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RESULTS OF MODELLING OF SNOW WATER EQUIVALENT WITH USING MODSNOW MODEL IN ESIL RIVER MANAGEMENT BASIN

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The article presents the results of modeling of snow water equivalent using the V03 module of the MODSNOW model, based on the empirical modeling method, for the territory of the Esil water management basin for 1980…2021 periods. The multi-year period was divided into two equal parts: 1980...1999 for model calibration, 2000...2021 for model validation. For this purpose, 20 meteorological stations located in the section of the water management basin, which have continuous input daily data of average daily air temperature, precipitation, snow cover height and ten-day data of snow water equivalent, were selected. The results of model calibration and validation for reproducibility were evaluated by Nash-Sutcliffe, RSR, and PBIAS criteria. Good reproducibility of modeled snow water equivalent at the meteorological stations Blagoveshenka, Balkashino, Sergeevka, Stepnogorsk, Yavlenka, Bulayevo was revealed; for these stations the results corresponded to the «good» reproducibility rating. It is concluded that the model for these stations can be used for short, medium- and long-term forecasting of snow water equivalent.

Key words: snow, climate, degree-day factor, calibration, validation, Kazakhstan

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INTRODUCTION

Information on spatially distributed snow cover is critical for assessing climatic variability of water resources and for calibrating and validating hydrological models in snow-dominated, in cold regions hydrology (Walter, 2005; WMO, 2009; Clark, 2011).

Snow cover melting in the spring season plays an important role in many parts of the regions as it is directly related to water supply and water resources (Zhang, 2020), also in mountainous areas where snow cover constitutes 50 % of the topography and sometimes reaches 95 %.

The formation of water resources in the continental territory of Central Asia (Gerlitz, 2019), in particular in Kazakhstan, occurs due to melting of snow and ice cover. As climate change continues, the effects of meltwater changes from snow, ice and permafrost will become increasingly relevant to the fragile mountain and plain environments of Central Asia (Barandun, 2020).These changes will affect the livelihoods, primarily of mountain communities, but also of densely populated downstream regions.

Under conditions of climate change, it is especially important to have data on snow cover as an indicator of climate change, as well as the main factor in the formation of water resources in Kazakhstan. In this regard, it is important to investigate changes in snow cover and its main characteristics.

Two basic approaches are used to model snowmelt for daily or short periods of time. The most thorough method is to measure or estimate each term in the energy balance equation and model the energy fluxes in the snow cover. This method requires large amounts of data and sometimes cannot be used due to lack of data.

An alternative (alternate) method for modeling snowmelt has a broad application - degree-day. In this method, air temperature is used to index all energy fluxes. Although the index-based approach has drawbacks, The main objective in this research is to model snow water equivalent (SWE). To achieve this goal, the MODSNOW model's V03 module was used (Gafurov, 2016), which is based on the degree-day factor method.

MATERIALS AND METHODS OF RESEARCH

In this research to simulate snow water equivalent was used the V03 module of MODSNOW model (Gafurov, 2016). Modeling water equivalent in this model is based on the «degree-day factor» method. The method is based on the approach of using a temperature index that equates the total daily melting with a coefficient multiplied by the temperature difference between the average daily temperature and the base temperature (usually 32 °F or 0 °C):

$$M = C_M(T_a - T_b) \quad (1)$$

where: M is the daily melting of the snow cover (mm/day); C_M – «degree-days» coefficient (mm/°C degrees per day); T_a – average daily air temperature (°C); T_b – base temperature (°C).

The C_M ratio varies according to the local area and season period. Usually its magnitude fluctuates between 1,6...6,0 mm/ °C degree day. The C_M coefficient is also related to snow density and wind speed (Martinec, 1960) and snow height and accumulated degrees-days (Rosa, 1956). These changes reflect different energy dynamics in time and space and changing conditions of snow cover. And taking into account the continental climate of Central Asia in MODSNOW model, the coefficient C_M – «degree-day» varies from 2.0 to 8.0 mm/day °C. And the temperature variation ranges from -5,0 to +5,0 °C.

As inputs, the model for simulating snow water equivalent uses average daily air temperature and precipitation data, as well as snow height.

For modeling the water equivalent of snow cover in the Yesil reservoir, data from 20 meteorological observations (Fig. 1) of the observation network of RSE «Kazhydromet» were used. In order to assess the efficiency of reproduction of snow water equivalent of the «degree-day» methodology, the model calculates the following criteria: Nash-Sutcliffe efficiency (NSE), standard deviation coefficient (RSR), percentage deviation (PBIAS), coefficient of determination (R^2) (Moriasi, 2007).

