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Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
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КАЗАХСТАН»
ЧФ «Халық»

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В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением, Благотворительный Фонд «Халык»!

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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MODELLING RIVER DISCHARGE FOR THE OBA AND ULBI RIVER BASINS USING THE SWIM MODEL

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Abstract. The Shulbinsk Hydroelectric Power Plant (HPP) located on the Irtysh River in the eastern part of Kazakhstan is one of the largest and oldest hydropower plants in the country. The efficiency of water management systems in the Shulbi reservoir heavily depends on discharge of the Oba and Ulbi rivers, which are the right-hand tributaries of the Irtysh River. This region is characterized by a sparse network of observation stations, which do not allow to fully represent hydrological processes occurring in the area, and therefore planning of adaptation measures related to climate change could be problematic. To overcome this limitation, our study uses the available high-resolution global climate dataset WATCH and explores the possibility of using the Soil and Water Integrated Model (SWIM) to predict river discharge in the basins of the Oba and Ulbi rivers. SWIM was calibrated and validated for the entire Oba and Ulbi river basins. The period from 1962 to 1971 was used as a calibration period, and the period from 1972 to 2016 as a validation period considering every decade separately. The Nash and Sutcliffe efficiency (NSE) and relative volume error (RVE) were used to assess performance of the model. The calibration results showed a good agreement between the modeled and observed discharge with NSE of 0.86 and RVE of 5.6 % for the Oba River and NSE of 0.84 and RVE of 0.2 % for the Ulbi River. The analysis of modelling results shows that also the high flow indices Q10 and Q5 corresponding to 90th and 95th percentiles, respectively, are represented sufficiently well by the model SWIM. Based on the obtained results, we can conclude that the model could be successfully applied for predicting discharge and high flows of both rivers in the coming decades, and for projecting discharge in the future under climate change scenarios.

Keywords: Oba, Ulbi; hydrological modelling; SWIM; river basin; calibration, validation, high flow indices

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SWIM МОДЕЛІ НЕГІЗІНДЕ ОБА ЖӘНЕ ҮЛБІ ӨЗЕНДЕРІНІҢ АҒЫНДАРЫН ҮЛГІЛЕУ

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Анноттация. Қазақстанның шығыс бөлігінде Ертіс өзенінде орналасқан Шүлбі су электр стансасы (СЭС) мемлекеттің ең үлкен және көне су электр стансаларының бірі болып табылады. Шүлбі су қоймасының су ресурстарын басқару жүйесінің тиімділігі Ертіс өзенінің оң жақ салалары Оба және Үлбі өзендерінің ағынына айтарлықтай тәуелді. Бұл аймақ болып жатқан гидрологиялық үдерістерді толығымен айқындауға мүмкіндік бермейтін сирек орналасқан бақылау бекеттер жүйесімен сипатталады. Осыған орай, климаттың өзгеруіне байланысты адаптациялық шараларды жоспарлау күрделі болуы мүмкін. Аталған шектеулерді асу мақсатында біздің зерттеулерімізде ажыратымдылығы жоғары WATCH климаттық деректер жиынтығы қолданылады және Оба мен Үлбі өзендерінің алаптарында ағынды болжау мақсатында топырақ пен судың біріктірілген моделінің (SWIM) қолдану әдістері қарастырылады. SWIM Оба мен Үлбі өзендерінің барлық бассейндеріне сұрыпталды және валидацияланды. Сұрыптау кезеңі ретінде 1962 жылдан бастап 1971 жылға дейін, ал 1972 жылдан бастап 2016 жылға дейін әр онжылдықты жеке ескере отырып валидация кезеңі ретінде пайдаланды. Нэш пен Сатклифф тиімділігі (NSE) және көлемнің қатысты қателігі (RVE) модельдің өнімділігін бағалау үшін қолданылды. Сұрыптау нәтижелері Оба өзені бойынша NSE 0,86 мен RVE 5,6 % және Үлбі өзені бойынша NSE 0,84 мен RVE -0,2 % мәндерімен сәйкесінше модельденген және өлшенген су өтімдерінің арасында жақсы сәйкестігін көрсетті. Модельдеу нәтижелерінің сараптамасы 90 мен 95 процентильдеріне сәйкес Q10 мен Q5 жоғары ағын индекстері де SWIM моделімен айтарлықтай жақсы ұсынғанын көрсетеді. Алынған нәтижелер негізінде модель екі өзеннің де ағындарын алдымыздағы онжылдықтарға болжауында және де болашақта климаттың өзгеруінің әртүрлі сценарийлері бойынша ағынын болжауында пайдалануға мүмкіндік береді деп тұжырымдауға болады.

Түйін сөздер: Оба, Үлбі; гидрологиялық үлгілеу; SWIM; өзен алабы; сұрыптау; валидация; максималды ағын индексі

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МОДЕЛИРОВАНИЕ РЕЧНОГО СТОКА БАССЕЙНОВ РЕКИ ОБА И УЛЬБИ С ИСПОЛЬЗОВАНИЕМ МОДЕЛИ SWIM

