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ИСПОЛЬЗОВАНИЕ ДАННЫХ О СНЕЖНОМ ПОКРОВЕ СО СПУТНИКОВЫХ СНИМКОВ MODIS ДЛЯ ПРОГНОЗА СТОКА РЕК НАРЫНСКОГО БАССЕЙНА

WATER AVAILABILITY FORECASTING IN NARYN BASIN USING MODIS SNOW COVER DATA

Бул изилдөөдө биз MODIS сүрөттөрүнөн алынган кар катмары боюнча информацияны колдонуп 1990 жылдары жабылган гидропосттор үчүн дарыялардын агымын суу толук айларда (май-сентябрь) аныктоого колдонуу мүмкүнчүлүктөрүн анализ жасадык. MODIS сүрөттөрүн иштеп чыгуу MODSNOW программсы менен аткарылат жана кар катмарынын аянтын суббассейндер боюнча аныктап анализдөө ГИС (ArcMap) программаны колдонуу менен эсептелет. 1990 жылдары жабылган гидропосттор үчүн дарыялардын агымын реконструкциялоо азыркы заманбап аспаптар менен жабдылган гидропосттордо байкоолордун негизинде сызыктык регрессияны колдонуп аткарылган. Биздин изилдөөлөрдүн жыйынтыктарында суу толук кездеги агымды эсептөөнүн тактыгы 0.62-0.77 корреляция коэффициенти менен аныкталган.

Ачкыч сөздөр: *ГИС карталар, мейкиндиктик аналититка куралдары, MODIS жандоочтук сүрөттөрү, суу топтоо аянты, кар катмары.*

В данном исследовании мы проанализировали возможность использования информации о снежном покрове со снимков MODIS для прогнозирования стока рек на период половодья (май-сентябрь) для гидропостов закрытых в 1990-е годы. Обработка информации о снежном покрове со снимков MODIS производится в программе MODSNOW и анализируются с использованием ГИС (ArcMap), в котором проводятся расчеты площади снежного покрова по суббасейнам. Для закрытых с 1990-х годов гидропостов, была проведена реконструкция стока с данными о стоке рек по гидропостам имеющими современные наблюдения методом линейной регрессии. Результаты наших исследований показывают, точность применения расчетов стока на период половодья с коэффициентом корреляции 0.62-0.77.

Ключевые слова. *ГИС карты, инструменты пространственной аналитики, спутниковые снимки MODIS, водосбор, снежный покров*

In this study we analyzed the usefulness of MODIS snow cover images for forecasting discharge for hydroposts closed in 1990s for vegetation period. A MODSNOW processed MODIS snow cover images are used for this purpose which are analyzed using GIS (ArcMAP) in which subbasin specific snow cover areas are estimated. For already closed hydroposts after 1990s, the reconstruction of discharge at those gauging stations was done using discharge data from other still operated gauging stations and linear regression method. The results of this study show R^2 of 0.62-0.77 accuracy in ungauged basins.

Keywords: *GIS Map, Spatial Analyst Tools, MODIS images, watershed, snow cover*

Introduction

The melt water from seasonal snow cover is one of the most important components of river runoff formation in Central Asia. Up to 70% of total precipitation in Tien Shan falls as snow providing 60% of the total river runoff (*Schultc, 1965; Aizen and others, 1995*) /1/. Currently forecast of seasonal water availability is done using total rainfall in winter month which is taken from meteorological stations. However, total precipitation and observation stations is a point information which does not represent always the entire watershed area. Remote sensing data on snow cover is useful in this case which delivers spatially distributed information over the whole watershed area which can act as better predictand than total rainfall.

The Naryn River basin, the major tributary of Syr Dar'ya River is the second largest river in Central Asia. The water of Naryn River is originated in the inner Tien Shan at the Akshiirak glacier massif (41°50'N 78°15'E) and the vast seasonal snow covered areas at the upper Kichi-Naryn and Chong-Naryn river basins. The watershed area of Naryn River Basin, above the Toktogul Dam Stream Gauge (SG) is 58,000 km^2, which include about 926 km^2 (in 2000s) of glacier covered area (*Kriegel, et al., 2013*) /5/. The watershed elevation range is between 700 and 5000 m asl. The main hydrological characteristics of the Naryn River tributaries are presented /6/ in Table 1.

Table 1 - Main hydrological characteristics of tributaries in the Naryn River basin /6/

№	Stream Gauge	River length, km	Watershed area, km^2	Mean elevation of sub-basins, m asl	Average discharge during May-Sept, m^3/s	Average annual discharge, m^3/s
1	2	3	4	6	7	8
1	Naryn R. – Naryn City	-	10500	3570	175	93.0
2	Naryn R. – Uchterek SG	578	48200	2890	558	324
3	Chong-Naryn R. (mouth)	132	5710	3720	85.3	47.2
4	Kichi-Naryn R.– (mouth)	144	3870	3500	78.7	41.3
5	Atbashy R.– confluence with Acha-Komandy R.	180	1500	3500	31.2	17.7
6	Alabuga – Koshtube Village	182	3710	3260	48.9	29.5
7	Torkent R.- Torkent Village	-	572	2420	19.5	10.3
8	Chychkan R. – 5.5 km from Balachychkan R.	78	903	2890	32.5	17.5
9	Uzunakhmat R.- at confluence with Ustasai R.	90	1790	2360	50.0	28.7

Major source of water flow in Naryn river basin is the meltwater from seasonal snow with the runoff peak in June-July /7/. Glacier melt water amount only 7.8% in the total river runoff (*Dikih and Usubaliev, 2010*) /4/ and therefore, the amount of runoff in July-September do not exceed the amount of runoff in April-June. Figure 1 illustrates the seasonal flow regime of tributaries in the Naryn basin.