The Nash-Sutcliffe Efficiency (NSE) criterion is based on normalized statistical calculations that determine the relative magnitude of the residual variance («noise») compared to the measured variance of the data («information»). NSE indicates how well the observed and modeled data values match each other and is determined using the following equation:

$$NSE = 1 - \frac{\sum(SWE_{obs} - SWE_{sim})^2}{\sum(SWE_{obs} - \overline{SWE}_{sim})^2} \quad (2)$$

where, SWE_{obs} – observed values of snow water equivalent, SWE_{sim} – simulated values of snow water equivalent, $\overline{SWE}_{sim}$ – average values of snow water equivalent for a multiyear period.

NSE statistical indicator ranges from -1.0 < NSE < +1.0. An NSE=1 indicates an optimal result if the indicator is in the range of 0.0 < NSE < +1.0, usually considered as an acceptable level of performance, while NSE < 0.0 indicates that the mean observed value is a better predictor than the modeled value, i.e. indicates unfavorable performance. The NSE score is very commonly used in evaluating the performance of a methodology, e.g., for hydrologic (ASCE, 1993) and hydroclimatic model validation purposes, but (Sevat, 1991) also concluded that NSE is the best objective function that reflects the overall suitability of the hydrograph.

The coefficient of standard deviation of the root means square deviation (RMSE) (RSR). The root mean square deviation (RMSE) is one of the most commonly used error index statistics (Chu, 2004). It has been known that the lower the RMSE, the better the model performance, except that (Singh, 2004) published guidelines for determining what is considered a low RMSE based on the standard deviation of the observations. Following Singh's suggestion, (Singh, 2004) introduced a statistical measure of model output called the standard deviation of the root mean square deviation (RMSE) coefficient (RSR). As shown in the following equation, RSR is calculated as the ratio of RMSE to the standard deviation of the measured data:

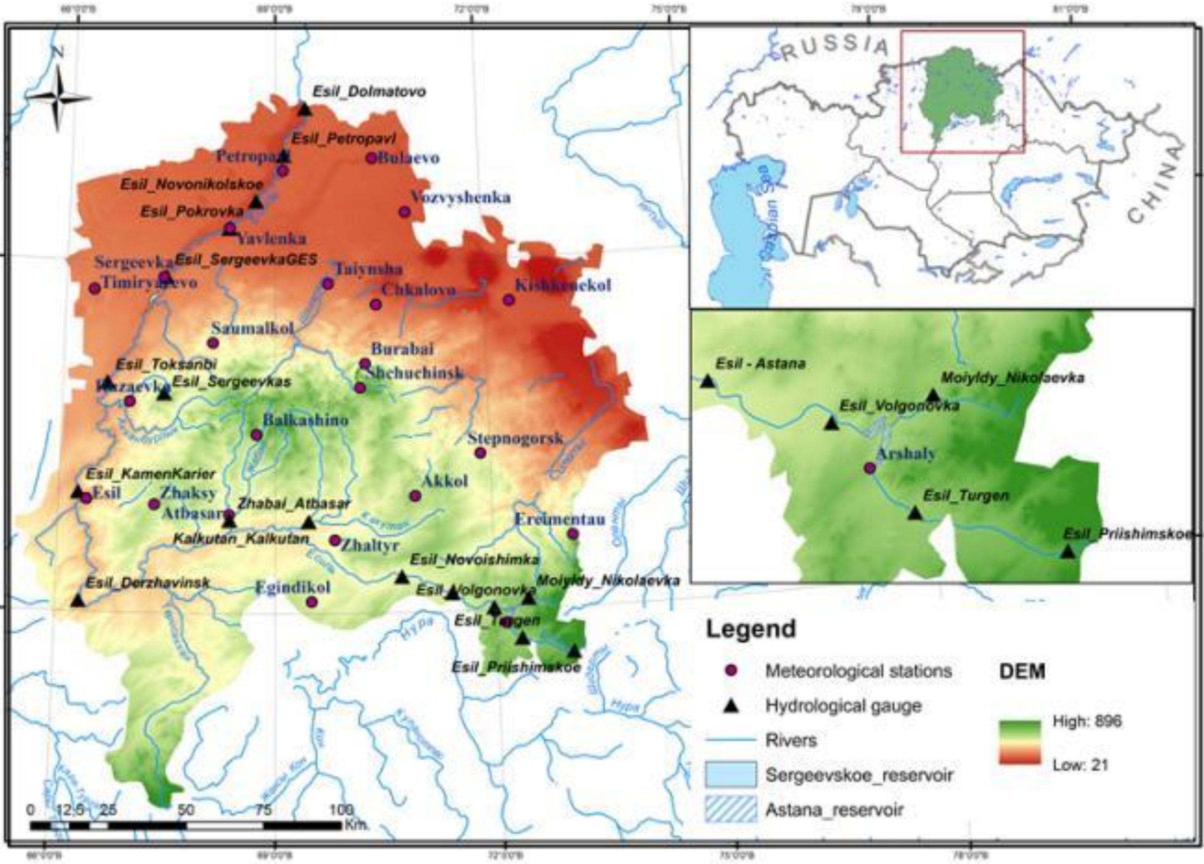

Fig. 1. *Map of the Esil water management basin*

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]} \qquad (3)$$

The RSR varies from an optimal value (RSR = 0), which indicates zero value of standard deviation or residual variation, to an infinite value of positive value. That is, the lower the RSR, the lower the RMSE, indicating higher model performance.

Percentage Bias (PBIAS). Percent deviation measures the average trend of the modeled data as greater or lesser than their observed counterparts. The optimal value of PBIAS is 0.0, and lower values indicate accurate model simulation of the model. Positive values indicate a systematic error in model estimation (underestimation), and negative values indicate a high systematic error in model estimation (overestimation):

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

The statistical criteria presented for the performance assessment are evaluated by the level of performance presented in Table 1.

RESULTS AND DISCUSSION

The multi-year 1980…2021 period was divided into two identical periods for the purpose of model calibration and validation: 1980…1999 and 2000…2021, respectively.

It is important to remember that the calibration method should provide the most accurate representation of the different phases of the hydrometeorological regime. So, we calibrate the model so that the modeled value is as close as possible to the real one

The model selects the optimal parameters based on the observed data for each observation station during the calibration phase, that is, during this process, the model compares each degree-day coefficient and temperature with each other. For example, for each «degree-day» coefficient, starting from -5.0 °C and ending at +5 °C selecting all possible options in steps of 0.1 or 1.0 °C selects the most optimal ones. Then you select the parameters depending on the physiographic, topographic, climatic features of the area.

Thus, for the Esil water management basin in 1980…1999, the results of parameterization and efficiency obtained from the model calibration results are presented in Table 2.

Table 1

Statistics provided for the assessment of effectiveness (Moriasi, 2007)

Performance level	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
Unsatisfied	RSR> 0.70	NSE <0.50	PBIAS> ±25

As a result of calibration of stations, located in the Esil water management basin, based on calculations of evaluation criteria, it was established that the performance rating «excellent» for all indicators is observed at the stations Sergeevka, Kishkenekol, Blagoveshenka, Yavlenka, and performance rating «good» - at the stations Akkol, Balkashino, Ruzaevka, Stepnogorsk, Bulayevo, Chkalovo, Ereimentau, Zhaltyr. And the results of the remaining 8 meteorological stations corresponded to the level of «satisfactory» or «unsatisfactory» performance rating.

At the meteorological stations (Sergeevka, Kishkenekol, Blagoveshchenka, Yavlenka) that meet the model performance rating of «excellent», the precipitation-to-snow conversion temperature ranges from 0,0 °C to -2,5 °C. And in stations that meet the «good» performance rating, this indicator has a large range, that is, it covers a range from +1,0 °C to -3,5 °C. If consider the spatial distribution, in the north-eastern plain zone of the basin, precipitation in the form of snow occurs at 0,0...+0,5 °C, in the downstream area of the Esil river it was found that precipitation in the form of snow occurs at low temperatures, i.e. at -1,0...-2,5 °C.