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Анноттация. Шульбинская гидроэлектростанция (ГЭС), расположенная на реке Иртыш в восточной части Казахстана, является одной из крупнейших и старейших гидроэлектростанций страны. Эффективность систем управления водными ресурсами Шульбинского водохранилища во многом зависит от стока рек Оба и Ульби, которые являются правыми притоками Иртыша. Этот регион характеризуется разреженной сетью наблюдательных пунктов, которые не позволяют в полной мере отображать гидрологические процессы, происходящие в районе, в связи с чем планирование адаптационных мероприятий, связанных с изменением климата, может быть проблематичным. Чтобы преодолеть это ограничение, в нашем исследовании используется доступный глобальный набор климатических данных высокого разрешения WATCH и изучается возможность использования интегрированной модели почвы и воды (SWIM) для прогнозирования речного стока в бассейнах рек Оба и Ульби. Model SWIM была откалибрована и валидирована для бассейнов рек Оба и Ульби. Период с 1962 по 1971 год был использован в качестве периода калибровки, а период с 1972 по 2016 год – в качестве периода валидации с учетом каждого десятилетия в отдельности. Эффективность Нэша и Сатклиффа (NSE) и относительная ошибка объема (RVE) использовались для оценки качества моделирования. Результаты калибровки показали хорошее соответствие смоделированного и наблюдаемого расхода воды при NSE 0,86 и RVE 5,6 % для реки Оба и NSE 0,84 и RVE -0,2 % для реки Ульби. Анализ результатов моделирования показывает, что и индексы высокого стока Q10 и Q5, соответствующие 90-му и 95-му процентилям соответственно, достаточно хорошо представлены моделью SWIM. На основании полученных результатов можно сделать вывод, что модель может быть успешно применена для прогнозирования стока обеих рек в ближайшие десятилетия, а также для прогнозирования стока в будущем при различных сценариях изменения климата.

Ключевые слова: Оба, Ульби; гидрологическое моделирование; SWIM; бассейн реки; калибровка, валидация, индексы максимального стока

Introduction

Kazakhstan has set the plan to become carbon-neutral state by 2060. With rapid population and economy growth the finding of new sources of green energy is vital. Accordingly, the further development and modernization of green energy sources, including hydroelectric power plants, is a promising direction now. The Shulbinsk hydro-power plant (HPP) is located 70 kilometers from the city of Semey, it is the third station in the Irtysh HPP cascade and the largest in Kazakhstan in terms of installed capacity. The water management systems in the Shulbi reservoir depend on water supply from the Oba and Ulbi rivers, which are tributaries of the Irtysh river (Fig. 1). The main function of the Shulbinsk HPP is generation of electricity, and other functions include compensatory regulation of the Irtysh river discharge, accumulation of runoff from the Ulbi and Oba rivers, and spring flooding of floodplain meadows in the Pavlodar region. Therefore, a competent management of water resources in this region is very important.

River flow forecasting is one of the measures used in water resource management to address climate uncertainty, as well as in the management of water uses such as hydropower, water supply, irrigation, navigation, flood control and environmental protection (WMO, 2002). Forecasting floods caused by melting of snow and ice in spring and heavy rains and wind waves in areas along the coast and estuaries (Merkuryeva et al., 2015) is a complex area of operational hydrology. The calculation and forecasting of river flow using existing traditional methods become ineffective under the conditions of already noticeable global climate changes, reduction of the network of hydrometeorological monitoring stations, and violation of homogeneity of the observation time series due to significant anthropogenic load on individual river catchments causing changes in their water regime. There are practically no reliable methods for predicting runoff of ungauged and poorly monitored rivers. A successful solution of many hydrological problems requires development of new methodological tools for studying conditions of runoff formation and implementation of forecasting schemes. One of the promising ways is the mathematical modelling of river runoff based on the landscape-hydrological principles using modern geoinformation technologies and hydrological modelling capabilities.

Standard tools such as hydrological and ecohydrological models are used to study hydrological processes and support flood forecasting, effective water management and water quality assessment considering nutrient cycling, erosion and sedimentation (Gayathri, 2015). Such models can assess potential changes in hydrological processes under land use and climate change. Hydrological models, being important and necessary tools for managing water resources, vary substantially in their spatial disaggregation and level of complexity — from simple lumped models with a few parameters to semi-distributed and distributed models with thousands of spatial elements and tens to hundreds of parameters in each (Vinogradov and Vinogradova, 2010). For example, Kauffeldt et al. (2016) provide a technical review of large-scale hydrological models for implementation in operational flood forecasting schemes at the continental level.

Recently, several studies, which included modelling of the river basins in Kazakhstan using modern models of runoff formation and General Circulation Models (GCMs), were published. The authors of the article by Shahgedanova et al. (2020) investigated the impacts of projected climate and glacier change on river discharge of five glacierized catchments in the northern Tien Shan, Kazakhstan, using a conceptual hydrological model HBV-ETH. Their results suggest that peak flow in the region occurs in the first quarter of the 21st century. Glaciers are projected to lose 34–39 % of their area by 2095. Total river discharge in July–August is projected to decline by 20–37 % in the catchments with low (2–4 %) glacierization by 2095. In the catchments with high glacierization (16% and more), no significant changes in summer discharge are expected while spring discharge is projected to increase.

The article by Rakhimova et al. (2020) based on Climate Elasticity Method and General Circulation Model (GCM) concluded that changing climatic conditions would influence the hydrological cycle in the Buqtyrma river basin. Authors calculated runoff in three different elevation zones over the last 65 years (1950–2015) to detect variations and clarify the effects of climatic factors on runoff in the Buqtyrma basin. The study was split into two periods: period 1950–1982 and human-influenced period 1983–2015. The impacts induced by climate change on runoff for the period 1950–2015 were as follows: 70 % increase in the upstream, 62.11 % increase in the midstream and 15.34 % increase in the downstream areas. The impacts of human activities on runoff were higher in the downstream area (84.66 %) than in the upstream and midstream areas.

