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MODIS Imagery Based Water Content Forecasting Methodology for Mountain Rivers in Central Asia

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Abstract

The article investigates the possibility of using snow cover satellite data for short-term hydrological forecasting for Central Asian rivers with high-altitude catchments. The research aimed to elaborate a methodology for forecasting mean 10-day (decadal) river discharge (MDD) of the Varzob and Tar Rivers based on MODSNOW-processed MODIS satellite imagery. The objectives of the study were to calculate the snow cover index (SCI) for high-altitude zones in 200 m increments for selected river basins, and to analyze the closeness of dependency between the corresponding SCIs and MDDs. The research resulted in equations applicable for producing operational river water content forecasts. Timely and reliable information on expected river water content during the forthcoming 10-day period allows decision makers (water management and hydropower agencies, emergency authorities) plan water supply for various economic sectors, as well as take measures to prevent hazardous hydrological phenomena on the rivers of Tajikistan and Kyrgyzstan.

Key words: water discharge, snow cover, hydrological forecasting, space imagery, Central Asia.

Paper type: Research article.

1. Introduction

For the first time, satellite information about snow cover contained in satellite images was applied for hydrological forecasting in 1977 in the Martinek-Rango SRM (Snowmelt Runoff

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Model) (Rango, 1977). However, the 1.1 km spatial resolution of the AVHRR (NOAA) imagery allowed using snow cover data only for watersheds with significant areas; in addition, satellite images could be used only in case of clouds not distorting the snow cover picture. For long-term forecasting of Central Asian river runoff, snow cover data of AVHRR imagery were processed using the ERDAS Software with 10-day interpolation (Pertzinger, 2002; Baumgartner, 2000).

The emergence of algorithms for calculating snow cover area allowing to remove cloud cover from MODIS images proposed by A. Gafurov made it possible to obtain daily data on snow cover dynamics (Gafurov, 2009). Using satellite information about snow cover contained in MODIS images for operational hydrological forecasting in Central Asian countries became possible thanks to A. Gafurov creating the MODSNOW application. It allows automatically downloading images from the Internet, removing cloud noise and calculating snow cover area for various river basins (Gafurov, 2016). As studies have shown, the 500 m spatial resolution of MODIS imagery permits using this information for a wider range of catchments – from 1,000 km^2 or more.

The river water content forecasting methods based on MODIS imagery were successfully applied for producing vegetation season and monthly forecasts for the rivers in the Naryn Basin (Kalashnikov, 2015; 2017; 2020), as well as for forecasts for vegetation season months for the Pamir-Alai rivers (Niyazov, 2020). When designing the river discharge forecasting methodologies for vegetation months for the Tien Shan and Pamir-Alai rivers, the method accommodating the duration of snow cover accumulation based on MODIS imagery was applied (Gafurov, 2018; 2019). H. Apel conducted a significant amount of work on MODIS-based statistical modeling for the Central Asian region (Apel, 2018); he demonstrated the efficiency of using snow cover information in these images to forecast seasonal river runoff.

The efforts of the academic community in recent years have focused on the prevention of hydrological droughts in the Central Asian region important for integrated water resources management. The evidence-based approach to water resource management by riparian countries (Uzbekistan, Turkmenistan, Kazakhstan, Tajikistan, and Kyrgyzstan) allows decision makers to use effective early warning techniques for hydrological hazards like floods and hydrological droughts (Gerlitz et al., 2020).

Water content forecasting for the Varzob (Tajikistan) and Tar (Kyrgyzstan) Rivers is important both for water resource planning and preventing hydrological hazards associated with expected low-water (hydrological drought) or high-water (flood) periods. Large cities are located in the lower reaches of the target rivers – Dushanbe on the Varzob, and Uzgen on the Tar – using their water for economic, power and municipal purposes.

The authors of the article possess the experience of successfully applying MODIS satellite imagery data for long-term hydrological forecasting (flood period and its months) for the river catchments of the Pamir-Alai and Tien Shan. Using the forecasting equations for 10-day (decadal) intervals makes this approach innovative.

The study used the snow cover information contained in MODIS satellite imagery processed in MODSNOW to determine the spatial characteristics of seasonal snow cover reserves in the high-altitude Varzob and Tar River Basins.

The research aimed to analyze the correlation dependencies between mean 10-day river discharge and snow cover area in high-altitude zones in 200 m increments. The analysis led to elaborating prognostic equations of applied significance for executing timely and high-quality decadal river water content forecasts.