Table 2

Model calibration results for 1980…1999

№	Meteorological station	Performance indicators				Parameters		
		RSR	PBIAS, %	NSE	R	Tt, °C	Fdeg, мм/°C day	t0, °C
1	Akkol	0.53	15.11	0.71	0.85	0.50	5.00	-0.50
2	Blagoveshchenka	0.46	16.78	0.79	0.90	-2.00	6.50	0.00
3	Balkashino	0.47	19.43	0.78	0.90	1.00	7.00	0.00
4	Ruzaevka	0.54	10.82	0.71	0.85	1.00	2.00	-3.50
5	Sergeevka	0.43	3.79	0.81	0.91	-2.50	7.00	0.00
6	Stepnogorsk	0.52	13.91	0.73	0.87	1.00	4.00	-2.00
7	Yavlenka	0.48	13.37	0.77	0.88	-1.00	6.50	-0.50
8	Arshaly	0.73	-2.17	0.46	0.75	1.00	4.50	-1.00
9	Bulaevo	0.55	6.53	0.70	0.84	1.00	8.00	5.00
10	Chkalovo	0.49	2.98	0.76	0.87	0.50	2.00	-2.00
11	Egindikol	0.60	0.25	0.64	0.82	1.00	2.00	-2.00
12	Ereimentau	0.56	3.35	0.69	0.84	-3.00	6.00	0.00
13	Kishkenekol	0.38	5.88	0.85	0.93	0.00	2.00	-2.50
14	Saumalkol	0.55	29.50	0.70	0.89	1.50	8.00	0.50
15	Schuchinsk	0.71	10.57	0.50	0.71	0.00	4.00	3.00
16	Taiynsha	0.56	18.84	0.69	0.84	0.50	2.50	-2.50
17	Timiryazevo	0.56	19.04	0.69	0.85	1.00	6.00	0.50
18	Vozvyshenka	0.84	21.56	0.29	0.56	3.50	2.00	4.00
19	Zhaksy	0.92	33.43	0.16	0.57	-5.00	8.00	-5.00
20	Zhaltyr	0.59	11.82	0.66	0.82	-3.50	3.00	0.00

In addition, in the central areas of the basin, except for the Kalkutan river basin (at Zhaltyr station -3,5 °C), precipitation in the form of snow falls at +0,5...+ 1,0 °C.

It was revealed that the snow melting temperature in the whole basin varies within the range of -2,5...0,0 °C. In areas with basin altitudes of 300…400 m (the basins of the Zhaibai, Kalkutan, and Shagalaly rivers), snow melting occurs at an average of 0.0 °C, and snow melting in the area of the lower Esil River occurs at -0,5...0,0 °C. And in the northeastern plain zone of the basin (Kishkenekol and Chkalovo stations), snow cover melting occurs at -2,0...-2,5 °C.

It was determined that the «degree-day» coefficient, involved in the calculation of daily snow melting, in the zone of formation of the main water resources of the Esil basin, i.e. in the central and southern zones of the basin, melting per day is 4,0… 5,0 mm/°C. And in the lower reaches of Esil river basin, it is noted that this indicator is 6.0…8.0 mm/day (table 2).

As a result of calibration, it was revealed that, the snow water equivalent content by NSE criterion varies within 0,16…0,85, RSR indicator - within 0,38…0,84, percentage error of PBIAS +0,2...+33,4 %. These measures were shown to span the interval between a «very good» performance rating and an «unsatisfactory» rating. As a result of the analysis of indicators to «very good» level of performance belong to Sergeevskaya, Chkalovo, Kishkenekol and Ruzaevska stations, and to «good» level – Akkol, Blagoveshchenka, Balkashino, Stepnogorsk, Yavlenka, Bulaevo, Ereimentau, Saumalkol, Taiynsha, Timiryazevo stations. It is noted that the results of other meteorological stations belong to the «unsatisfactory» level (table 2).

Thus, in 1980…1999, according to the results of calculations of performance indicators for the calibration period, at most of the meteorological stations of MODSNOW V03 model, located in the area of Esil water management basin, snow cover showed the results of moisture reserves modeling at a «good» level.

Model validation. The optimal parameters obtained from the model calibration process, for a period outside the calibration period, need to be validated, i.e., work is done to verify the optimal parameters.

For this purpose, the validation process of 20 meteorological stations located in the Esil water management basin was carried out for the period 2000…2021. In addition, performance indicators for this period of the year were calculated (table 3).

According to the performance measures calculated as a result of the validation process, the percentage error ranges from -3,64 % to +88,6 %, for the NSE criterion, the performance ranges from -0,08…0,88, it is also found that the coefficient of standard deviation ranges from 0,35… 1,04. That is, the performance measures are consistent across all performance ratings.