In the paper by Didovets et al. (2021) the possibility of using the Soil and Water Integrated Model (SWIM) for eight watersheds located in Central Asia under the conditions of climate change was studied. This paper considers two watersheds located in Kazakhstan: the Zhabay river basin (Northern Kazakhstan) and the Bukhtarma river basin (Eastern Kazakhstan), as well as the Aspara river basin, partially located on the territory of Kyrgyzstan. The results obtained in this paper indicate a clear trend towards an increase in runoff in Zhabay. Seasonal changes are characterized by a shift in the peak flow of the river up to one month, a reduction in the period of snow accumulation, and a decrease in water flow in the summer months.

The article by Lobanova et al. (2021) analyzes how the impact of climate change on the hydrological regime and temperature regime can affect irrigated agricultural production in the Aspara (located partly in Kazakhstan and partly in Kyrgyzstan) and Isfara (in Tajikistan and Kyrgyzstan) river basins. Modelling results using SWIM and climate change scenarios (RCP4.5 and RCP8.5) show that climate change will create adverse conditions for irrigated spring crops due to reduced water flow during the growing season. On the other hand, the projected shift of peak flow to an earlier date benefits irrigated winter crops by providing more water for spring irrigation.

Our current study aims at assessment of the possibility of using the model SWIM for modelling river discharge of the Oba and Ulbi rivers. In spring, high flows on rivers originating in mountains could be dangerous, leading to risk of flooding. As modelling and prediction of high flows and floods are very important for our study region, the ability of SWIM to reproduce high flows should be also checked. Therefore, specific objectives were threefold: (1) to assess the performance of the WATCH Era Interim meteorological data (Weedon et al., 2011) in comparison with the observational meteorological data in the study area, (2) to evaluate results of calibration and validation of SWIM driven by the WATCH Era Interim data in comparison with the measured discharge data in the Oba and Ulbi, and (3) to compare the high flow indices Q5 and Q10 corresponding to 95^{th} and 90^{th} percentiles of water flow, respectively, estimated for every year based on the simulated and observed time series for the both rivers.

Study Area. The rivers Oba and Ulbi located in the eastern part of Kazakhstan (Fig. 1) are the right-hand tributaries of one of the main rivers in Kazakhstan, Irtysh, which is the chief tributary of the Ob River. The Oba is formed from the confluence of the Black and White Oba rivers, and the Ulbi is formed from the confluence of the Gromotukha and Tikhaya rivers, all four originating in the mountains of the Western Altai. The main characteristics of the Oba and Ulbi river basins are given in Table 1. The glaciers are located in the highland parts of the catchments and occupy 0.05 % and 0.04 % of the total catchment areas of the Oba and Ulbi, respectively. The rivers are mainly fed by snow melting (up to 50 %), and also from glaciers melting and precipitation. A stable ice cover in both rivers is formed in November — December, and it melts in April.

The climate in the basins is continental with cold winters and hot summers. The average annual temperature is about 7°C, the average temperature in January is about -15.3°C, and 20.5°C in July in the lower part of the basins, which was estimated as average values from three stations located in lowland (Fig. 1). The distribution of precipitation over the catchment areas is not uniform: it is varying from 300 mm a^{-1} in the lowland part of the basins (steppe zone) to 1000-1200 mm a^{-1} in the highlands. About 60–75 % of the annual precipitation over the area occur in the warm season (April to September) reaching about 600–800 mm in highlands during this period.

The major land use types in the considered river basins are represented by cropland, forest and grassland (see Table 1).

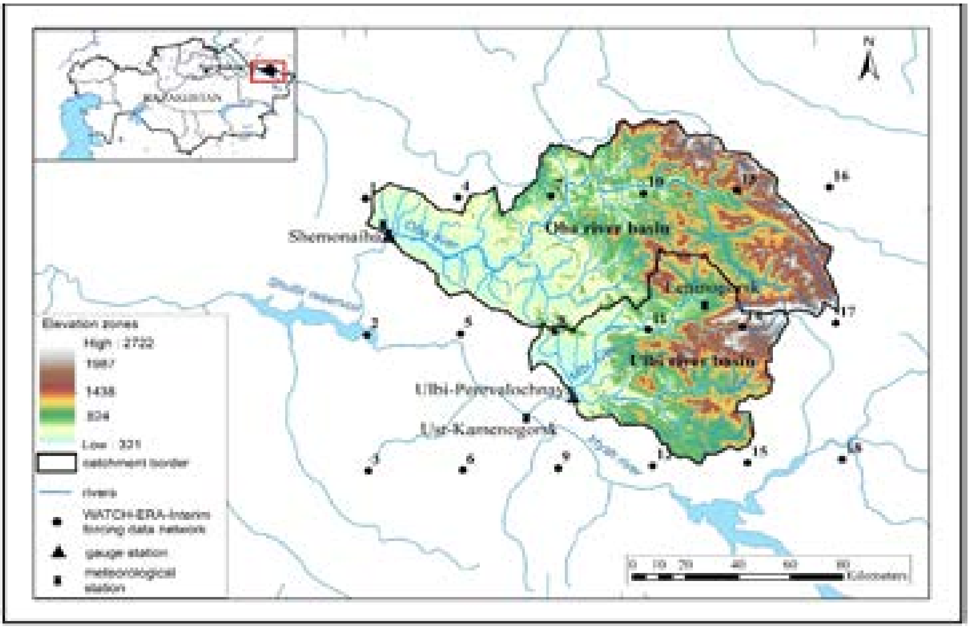

Fig. 1. The Oba and Ulbi river basins

Table 1 - The main characteristics of the Oba and Ulbi river basins

	Oba	Ulbi
Catchment area, km^2	8888	4858
River length, km	278	100
Mean discharge, m^3/s (1984-2010)	164	88
Elevation, max and mean, m	2622 1195	2722 1201
Gauging stations close to the river mouth	Shemonaikha	Ulbi Perevalochnaya
Dominant land use types (in % of the total basin area)	forest (42%) cropland (27%) heather (17%) grassland (13%)	grassland (34%) cropland (30%) heather (20%) forest (15%)

Materials and methods

Input datasets. For calibration and validation of the SWIM model the following input data are needed: topographic map, land use map, soil map with soil parameters and daily meteorological data, as well as river discharge data for comparison with the simulated discharge. All the required time series were obtained for the period from 1962 to 2016.