The article includes the review of the main characteristics of the studied objects, i.e. the Varzob and Tar River Basins. It likewise presents the formulas for calculating the snow cover index, main equation parameters and quality criteria for the proposed short-term hydrological forecasting methodology. The outputs of calculations based on these formulas and equations for the Varzob and Tar River Basins allow assessing the quality and applicability criteria of the proposed methodology for predicting mean decadal water runoff for the target rivers. The article also presents the advantages of the newly developed methodology for operational short-term hydrological forecasting.

The article's Conclusions Section describes the main research findings and further research prospects.

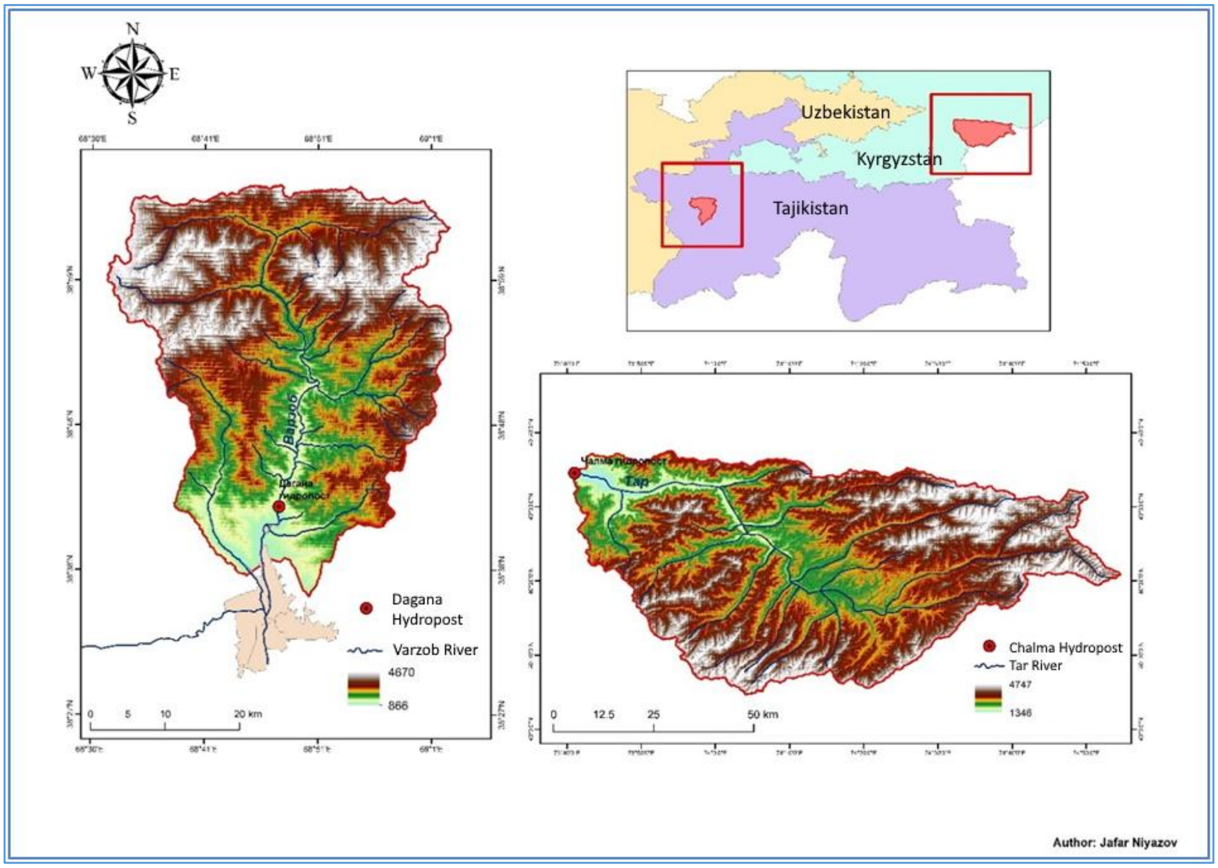
2. Materials and methods

The two main study subjects – the Varzob and Tar River Basins – were selected to validate mean decadal water discharge forecasting methods based on the snow cover data of MODIS imagery. Both basins are high-altitude with similar average catchment elevation (2,700-2,800 m ASL) and small glaciation area (1.6-3% of total basin area). In addition, the Varzob and Tar Rivers belong to the snow-glacial nourishment type (Schulz, 1965), as well as demonstrate same mean annual water flow (approx. 50 m^3/s).

