for rivers flowing into the Buktyrma reservoir reproduces well the dynamics of the simulated runoff, this can be judged by the performance criteria NSE, RSR, PBIAS, as well as the coefficient of determination R^2, which correspond to "very good" and "good" performance ratings.

Given the sparse network of meteorological stations and the overregulation of some rivers, the application of the HBV-light model showed good results in runoff modeling for mountain rivers in Kazakhstan.

The results of modeling the Buktyrma and Ulken Boken rivers can be used for forecasts in the daily section. For the Kurshim, Naryn and Turgysyn rivers, the results showed that it is possible to use them to assess water resources on an annual or monthly basis. But for the Kalzhyr River validation showed that the results aren’t applicable for future modeling.

References

Berglöv Gitte, Jonas German, Hanna Gustavsson, Ulrika Harbman and Barbro Johansson (2009). Improvement HBV model Rhine in FEWS Final report, Hydrology, №112, 10.

Bergstörm, S. (1992). The HBV model – its structure and applications. SMHI Reports RH, No. 4, Norrkping, Sweden.

Bolatova, A., Tillakarim, T., Raimzhanova M. (2019). Application of the hydrological model HBV to predict river flow on the example of the lateral inflow of water into the Shulba reservoir (Primenenie gidrologicheskoj modeli HBV dlya prognozirovaniya stoka rek na primere bokovogo pritoka vody v Shul'binskoe vodohranilishche). Hydrometeorology and Ecology, (3), 26-43.

Bolatova, A., Tillakarim, T., Serikbay, N., Raimzhanova M., Bagitova M., Bolatov, K. (2018). Results of calibration of the hydrological model HBV for mountain rivers of Kazakhstan (Rezul'taty kalibrovaniya gidrologicheskoj modeli HBV dlya gornyh rek Kazahstana). Hydrometeorology and Ecology, (3), 110-124.

Choduraev T.M., Galaeva A.V. (2016). Modeling the flow of the Ili River using the HBV model based on various climate change scenarios (Modelirovanie stoka reki Ili s pomoshch'yu modeli HBV na osnove razlichnyh scenariev izmeneniya klimata) // Science, New Technologies and Innovations of Kyrgyzstan, No. 10, 43-46.

Fleiscmann Ayan, Vinicius Siqueira, Paris Adrien, Collischonn Walter, Paiva Rodrigo, Pontes Paulo, Jean-Francois Cretaux, Berge-Nguyen Muriel, Biancamaria Sylvain, Gosset Marielle, Calmant Stephane, Tanimoun Bachir (2018). Modelling hydrologic and hydrodynamic processes in basins with large semi-arid wetlands Journal of Hydrology 561, 943-959.

Forero-Ortiz E., Martínez-Gomariz E., Monjo R. (2020). Climate Change Implications for Water Availability: A Case Study of Barcelona City. *Sustainability*. 12(5): 1779. https://doi.org/10.3390/su12051779.

Galaeva A.V. (2013). On the possibility of using the HBV model for modeling the flow of the Ili and Irtysh rivers (O vozmozhnosti primeneniya modeli HBV dlya modelirovaniya stoka rek Ili i Irtysh) // hydrometeorology and Ecology, No. 2, 108-114.

Golubtsov V.V. (2010). Modeling of the flow of mountain rivers in conditions of limited information (Modelirovanie stoka gornyh rek v usloviyah ogranichennoj informacii). – Almaty, 2010. – 232 p.

Huang Shaochun, Eisner Stephanie, Magnusson Jan Olof, Lussana Cristian, Yang Xue, Beldring Stein (2019). Improvements of the spatially distributed hydrological modelling using the HBV model at 1 km resolution for Norway, Journal of Hydrology, Volume 577, 123585, https://doi.org/10.1016/j.jhydrol.2019.03.051.

Jansen, K. F., Teuling, A. J., Craig, J. R., Dal Molin, M., Knoben, W. J. M., Parajka, J., et al. (2021). Mimicry of a conceptual hydrological model (HBV): What's in a name? Water Resources Research, 57, e2020WR029143. https:// doi.org/10.1029/2020WR029143.

Kishkimbayeva, A., Bolatova, A. (2015). Application of the HBV-light model for modeling the flow of the Sharyn River (Primenenie modeli HBV-light dlya modelirovaniya stoka reki Sharyn). Hydrometeorology and Ecology, (4), 141-144.

Lindström G. and S. Bergström (1992). Improving the HBV and PULSE-models by use of temperature anomalies. Vanneti Norden, 25(1): pp. 16–23.

Lindström, G. (1997). A simple automatic calibration routine for the HBV model. Nordic Hydrology, 8(3): 153–168.

Lindström, G. and J. Harlin (1992). Spillway design floods in Sweden. II: Applications and sensitivity analysis. Hydrological Science Journal, 37(5):521–539.

Moradkhani H., Sorooshani S. (2008). General review of rainfall-runoff modeling: model calibration, data assimilation, and uncertainly analysis, Hydro Model Water Cycle. 63, 1-24.

Moriasi, M., D.N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, *50*(3), 885-900.

Nash J.E. and Sutcliffe J.V. (1970). River flow forecasting through conceptual models, part 1-a discussion of principles, Journal of Hydrology, 10, 282-290 p.

Peel, M. C. and McMahon, T. A. (2020). Historical development of rainfall-runoff modeling, Wiley Interdiscip. Rev. Water, 7, 1–15, https://doi.org/10.1002/wat2.1471.

Seibert J. (2005). HBV light version 2. User’s manual. Stockholm University, Department of Physical Geography and Quaternary Geology, 32 p.

Seibert J. and Bergstrom S. (2021). A retrospective on hydrological modelling based on half a century with the HBV model // Hydrology and Earth system sciences, 1-28 p. https://doi.org/10.5194/hess-2021-542.

Seibert, J. and Vis, M. J. P. (2012). Teaching hydrological modeling with a user-friendly catchment-runoff-model software package, Hydrol. Earth Syst. Sci., 16, 3315–3325, https://doi.org/10.5194/hess-16-3315-2012.

Shivareva, S., Avezova A. (2015). Application of the HBV model for calculating the flow of p. Both are for the future, taking into account climate change (Primenenie modeli HBV dlya raschyota stoka r. Oba na perspektivu s uchyotom izmeneniya klimata). Hydrometeorology and Ecology, (4), 66-72.

Singh, V.P. (1995). Computer Models of Watershed Hydrology, Water Resources Publications, Colorado, 1144 pp.

SNA, (1995). Climate, Lakes and Rivers, The National Atlas of Sweden, Almqvist and Wiksell International, Stockholm.

Valent P., Szolgay J., Riverso C. (2012). Assesment of the uncertainties of a conceptual hydrologic model by using artificially generated flows. Slovak journal of civil engineering, Vol. XX, №4, 35-43.

World Meteorological Organization (2003). Integration and Coupling of Hydrological Models with Water Quality Models: Applications in Europe (B. Arheimer and J. Olsson). WMO Technical Reports in Hydrology and Water Resources, No. 75. WMO/TD-No. 1174. Geneva.

World Meteorological Organization. (2012). Guide to hydrological practice. Volume 2. Water resources management and the practice of applying hydrological methods (WMO-No. 168, Sixth Edition). Geneva: World Meteorological Organization, 320.