For topographic data, a Digital Elevation Model (DEM) with 90 m-resolution obtained from the Shuttle Radar Topography Mission website was used. The land use data were obtained from the CORINE Land Cover database, and soil data were downloaded from the European Soil Data Centre. Based on the DEM, sub-basins (43 for the Oba and 23 for the Ulbi) were delineated for two study catchments. By overlaying the sub-basin, land use and soil maps using GRASS GIS program, an additional map of hydrotopes within each sub-basin with their unique soil and land use types was generated as input for the SWIM model.

Hydrological data consists of daily water discharge, which was collected for the gauge stations located in the villages Shemonaikha (289 m a.s.l.) and Ulbi Perevalochnaya (322 m a.s.l.) (see Fig. 1) for the Oba and Ulbi rivers, respectively.

The network of meteorological stations in the study area is sparse: there is only one station, Leninogorsk (809 m a.s.l.), in the Ulbi catchment and one close to it, Ust-Kamenogorsk (287 m a.s.l.), and one station in the outlet of the Oba catchment, Shemonaikha (310 m a.s.l.) (Fig. 1), and there are no stations in the mountainous parts. Therefore, it was decided to use the WATCH Era-Interim reanalysis climate data (ERAI; Dee et al., 2011) which can be easily applied as input by SWIM. The WATCH data averaged on the daily basis cover the entire globe at 0.5° horizontal resolution, and 18 grid points are located within or close to our study area. In our study the following daily WATCH data were used: average, maximum and minimum temperatures, precipitation, wind speed, air humidity and solar radiation.

Before using the WATCH data for modelling, an analysis of comparability between the data derived from three meteorological stations and the virtual meteorological stations (WATCH) located close to them was done. The meteorological data: daily temperature and precipitation were collected from the three meteorological stations and downloaded from the WATCH website (see Weedon et al., 2011). The correlation analysis between these two datasets was conducted for the period from 1980 until 2016. The locations of all considered meteorological and hydrological stations are shown in Fig. 1.

SWIM model. The Soil and Water Integrated Model (SWIM) is an eco-hydrological process-based model for modelling hydrological processes, vegetation and nutrient cycling processes at the river basin scale. SWIM is based on two previously developed models: SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989). A detailed description of the model is presented in Krysanova et al. (2000). The input data of the model are daily precipitation, solar radiation, relative air humidity, and minimum, maximum and average air temperatures. The model uses a three-level disaggregation scheme: basin - sub-basins - hydrotopes. The hydrotopes are homogeneous spatial sets of units within a sub-basin obtained by overlaying sub-basin, soil and land use maps. The model has been successfully applied to many river basins in Europe, Asia, Africa and America (Krysanova et al., 2015; Didovets et al., 2019; Didovets et al., 2021; Koch et al., 2013; Liersch et al., 2018; Lobanova et al., 2021).

Calibration and validation. The reliability of results of hydrological watershed models is directly dependent on their performance, which is usually tested applying a calibration and validation procedure using measured data for comparison with the simulated model outputs. The calibration is usually a search for a single optimal set of parameters. The calibration requires time series of river discharge and meteorological data for 5–10 years, and the calibration period should include various hydrological years, both wet and dry. Various criteria of fit are used to assess the consistency of the simulated river flow in comparison with the observed river flow, such as visual assessment and statistical criteria. In our study, two statistical criteria were used to assess relationship between the simulated and observed discharges: the Nash–Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970) and the relative volume error (RVE):

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_{obs} - Q_{sim})^2}{\sum_{t=1}^{T}(Q_{obs} - \overline{Q_{obs}})^2}$$

$$RVE = (\frac{\overline{Q_{sim}}}{\overline{Q_{obs}}} - 1) \cdot 100$$

where Q_{obs} is the observed monthly or daily discharge, $\overline{Q_{obs}}$ is the mean of observed monthly or daily discharge, Q_{sim} is the simulated monthly or daily discharge and $\overline{Q_{sim}}$ is the mean of the simulated monthly or daily discharge. The NSE is an efficiency criterion, which relates a sum of squared differences between the observed and simulated discharges to the variance of the observed discharge, and it varies from minus infinity to 1.0, where 1.0 indicates a perfect fit. The RVE is the total deviation between the observed and simulated volumes of water discharged, expressed in percent, and it can vary from −100 to +inf, where 0 indicates a perfect fit. After the calibration, validation is performed for another, independent period.

In our case study, the calibration was carried out for the Oba and Ulbi rivers based on observational data from the hydrological stations Shemonaikha (Oba) and Ulbi Perevalochnaya (Ulbi) for the period 1962–1971, and validation for the period 1972–2016. For the Ulbi river basin, the year 2002 was excluded due to the lack of the observed discharge data. The calibration was firstly done manually, with a sequential refinement applying the automatic calibration tool PEST (Doherty, 2002). The calibration included refinement of nine parameters, which were constant over the entire basin: evapotranspiration correction coefficient, base flow factor, groundwater delay factor, two routing coefficients, two parameters related to snow fall and snow melt, and precipitaiton and temperature elevation correction factors.