The Varzob Basin belongs to the Pamir-Alai Mountain System, and is located in Tajikistan, Central Asia (68°30'E-69°00'E; 37°35'N-39°5'N). The basin's area amounts to 1,270 km^2. The basin stretches between 866 and 4,670 m ASL (Fig. 1.), with the average catchment elevation of 2,670 m ASL. The glaciation area is 36.1 km^2, i.e. 3% of the total basin area

(Catalogue of glaciers of the USSR, 1980). The length of the Varzob River is 71 km. It is a large right-bank tributary of the Kafirnigan River, further flowing into the Amudarya River.

The Tar River Basin belongs to the Tien Shan Mountain System, and is located in Kyrgyzstan, Central Asia (73°40'E-74°60'E; 40°00'N-40°40'N). The basin's area is 3,840 km^2. The basin stretches between 1,346 and 4,747 m ASL (Fig. 1.), with the mean catchment elevation of 2,810 m ASL. The glaciation area is 61.4 km^2, i.e. 1.6% of the total basin area (Shabunin, 2018). The length of the Tar River is 147 km (up to Chalma Village Hydropost). The river is a large left-bank tributary of the Karadarya River, further flowing into the Syrdarya River.



Author: Jafar Niyazov

Figure 1. Geographic location of the Varzob and Tar River Basins on the territory of Central Asia.

High water is observed on the Varzob River from March to September, and from April to September on the Tar River. Both target rivers belong to the snow-glacial nourishment type. Peak floods and maximum water discharge are observed during May-June. During high-water period, the main sources of river nourishment are meltwater from seasonal snowmelt and, to a lesser extent, glacial meltwater, ground- and rainwater. Due to this, the hydrological forecasting practice has been taking into account the snow reserves accumulated during the cold season. The information on the snow cover depth and water content is collected via a network of observation stations of national hydrometeorological services. Yet, the point nature of the information and the widely spaced grid of the observation network do not allow assessing the situation with snow reserves in the mountains reliably. The study team used the snow cover information in MODIS satellite imagery providing for spatial characterization of its distribution in high-altitude zones. MODIS snow cover data underwent processing using the MODSNOW software.

To develop a methodology for 10-day river water content forecasting, snow cover data calculated for high-altitude zones with 200 m increments were used. Calculations of the snow cover area (SCA) as a percentage of basin area were carried out for each day in the series.

Snow cover duration (or the number of days with snow cover) also affects the formation of river runoff. In this regard, the snow cover index (SCI) was also applied calculated based on the following formula (Gafurov et al., 2018):

$$SCI_t = \sum_{n=1}^{n=365/366} SCA_i \qquad (1)$$

where *SCA* represents snow cover area as a percentage of basin area for *i*-day (in our case for each day);
SCI – snow cover index, duration of snow cover accumulation during forecast time (*t*); and
n is the number of days with snow cover for hydrological year.

The linear regression method (Podrezov, 2019) was used to analyze the dependence between MDD and SCI.

The quality criteria for the forecasting methodology and, thus its applicability for the purposes of operational hydrological forecasting prove its reliability and effectiveness. The relation $\bar{S}/\bar{\sigma}$ was accepted as the criterion of forecasting applicability and quality (Guided Tutorial for Forecasting Services, 1967).

$\bar{S}$ – mean-root-square error of validation forecasts was determined as per the following formula:

$$\bar{S} = \sqrt{\frac{\sum_{1}^{n}(Q-Qi)^2}{n-2}} \qquad (2)$$

with $\bar{S}$ representing the mean-root-square error of validation forecasts;
Qi – runoff in long-term observation series;

Q – runoff calculated based on the same data based on which the correlation relation itself was established; and
n – number of members in multi-year series.
$\bar{\sigma}$ – root-mean-square deviation of the forecasted water discharge from the norm was determined as per the following formula:

$$\overline{\sigma}=\sqrt{\frac{\sum_{1}^{n}(Qi-\overline{Q})^{\wedge}2}{n-1}} \qquad (3)$$

with $\bar{\sigma}$ representing the root-mean-square deviation of forecasted water discharge from the norm;
Qi – water discharge in long-term observation series;
$\bar{Q}$ – norm, i.e. mean long-term water discharge; and
n – number of members in multi-year series.

A forecasting methodology is considered applicable for operational forecasts at the following $\bar{S}/\bar{\sigma}$ relation:

$$\text{with } n \le 15 \; \overline{S}/\overline{\sigma} \le 0.70; \qquad (4)$$

$$\text{with } 15 < n < 25 \; \overline{S}/\overline{\sigma} \le 0.75 \qquad (5)$$

where n is the number of series members used to establish forecast dependencies, i.e. the number of validation forecasts.