«Good» and «satisfactory» performance ratings for all criteria were shown by Blagoveshchenska, Balkashino, Stepnogorsk, Bulaevo, Sergeevka, Ruzayevka, Yavlenka and Shchuchinsk stations. At these stations, the NSE efficiency criterion ranged from 0,68 to 0,88, the percentage error -3,64… 39,8 %, and the standard deviation coefficient varies between 0,35… 0,56.

Some meteorological stations (Chkalovo, Akkol, Ereimentau, Saumalkol, Taiynsha, Timiryazevo, Zhaltyr) that showed a «good» performance rating for the performance indicator during the calibration process showed a «satisfactory» or «unsatisfactory» rating during the validation period. That is, the optimal parameters of these weather stations are new 2000…2021 shows that the snow cover for the period does not match in the modelling of moisture storage. In accordance with the results obtained for the calibration period and validation periods of V03 module of the MODSNOW model, the stations that better simulate snow cover moisture stocks were selected. These include Blagoveshenka, Balkashino, Sergeevka, Stepnogorsk, Yavlenka, Ruzayevka and Bulayevo stations. However, Ruzayevka station is excluded from this list because it physically does not coincide with the parameters of meteorological stations located in the basin.

As a result, the following 6 meteorological stations were accepted as stations corresponding to the performance rating «excellent» and «good»: Blagoveshenka, Balkashino, Sergeevka, Stepnogorsk, Yavlenka, Bulayevo. Calibration of these stations (1980…1999) and validation (2000…2021) results of the modelling stages are presented in figure 2 and 3.

As a result of model calibration and validation for meteorological stations located in the area of Esil water management basin,