Results

Comparison of observational climate data with WATCH. The comparison of annual precipitation and average daily temperature between the observational time series from three meteorological stations and the nearest to them WATCH grid points was assessed for the period of 1980–2016. The results of the correlation analysis are presented in Fig. 2. According to the obtained results, a high correlation between the observed and WATCH annual precipitation was found for the Leninogorsk (R^2 = 0.79) and Shemonaikha (R^2 = 0.81) stations. A lower correlation between those two data sets was estimated for Ust-Kamenogorsk (R^2 = 0.53), which can be explained by the large difference in altitude between the centre of grid point (659 m a.s.l.) and the Ust-Kamenogorsk meteorological station (287 m a.s.l.). The comparison of observed daily temperature with that in the WATCH time series showed a strong correlation for all three stations, with R^2 varying from 0.95 to 0.97 (see Fig. 2). A quite high correlation between the observed time series and the WATCH data suggests that the meteorological parameters from WATCH with better spatial distribution (18 grid points) can be applied in SWIM for calibration/validation and further analysis.

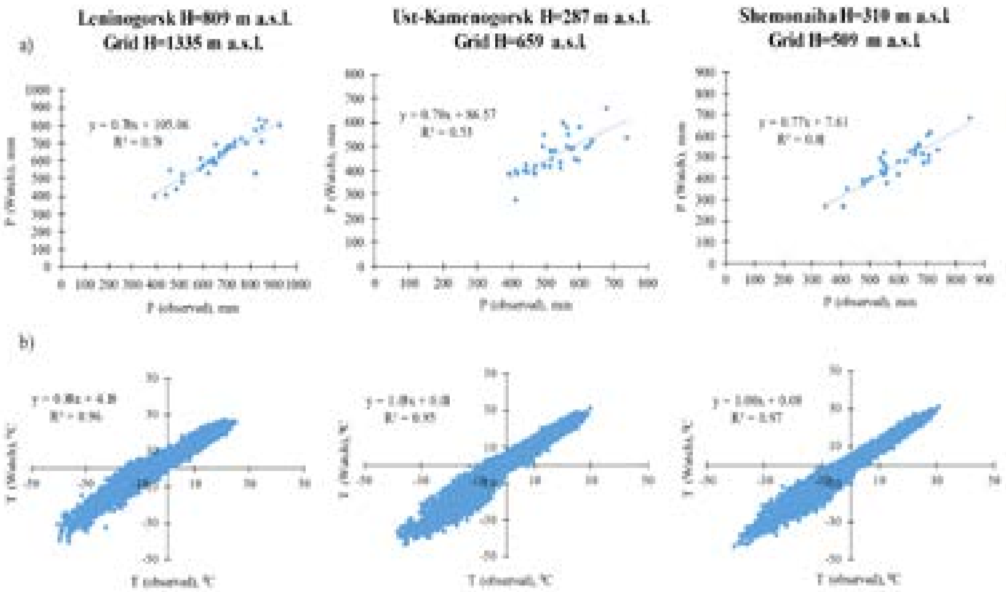

Fig. 2. Comparison of annual precipitation (a) and average daily temperature (b) of the WATCH climate data with the observed climate data for Leninogorsk, Ust-Kamenogorsk and Shemonaiha stations in the historical period 1980–2016

SWIM calibration and validation. Figures 3 and 4 show a comparison of the simulated and observed discharges for the Oba and Ulbi rivers considering monthly dynamics in the calibration period and in one of the validation sub-periods (left) and the long-term mean daily dynamics during the whole calibration and validation periods (right). The monthly dynamics is simulated quite well in the calibration period with NSE = 0.86, and RVE = 5.6 % for the Oba river, and NSE = 0.84, and RVE = -0.2 % for Ulbi river. The validation periods are represented by 2002-2011 for the Oba, and 1992-2001 for the Ulbi showing sufficiently high performance as well (NSE = 0.92, RVE = -0.9% and NSE = 0.96, RVE = -6.1 %, respectively).

The long-term average daily dynamics (Fig. 3 and 4, right) is also simulated quite well for the both catchments. Both rivers have higher discharge from April to June with a maximum at the end of April or beginning of May due to snow and glaciers melting and higher precipitation during this period. For example, the maximum average monthly discharge for the Oba and Ulbi were 1157 m^3/s (in May 1979) and 767 m^3/s (in May 1966), respectively. Other months are characterized by lower values of river discharge. The minimum flow rates are observed in the winter months (4–11 m^3/s in the Oba and

7–10 m^3/s in the Ulbi), which is lower than in May by two orders of magnitude. We can conclude that the SWIM model was able to reproduce well the monthly and long-term mean daily dynamics of discharge for both studied river basins.

The results of calibration and validation in terms of criteria of fit are summarized in Table 2. The calibration showed good fit of the simulated data with the observed ones at Shemonaiha and Ulbi Perevalochnaya. The validation for both catchments was performed for 1972–2016, separately for four decades 1972–1981, 1982–1991, 1992–2001, 2002–2011 and for 2012–2016 (excluding year 2002 for the Ulbi). The validation results with the monthly time step for two basins are "very good" (NSE higher or equal 0.86 for the Oba and higher or equal 0.88 for the Ulbi) according to the classification of Moriasi et al. (2007) in all validation sub-periods.

Table 2 - The Nash-Sutcliffe efficiency and Relative Volume Error values for the calibration and validation periods with the monthly and daily time step for the case study basins.