To estimate forecast accuracy, it is necessary to set an acceptable forecast error, i.e. the limit error value at which a forecast shall be considered accurate. A forecast shall be deemed accurate if its error is equal to or less than the permissible forecast error. The permissible forecast error ($\boldsymbol{\delta}$) for water discharge was taken as equal to the probable deviation from the norm:

$$\boldsymbol{\delta} = 0{,}674\overline{\sigma} \qquad (6)$$

As a criterion for the method applicability, the margin of error was calculated as the ratio of the number of water discharge rates calculated based on the proposed method that fell within the permissible forecast error thresholds to the total number of water discharge rates for the entire observation period for each 10-day interval. A method is considered applicable if the margin of error exceeds 60%.

3. Research results

The snow cover area as a percentage of the total basin area for high-altitude zones with 200 m increments was calculated for every day during 2000-2017 for the Tar and Varzob River Basins (Fig. 2.).

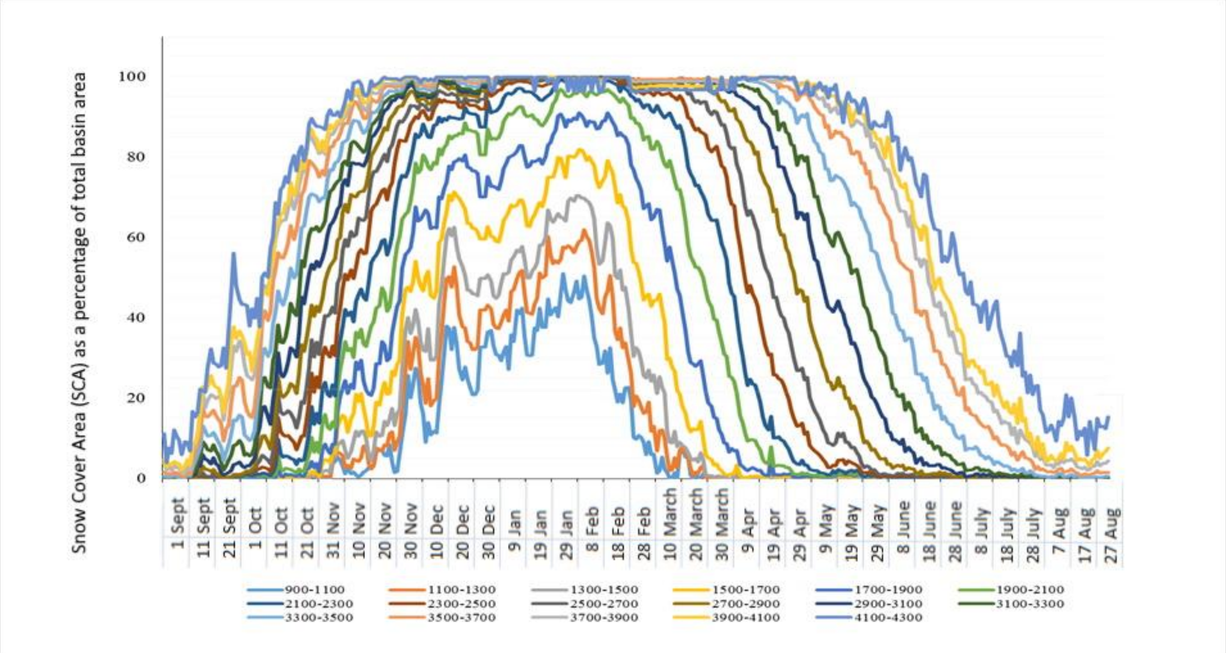


Figure 2. Snow cover area as a percentage of total river basin area (Varzob River, high-altitude zones in 200 m increments).

According to formula (1), SCI was calculated from September 1 up to the forecasted 10-day interval. For instance, to forecast the situation during the first 10-day interval of May, SCI was calculated from September 1 until April 30; and to forecast the situation during the second 10-day interval of May – from September 1 until May 10, and so forth.

Further, the linear dependency correlation ratios between mean 10-day water discharge and SCI for high-altitude zones with 200 m increments for the Varzob and Tar were calculated. The highest correlation ratios corresponded to the discharge during the third 10-day interval of April and to the period from the second 10-day interval of May up to September for the Tar River, as well as for the second 10-day interval of April and to the period from the third 10-day interval of May up to the second 10-day period of September for the Varzob River. The calculation results are shown in Figures 3 and 4.