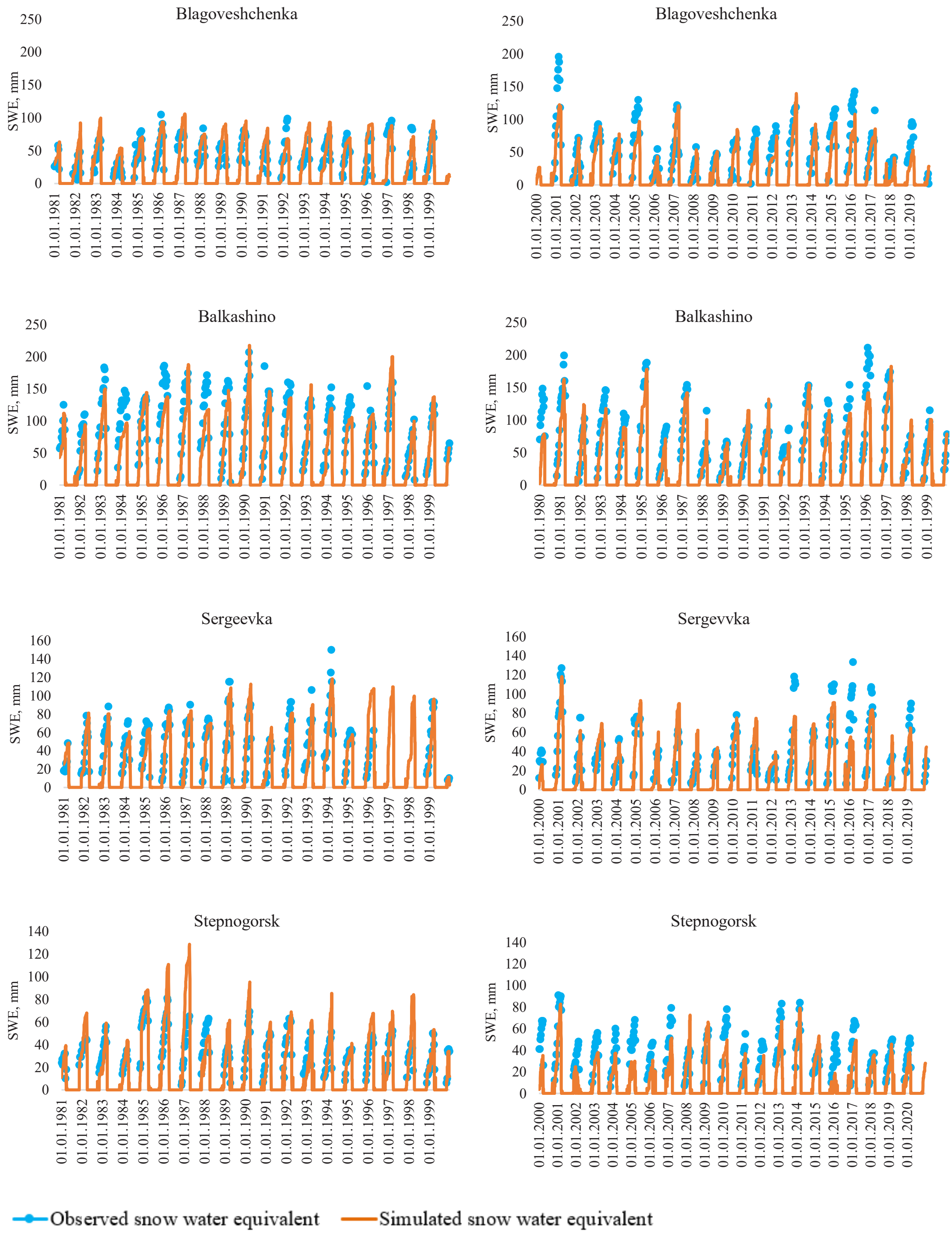

Fig. 2. *Observed and simulated SWE of a meteorological station located in the Esil water management basin during the calibration (1980…1999) and validation (2000…2021) periods*

it was found that for some stations the «degree-day» method does not satisfactorily model snow data, according to preliminary estimates, they are associated with poor quality of observation data. This process is especially pronounced at the stations of Ereimentau, Vozvyshenka and others.

The model for meteorological stations shown in Figure 2, 3 can be used to predict moisture storage or snow cover height over short, medium and long time periods.

CONCLUSION

As a result of modeling of water reserves in snow cover for the territory of the Esil water basin for 1980…2021 periods by the degree-day method showed that, the model reproduces well the data of moisture reserves, which is evaluated by statistical criteria of efficiency.