River		Time period	Nash-Sutcliffe Efficiency (monthly)	Relative volume Error, % (monthly)	Nash-Sutcliffe Efficiency (daily)	Relative volume Error, % (daily)
Oba						
	Calibration	1962-1971	0.86	5.6	0.76	5.7
	Validation	1972-1981	0.9	-2.9	0.8	-3.0
		1982-1991	0.89	-13.2	0.8	-13.2
		1992-2001	0.86	2.2	0.74	2.2
		2002-2011	0.92	-0.9	0.81	-0.9
		2012-2016	0.94	-9.6	0.9	-9.6
Ulbi						
	Calibration	1962-1971	0.84	-0.2	0.76	-0.02
	Validation	1972-1981	0.92	-4.2	0.84	-4.2
		1982-1991	0.91	-3.1	0.83	-3.0
		1992-2001	0.9	-3.2	0.82	-3.1
		2003-2011	0.96	-6.1	0.87	-6.0
		2012-2016	0.88	-3.8	0.87	-3.8

The calibration and validation results show a good agreement between the simulated by SWIM and observed discharges, and a possibility of using reanalysis data WATCH Era Interim for hydrological modelling in the study area.

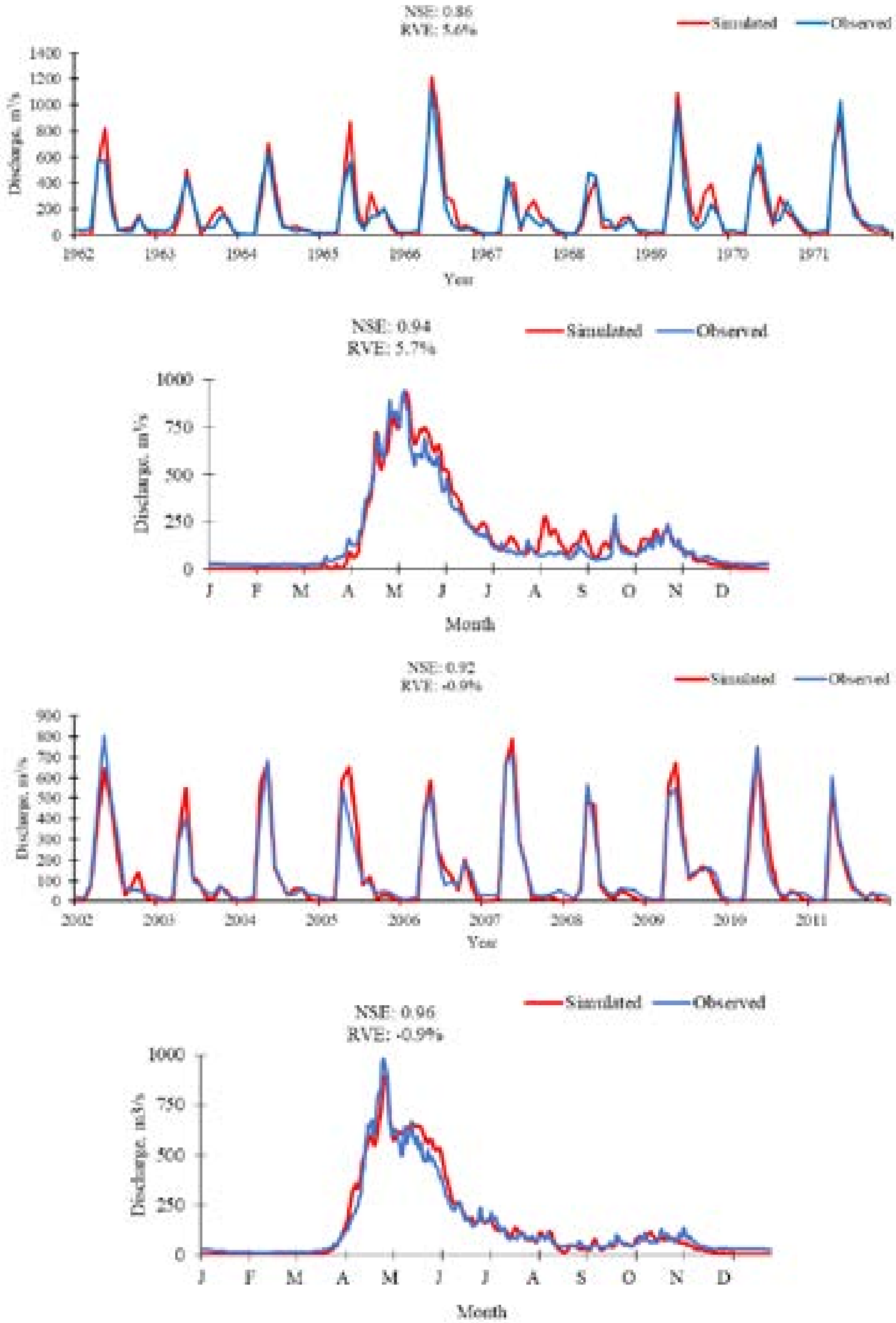

Fig. 3. Comparison of the simulated and observed discharges for the Oba river showing monthly dynamics in the calibration period and in one of the validation sub-periods (left) and the long-term mean daily dynamics during the whole calibration and validation periods (right).