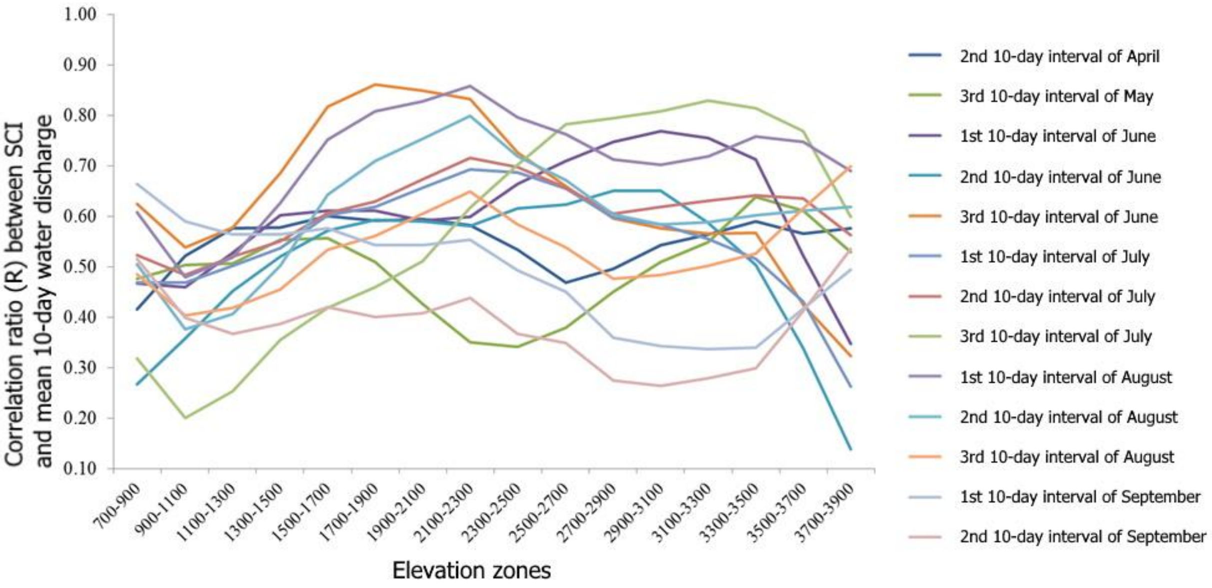


Figure 3. SCI and mean decadal discharge correlation ratios (R)
(Varzob-Dagana River Basin, high-altitude zones in 200 m increments).

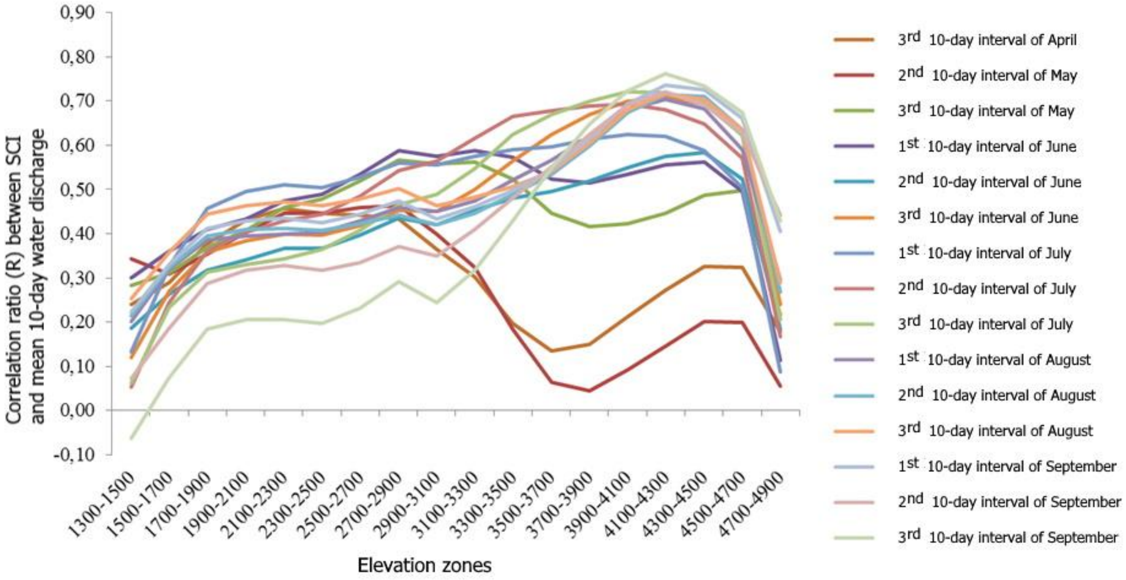


Figure 4. SCI and mean decadal discharge correlation ratios (R)
(Tar-Chalma River Basin, high-altitude zones in 200 m increments).