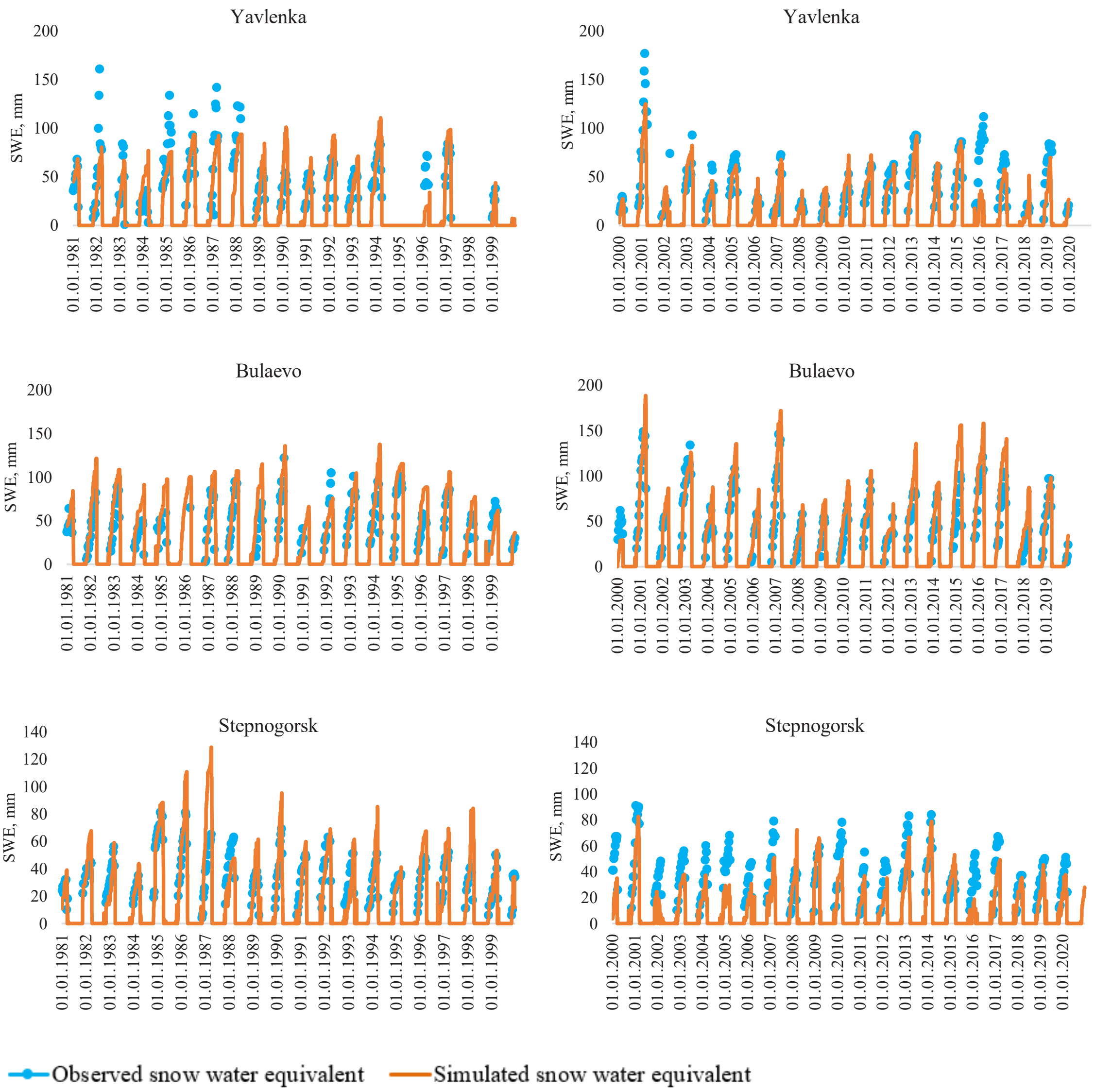

Fig. 3. *Observed and simulated SWE of a meteorological station located in the Esil water management basin during the calibration (1980…1999) and validation (2000…2021) periods*

The models for meteorological stations Blagoveshchenka, Balkashino, Sergeevka, Stepnogorsk, Yavlenka, Bulaevo, Stepnogorsk can be used for operational forecasting of water reserves in snow, also applied for long-term forecasting under climate change conditions.

REFERENCES

1. ASCE. 1993. Criteria for evaluation of watershed models. J. Irrigation Drainage Eng. 119(3): 429-442.
2. Barandun Martina, Fiddes Joel, Scherler Martin, Mathys Tamara, Saks Tomas, Petrakov Dmitry, Hoelzle Martin, The state and future of the cryosphere in Central Asia, Water Security, Volume 11, 2020, 100072, ISSN 2468-3124, https://doi.org/10.1016/j.wasec.2020.100072.
3. Clark, M. P., Hendrikx, J., Slater, A. G., Kavetski, D., Anderson, B., Cullen, N. J., Kerr, T., Örn Hreinsson, E., and Woods, R. A. (2011), Representing spatial variability of snow water equivalent in hydrologic and land-surface models: A review, Water Resour. Res., 47, W07539, https://doi.org/10.1029/2011WR010745
4. Chu, T. W., and A. Shirmohammadi. 2004. Evaluation of the SWAT model's hydrology component in the piedmont physiographic region of Maryland. Trans. ASAE 47(4): 1057-1073.
5. Gafurov A., Lu¨dtke S., Unger-Shayesteh K., Vorogushyn S., Scho¨ne T., Schmidt S., Kalashnikova O., Merz B. MODSNOW-Tool: an operational tool for daily snow cover monitoring using MODIS data // Environ Earth Sci (2016) 75:1078 DOI 10.1007/s12665-016-5869-x.
6. Gerlitz, L., E. Steirou, C. Schneider, V. Moron, S. Vorogushyn, and B. Merz, 2019: Variability of the Cold Season Climate in Central Asia. Part II: Hydroclimatic Predictability. J. Climate, 32, 6015–6033, https://doi.org/10.1175/JCLI-D-18-0892.1.
7. Martinec, J. 1960. The degree-day factor for snowmelt runoff forecasting. IUGG General Assembly of Helsinki, IAHS Publ. No. 51, 468-477.
8. Moriasi D. N., Arnold J. G., Van Liew M. W., Bingner R. L, Harmel R.D., Veith T.L. Model evaluation