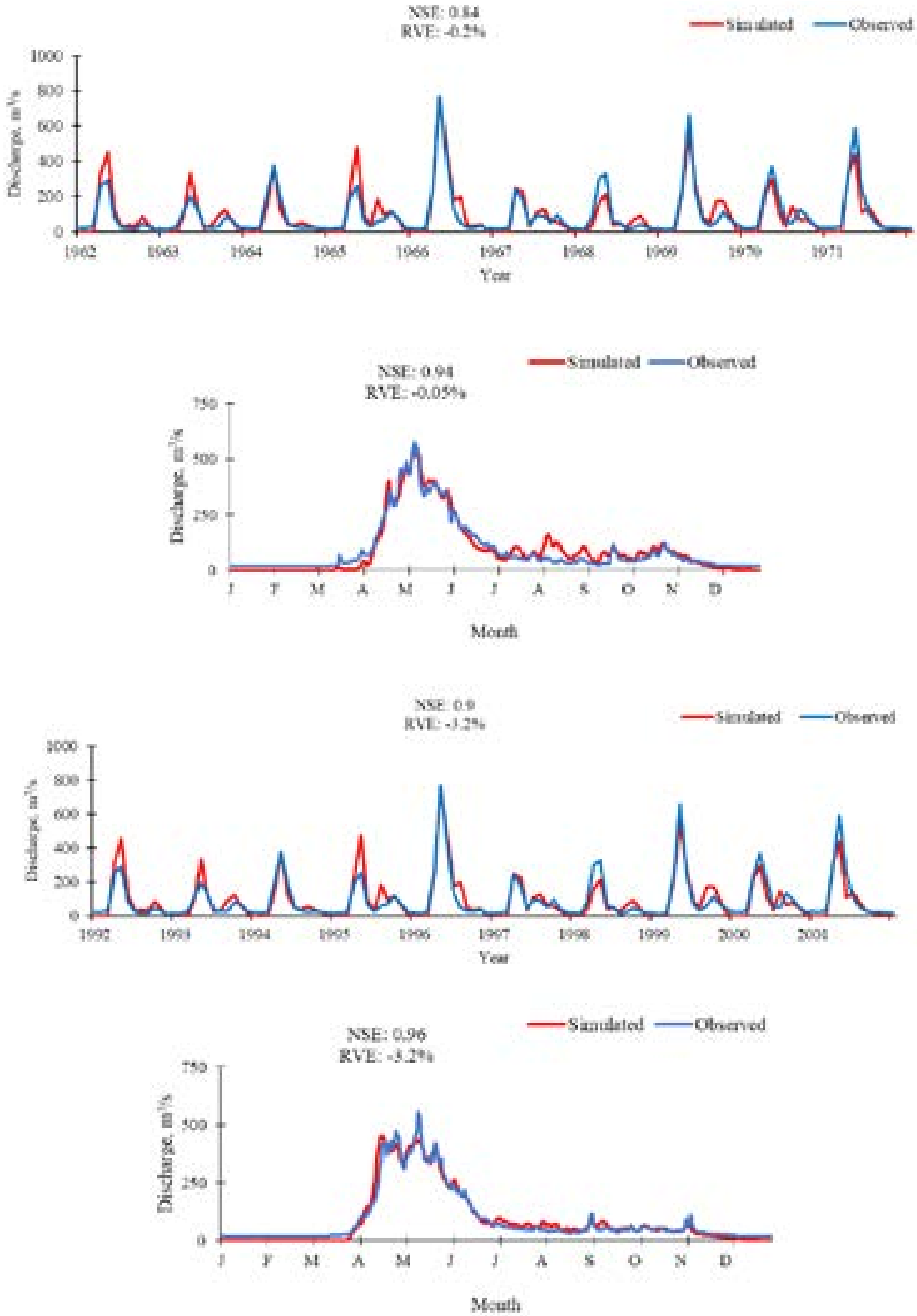

Fig. 4. Comparison of the simulated and observed discharges for the Ulbi river showing monthly dynamics in the calibration period and in one of the validation sub-periods (left) and the long-term mean daily dynamics during the whole calibration and validation periods (right).

Simulation of high flow indices Q10 and Q5. As the Oba and Ulbi originate in high mountains (> 2700 m a.s.l.), high flows in spring could be very dangerous, and the risk of flooding there is pronounced. The time of onset of the maximum flow level depends on the combination of factors such as time of the beginning of snowmelt and intensity of its development, intensity of temperature rise throughout the catchments, and liquid precipitation. Therefore, we investigated the high flow indices Q10 and Q5 corresponding to 90th and 95th percentiles using the calibrated and validated model SWIM, and compared them with those estimated from the observed time series. These indices are robust indicators for high flows. Q10 is the flow in cubic metres per second which was equalled or exceeded for 10% of the specified term (one year, decade, etc.), and Q5 is the flow equalled or exceeded for 5 % of the time. A positive (negative) trend in Q10 and Q5 means an increase (reduction) in flood hazard, with Q5 being more informative for more extreme hazards.

In our study we compared how well the model SWIM can reproduce the high flow indices in the whole historical period 1962–2016. For that, the Q10 and Q5 indices were estimated for every year in the whole period based on the observed discharge data and the simulated time series. Figure 5 shows the relationships between the high flow indices Q10 and Q5 based on the observed and simulated time series for both rivers in the period 1962–2016.