The analysis of calculation results of the correlation ratios between mean 10-day water discharge and SCI for various altitude ranges allowed identifying the most effective linear relations and elaborating the corresponding equations. Table I shows the obtained equations of linear dependence between mean 10-day water discharge of the Varzob and Tar Rivers and SCI, correlation ratios (R), $\overline{S}/\overline{\sigma}$ and acceptable error calculated for the observation period from 2000 to 2017. The best $\overline{S}/\overline{\sigma}$ results calculated based on formulae (2) and (3) and falling into the category of applicable and high-quality method, as per formulae (4) and (5), were between July and September for the Tar River; and from June to the first 10-day interval of September for the Varzob River. Worse $\overline{S}/\overline{\sigma}$ results were for the periods from April to June for Tar River, and from April to May for the Varzob River. Yet, at the same time the margin of error forecast calculated based on formula (6) for all 10-day intervals for the observation period (2000 through 2017) was 64-100% for the Tar River and 78-100% for the Varzob River, which corresponds to the applicability criteria for an operational forecasting methodology.

Table I. Linear dependency equations for mean monthly water discharge and SCI by high-altitude zones in 200 m increments.

Ten-day interval	Range of altitudinal zones, m ASL	Equation	R	$\overline{S}/\overline{\sigma}$	Margin of error, %
Tar-Chalma Rivers					
3rd 10-days (April)	2100-2300	64.339SCI + 26.583	0.46	0.89	86
2nd 10-days (May)	2500-2700	118.57 SCI + 27.354	0.46	0.89	64
3rd 10-days (May)	2700-2900	168.68 SCI + 4.7742	0.57	0.82	79
1st 10-days (June)	3100-3300	248.63 SCI – 40.515	0.59	0.81	86
2nd 10-days (June)	4100-4300	581.52 SCI – 218.72	0.57	0.82	79
3rd 10-days (June)	4100-4300	594.39 SCI – 256.54	0.71	0.70	93
1st 10-day (July)	4100-4300	352.72 SCI – 109.48	0.62	0.78	93
2nd 10-days (July)	3900-4100	326.27 SCI – 132.29	0.69	0.48	100
3rd 10-days (July)	3900-4100	230.71 SCI – 89.044	0.72	0.69	100
1st 10-days (Aug)	4100-4300	193.39 SCI – 71.329	0.70	0.71	100
2nd 10-days (Aug)	4100-4300	253.45 SCI – 127.9	0.71	0.70	86
3rd 10-days (Aug)	4100-4300	184.58 SCI – 88.256	0.72	0.69	86
1st 10-days (Sept)	4100-4300	145.4 SCI – 66.314	0.74	0.67	85
2nd 10-days (Sept)	4100-4300	94.834 SCI – 34.449	0.72	0.69	85
3rd 10-days (Sept)	4100-4300	77.741 SCI – 26.938	0.76	0.65	85
Varzob-Dagana Rivers					
2nd 10-days (April)	2100-2300	55.01 SCI + 42.024	0.58	0.81	78
3rd 10-days (May)	1500-1700	33.548 SCI + 88.811	0.56	0.83	100
1st 10-days (June)	2700-2900	91.565 SCI + 39.746	0.75	0.66	100

Table I (continued)

Ten-day interval	Range of altitudinal zones, m ASL	Equation	R	$\overline{S}/\overline{\sigma}$	Margin of error, %
Varzob-Dagana Rivers					
2nd 10-days (June)	2700-2900	66.534 SCI + 61.154	0.65	0.75	100
3rd 10-days (June)	2100-2300	67.259 SCI + 54.519	0.60	0.80	100
1st 10-day (July)	2100-2300	52.334 SCI + 61.532	0.69	0.72	100
2nd 10-days (July)	2100-2300	49.125 SCI + 47.773	0.72	0.69	100
3rd 10-days (July)	2700-2900	70.668 SCI + 13.595	0.79	0.61	89
1st 10-days (Aug)	2900-3100	78.462 SCI + 7.5133	0.81	0.59	89
2nd 10-days (Aug)	2100-2300	46.3 SCI + 21.451	0.86	0.51	89
3rd 10-days (Aug)	2100-2300	32.015 SCI + 22.25	0.80	0.60	100
1st 10-days (Sept)	2100-2300	19.599 SCI + 22.007	0.65	0.75	100
2nd 10-days (Sept)	2100-2300	15.439 SCI + 17.844	0.55	0.83	100