guidelines for systematic quantification of accuracy in watershed simulations. American Society of Agricultural and Biological Engineers, 2007, Vol. 50(3): 885−900.
9. Rosa, J. 1956. Forest snowmelt and spring floods. J. Forestry 54 (4).
10. Sevat, E., and A. Dezetter. 1991. Selection of calibration objective functions in the context of rainfall-runoff modeling in a Sudanese savannah area. Hydrological Sci. J. 36(4): 307-330.
11. Singh, J., H. V. Knapp, and M. Demissie. 2004. Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT. ISWS CR 2004-08. Champaign, Ill.: Illinois State Water Survey. Available at: www.sws.uiuc.edu/pubdoc/CR/ ISWSCR2004-08.pdf.
12. Walter M. Todd, Brooks Erin S., McCool Donald K., King Larry G., Molnau Myron, Boll Jan, Process-based snowmelt modeling: does it require more input data than temperature-index modeling?, Journal of Hydrology, Volume 300, Issues 1–4, 2005, Pages 65-75, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2004.05.002.
13. WMO Guide to hydrological Practices, Vol. II, Management of water resources and application of hydrological practices, WMO-No. 168, 2009, 302.
14. Zhang Q., Chen Y., Li Zh., Fang G., Xiang Y., Li Y., Ji H. Recent Changes in Water Discharge in Snow and Glacier Melt-Dominated Rivers in the Tienshan Mountains, Central Asia. Remote Sens. 2020, 12, 2704; https://doi.org/10.3390/rs12172704.
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ЕСІЛ СУШАРУАШЫЛЫҒЫ АЛАБЫНДА ҚАР ЖАМЫЛҒЫСЫ ЫЛҒАЛ ҚОРЫН MODSNOW МОДЕЛІ КӨМЕГІМЕН МОДЕЛЬДЕУ НӘТИЖЕЛЕРІ

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Мақалада 1980…2021 жылдардағы Есіл сушаруашылығы алабы аумағы үшін эмпирикалық модельдеу әдісіне негізделген MODSNOW моделінің V03 модулімен қар жамылғысының ылғал қорын модельдеу нәтижелері келтірілген. Көпжылдық кезең екі тең бөлікке бөлінді: 1980…1999 модельді калибрлеу үшін, 2000…2021 модельді тексеру үшін. Ол үшін су сушаруашылығы алабында орналасқан 20 метеорологиялық станция таңдалды, оларда ауаның орташа тәуліктік температурасы, жауын-шашын, қар жамылғысының биіктігінің тәуліктік және қар жамылғысы ылғал қорының онкүндік деректері үздіксіз кіріс деректері бар. Модельді калибрлеу және валидациялау нәтижелері Нэш-Сатклифф, RSR және PBIAS критерийлері бойынша бағаланды. Благовещенка, Балкашино, Сергеевка, Степногорск, Явленка, Булаево метеорологиялық станцияларында қар жамылғысы ылғал қорының жақсы өнімділік деңгейі анықталды. Бұл станцияларға арналған модель қар жамылғысы ылғал қорын қысқа, орта және ұзақ мерзімді болжау үшін пайдаланылуы мүмкін деген қорытындыға келді.

Түйін сөздер: қар, климат, градус-тәулік әдісі, калибрлеу, валидация, Қазақстан

РЕЗУЛЬТАТЫ МОДЕЛИРОВАНИЯ ЗАПАСОВ ВОДЫ В СНЕЖНОМ ПОКРОВЕ С ИСПОЛЬЗОВАНИЕМ МОДЕЛИ MODSNOW В ЕСИЛЬСКОМ ВОДОХОЗЯЙСТВЕННОМ БАССЕЙНЕ

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В статье представлены результаты моделирования запасов воды в снежном покрве с помощью модуля V03 модели MODSNOW, основанные на методе эмпирического моделирования, для территории Есильского водохозяйственного бассейна за периоды 1980…2021 гг. Многолетний период был разделен на две равные части: 1980…1999 гг. для калибровки модели, 2000…2021 гг. для валидации модели.

Для этого были выбраны 20 метеорологических станций, расположенных на территории водохозяйственного бассейна, которые имеют непрерывные входные суточные данные среднесуточной температуры воздуха, осадков, высоты снежного покрова и декадные данные водного эквивалента снега. Результаты калибровки и валидации модели на воспроизводимость оценивались по критериям Нэша-Сатклиффа, RSR и PBIAS. Выявлена хорошая воспроизводимость моделированного запасов воды в снежном покрве на метеорологических станциях Благовещенка, Балкашино, Сергеевка, Степногорск, Явленка, Булаево, для которых результаты соответствуют оценке воспроизводимости «хорошо». Сделан вывод, что модель для этих станций может быть использована для краткосрочного, среднесрочного и долгосрочного прогноза водного эквивалента снега.

Ключевые слова: снег, климат, фактор градусо-дня, калибровка, валидация, Казахстан

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