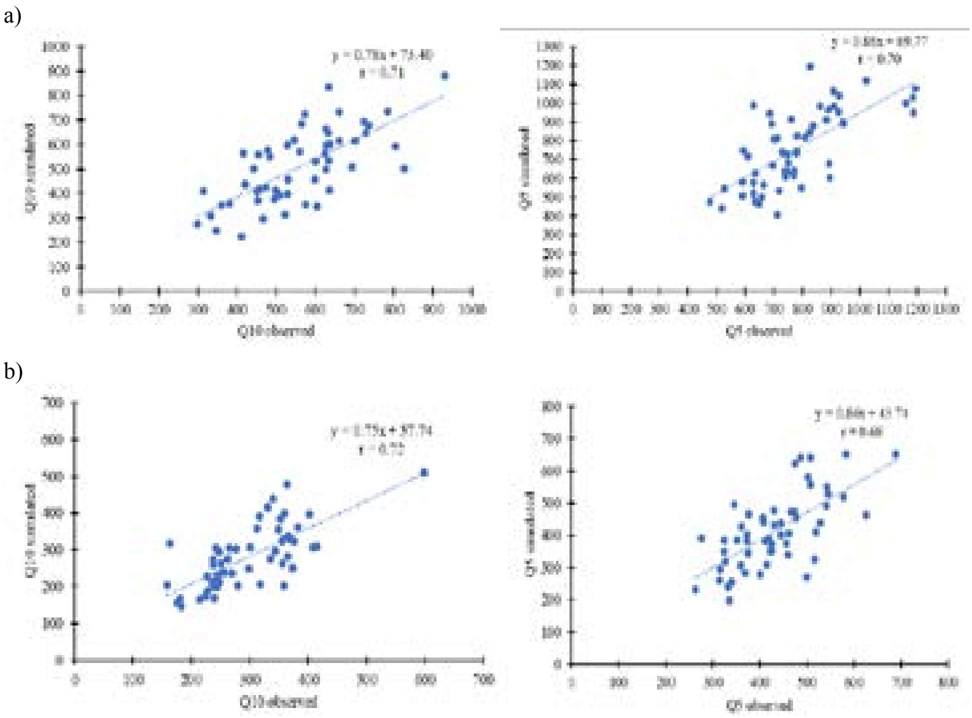

Fig.5. Relationships between the high flow indices Q10 and Q5 based on the observed data and the simulated with SWIM time series for the Oba (a) and Ulbi (b) rivers in the period 1962–2016

As one can see in Fig. 5, the correlation coefficients between the high flow indices estimated from the simulated and observed discharge data are quite high. This confirms that the model is suitable for reproducing not only daily and monthly dynamics of river discharge, but could be also applied for predicting high flows and maybe also floods, though the latter case requires an additional verification.

Discussion

This study was aimed in accessing the possibility of applying the SWIM eco-hydrological watershed model for two river basins located in Eastern Kazakhstan, the Oba and Ulbi. The SWIM model has been successfully calibrated and validated for both basins, taking into account their climatic, hydrological and geophysical heterogeneity. The results of the calibration and validation showed a close relationship between the modeled and observed data, with quite high NSE values and low bias.

In the paper by Didovets et al. (2021), the modelling with SWIM was carried out for the Zhabai and Bukhtarma river basins in Kazakhstan, which also showed good simulation results. Compared to this work, our study included a longer observation period. The NSE criterion when using monthly data has averaged to 0.91, and with daily data to 0.83. The NSE for the 1992–2001 validation sub-period for the Oba basin showed the lowest value of 0.74.

The analysis of the 90th and 95th percentiles (Q10 and Q5 indices) for the period of 1962–2016 for both the modeled and observed discharges showed a close relationship with quite high coefficients of correlation. A similar comparison of the high and low discharge percentiles was performed for eight river basins in Europe (Lobanova et al., 2018).

The main problem related to hydrological modelling in our two basins was insufficient number of meteorological stations in the study area. There are only three stations within or close to our catchment areas, and no stations at all in the hard-to-reach high-mountainous part. The authors of the article by Didovets et al (2021) faced the same problem. For this reason, WATCH reanalysis data was used as input to the model after preliminary checking. The comparison of the annual precipitation and average daily temperature between the data from the existing stations and the WATCH data showed close relationships, enabling application of the reanalysis data for the modelling.

Also other reanalysis data were used for modelling in this region. For example, the authors of the article by Changkun et al, (2015) used the APHRODITE dataset for the Chu river basin in Central Asia. Mingyong Cai et al. (2014) applied the multi-source spatial data with the Distributed Time-Variant Gain Model (DTVGM) for the Ili river basin to study changes in the hydrological regime. Their distributed hydrological model had good performance on the monthly time scale, and its simulation results can be used for water resource analysis.

Conclusions

In this study the SWIM model was applied for the Oba and Ulbi river basins, the main tributaries of the Irtysh River. The comparison of the WATCH Era Interim meteorological data with the observational meteoroloical time series done for the period of 1980-2016 showed satisfactory results. Especially, a very good agreement between the modelled and observed daily average temperatures at three meteorological stations (with R^2 higher than 0.96) was found. The correlation coefficients for the annual precipitation sums were slightly lower (R^2 from 0.60 to 0.95), which might be related to the differences in the altitudes of the compared points.

The calibration and validation of the SWIM model conducted for the period of 1962 to 2016 showed that the SWIM model can be a reliable instrument for simulation of river discharge of the Oba and Ulbi rivers. In addition, the analysis of high flow indices Q10 and Q5 based on the simulated discharge showed a close relationship with the same indices based on the measured discharge data.

The results of this work can be used to recover data gaps and as an additional source of hydrological data over the region with sparse observational network. The calibrated and validated SWIM model could be also applied for hydrological prediction in the coming decades. The results of the successful application of the SWIM model for the Oba and Ulbi river basins provide an opportunity to work further on river flow modelling in these basins, and to do climate and land use change impact assessment. Besides, the results of this work can be applied for planning water management activities in the region under study, including the planning of water releases from the Shulbi reservoir for more efficient use of water resources in the region, taking into account the needs of agriculture and the Shulbinsk HPP. They can also be used for assessing river flow of the studied river basins, for developing environmental measures, and for preparation of intergovernmental agreements.

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