4. Discussion

The lack of information on the conditions of snow accumulation in the discharge formation zones of Central Asian rivers with high-altitude catchments can be replenished by satellite sensing data. MODIS imagery processed using the MODSNOW software provide information on the daily snow cover dynamics, and can be applied for designing short-term hydrological forecasting methods. The method developed for the Tar (Tien Shan) and Varzob (Pamir-Alai) Rivers based on the snow cover data of MODIS images can be used for making 10-day forecasts. For the studied rivers, the method's efficiency for the period from June to September fell into the category of “good” and “satisfactory”. For the April-May period, the method's quality was estimated at the “consultation” level due to the synoptic situation in the mountainous regions of Central Asia during these months, i.e. frequent northwestern, western and northern invasions, cyclonic activities with rainfall and prolonged rains. The limitations of using MODIS imagery for developing river runoff forecasting methods are predetermined by image resolution. The snow cover on MODIS images has the spatial resolution of 500 m and, thus their use for watersheds smaller than 1,000 km^2 is considered inappropriate.

5. Conclusions

1. The main advantage of the applied method is the possibility of obtaining high-quality and reliable forecasts of high mountain river runoff based on MODIS satellite imagery processed in the MODSNOW application. This is particularly important for the catchments where no

land-based snow cover observations are carried out currently and/or for the river basins not sufficiently covered by observations;

2. Water content forecasting for the Varzob and Tar Rivers is extremely important for preventing hazardous hydrological events like floods, hydrological droughts and mud floods;
3. The analysis of the correlations between SCI calculated for high-altitude zones with 200 m increments and the mean water discharge pointed to their close dependence over the months when meltsnow and glacial runoff play a decisive role in the formation of river runoff (June-September);
4. Correlation ratios calculated based on the equations were 0.53-0.86 for the Varzob River, and 0.46-0.76 for the Tar River; and method applicability criterion $\overline{S}/\overline{\sigma} = 0.51\text{-}0.83$ for the Varzob, and 0.48-0.89 for the Tar. The margin of error for the Varzob River ranged between 78 and 100%, and between 64 and 100% for the Tar River;
5. In April and May, the correlations between MDDs and SCIs were low, since weather conditions in target river watersheds do not allow reliably forecasting river water content during these months;
6. Future studies will be conducted for other mountain river basins in Central Asia to elaborate MODIS-based methods for short-term hydrological forecasting for operational application by national hydrometeorological agencies.

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References

1. Apel, H., Abdykerimova, Z., Agalkhanova, M. et al. (2018). Statistical forecast of seasonal discharge in Central Asia using observational records: development of a generic linear modelling tool for operational water resource management. *Hydrology Earth System Sciences*, 2018, №2, pp. 2225-2254 (doi: 10.5194/hess-22-2225-2018);
2. Baumgartner, M., Spreafico, M., Weiss, H. (2000). Operational snowmelt runoff forecasting in the Central Asian mountains. Remote Sensing and Hydrology 2000 (Proceedings of a symposium held at Santa Fe, New Mexico, USA, April 2000). *IAHS-AISH Publication*, No. 267, pp. 66-71;
3. Catalogue of glaciers of the USSR [*Katalog lednikov SSSR*] (Ed.-in-chief O.N. Vinogradov), vol. 14. L.: *Gidrometeoizdat*, 1980, p. 44 [in Russian];
4. Gafurov, A., Bárdossy, A. (2009). Cloud removal methodology from MODIS snow cover products. *Hydrology and Earth System Sciences*, 2009, № 3(7), pp. 1361-1373 (doi: 10.5194/hess-13-1361-2009);
5. Gafurov, A., Kalashnikova, O., Apel, H. (2019). Hydrological forecast based on the snow

cover index, derived from basin-wide and elevation specific remote sensing snow cover data in mountainous basins. *Geophysical Research Abstracts*. Vienna: EGU2019, 2019, vol. 21, EGU2019-12817;

6. Gafurov, A., Lüdtke, S., Unger-Shayesteh, K., Vorogushyn, S., Schöne, T., Schmidt, S., Kalashnikova, O., Merz, B. (2016). MODSNOW-Tool: an operational tool for daily snow cover monitoring using MODIS data. *Environmental Earth Science*, 2016, №75(14), p. 1078 (doi: 10.1007/s12665-016-5869-x);
7. Gafurov, A., Nurbatsina, A., Kalashnikova, O. (2018). Assessment of water resources in Central Asia by remote sensing methods [*Ocenka vodnyh resursov v Central'noj Azii metodami distancionnogo zondirovanija*]. New methods and results of landscape research in Europe, Central Asia and Siberia [*Novye metody i rezul'taty issledovanij landshaftov v Evrope, Central'noj Azii i Sibiri*], edited by Sycheva, V. and Muller, L.) in 5 volumes, 2018, vol. 2, pp. 405-409 [in Russian];
8. Gerlitz, L., Vorogushyn, S., Gafurov, A. (2020). Climate informed seasonal forecast of water availability in Central Asia: State-of-the-art and decision making context. *Water Security*, 2020, vol. 10, 100061 (doi: 10.1016/j.wasec.2020.100061);
9. Guided Tutorial for Forecasting Services [*Nastavlenie po sluzhbe prognozov*]. Section 3, part 1. L.: *Gidrometeoizdat*, 1962, p. 196 [in Russian];
10. Kalashnikova, O., Gafurov, A. (2017). Using ground and satellite data on snow cover to predict the Naryn River runoff [*Ispol'zovanie nazemnyh i sputnikovyh dannyh o snezhnom pokrove dlja prognoza stoka reki Naryn*]. *Ice and Snow* [*Led i sneg*], 2017, vol. 57, №4, pp. 507-517 [in Russian];
11. Kalashnikova, O.Yu. (2015). On the issue of developing methods for long-term forecasting of mountain river runoff and water inflow to reservoir: Naryn River case study [*K razrabotke metodov dolgosrochnogo prognoza stoka gornyh rek i pritoka vody v vodohranilishhe na primere reki Naryn*]. *Science, new technologies and innovations of Kyrgyzstan* [*Nauka i novye tehnologii i innovacii Kyrgyzstana*], 2015, №5, pp. 100-103 [in Russian];
12. Kalashnikova, O.Yu., Gafurov, A.A., Omorova, E.A. (2020). Forecasting the water content of the Naryn River for the growing season months based on MODIS imagery [*Prognoz vodnosti reki Naryn na mesjacy vegetacionnogo perioda na osnove snimkov MODIS*]. *Science, new technologies and innovations of Kyrgyzstan* [*Nauka i novye tehnologii i innovacii Kyrgyzstana*], 2020, №3, pp. 14-18 [in Russian];
13. Niyazov, J.B., Kalashnikova, O.Yu., Gafurov, A.A. (2020). Water resource assessment of the Pamir-Alai rivers by remote sensing methods (Kafirnigan and Gunt Rivers case studies) [*Ocenka vodnyh resursov rek Pamiro-Alaja metodami distancionnogo zondirovanija (na primere rek Kafirnigan i Gunt)*]. *KRSU Bulletin* [*Vestnik KRSU*], 2020, vol. 20, №4, pp. 152-157 [in Russian];

14. Pertzinger, F., Baumgartner, M., Kobilov, T., Schulz, A., Vaselina, L. (2002). Model of snow cover formation and methodics of long-term prediction of inflow into water reservoir during flood season. Proceedings, International Conference on Flood Estimation, Bern, Switzerland;
15. Podrezov, O.A. (2019). Methods of statistical processing and analysis of hydrometeorological observations: textbook for bachelor hydrometeorologists [*Metody statisticheskoj obrabotki i analiza gidrometeorologicheskih nabljudenij: ucheb. dlja bakalavrov-gidrometeorologov*]. Bishkek: KRSU. 2019, p. 170 [in Russian];
16. Rango, A., Salomonson, V., Foster, J. (1977). Seasonal streamflow estimation in the Hymalayan region employing meteorological satellite snow cover observations. *Water Resources Research*, 1977, vol. 13, No. 1, pp. 109-112;
17. Shabunin, A.G. (2018). Catalogue of glaciers of Kyrgyzstan [*Katalog lednikov Kyrgyzstana*]. Central Asian Institute for Applied Geosciences (CAIAG). Bishkek, 2018, p. 709 [in Russian];
18. Shults, V.L. (1965). Rivers of Central Asia [Reki Srednej Azii]. L.: *Izd-vo GIMIZ*, 1965, p. 680 [in Russian].