Rainwater plays minor role in runoff formation in this basin as the annual precipitation maximum is observed in summer (almost 60%) that falls as snow at elevations above 3000 m asl. Therefore, the snow line in Naryn River basin reaches 4000-4300 m asl and snow melt water formed mainly at high elevation areas. The average annual precipitation is about 600-650 mm, with winter precipitation amounting only 10-15% of annual.

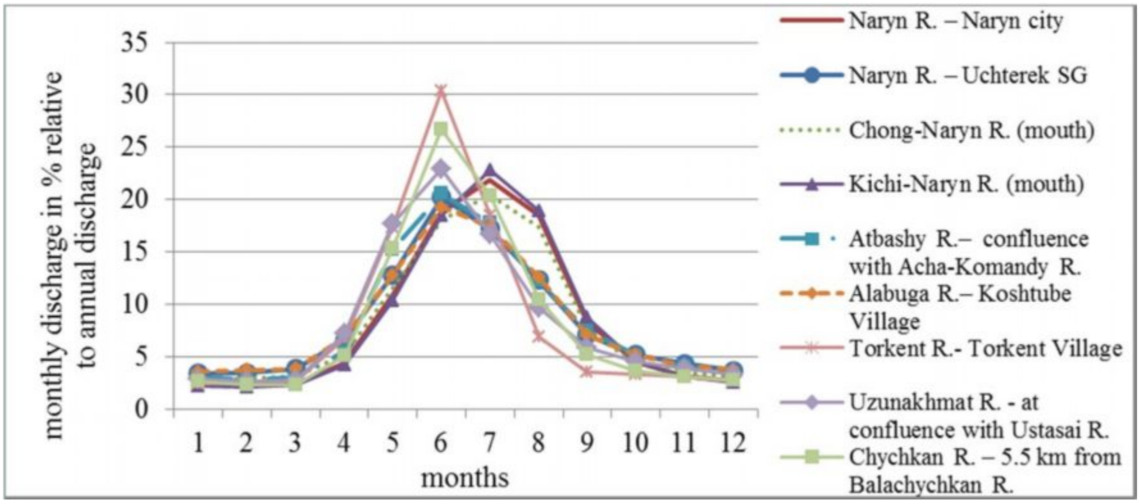

Figure 1. Monthly discharge distribution (in %) of rivers in Naryn Basin

The goal of our research was to develop a method of water availability forecasting during the flood time using remote sensing MODIS snow cover data and GIS for hydroposts (SG) where observations ceased after 1991.

Analytical method

A method of water forecasting during peak discharge from May to September was developed for ungauged basins based on the MODIS snow cover and hydrological data (river runoff) for the period of 2000 to 2013. The method is based on multiple linear regression analysis for which observed discharge and snow cover area are used as main predictors. Snow covered areas were computed using MODIS snow cover data processed using MODSNOW program (*Gafurov and Bárdossy, 2009*) /2/. Subbasin specific snow cover area which is used as an indicator in the forecasting methodology was prepared using ArcMap Spatial Analysis Tool.

Tributaries where hydroposts were ceased after collapse of Soviet Union in 1991 are: Atbashy River (confluence with Acha-Komandy River) Alabuga River (Koshtube Village) and Torkent River (Torkent Village). During peak discharge there is a potential in these tributaries for flooding in rural areas and villages that are located in these subbasins. Therefore it is important to forecast water availability during peak flow. Moreover, the Torkent River is one of the side tributary to Toktogul Reservoir and thus its inflow amount is important for reservoir operation. Above mentioned tributaries have higher correlation coefficient (0,69-0,83) with Uchterek hydropost and Naryn City hydroposts. Analysis of correlation matrix of runoff for the period before 1991 at these hydroposts show this evidence (Table.2).

Table 2 - Correlation matrix of closed hydroposts with other still operating hydroposts for mean discharge during May – September.

№	Name of river	1	2	3	4	5	6	7	8
1	Naryn R. – Naryn City	1.00	0.76	0.81	0.61	0.49	0.41	0.44	0.44
2	Naryn R. – Uchterek SG		1.00	0.75	0.83	0.69	0.83	0.65	0.69
3	Chong-Naryn R.			1.00	0.63	0.56	0.41	0.51	0.46
4	Atbashy R.				1.00	0.33	0.76	0.60	0.53
5	Alabuga R.					1.00	0.57	0.16	0.46
6	Torkent R.						1.00	0.61	0.48
7	Chychkan R.							1.00	0.75
8	Uzunakhmat R.								1.00

Equations 1, 2 and 3 lead to best estimation of discharge based on historical discharge data before 1991:

1. $Q_{5\text{-}9}$ Atbashi = 0,05*$Q_{5\text{-}9}$ Naryn R.- Uchterek SG + 1,2 (1)
2. $Q_{5\text{-}9}$ Alabuga = 0,07*$Q_{5\text{-}9}$ Naryn R. - Uchterek SG + 13,8 (2)
3. $Q_{5\text{-}9}$ Torkent = 0,036*$Q_{5\text{-}9}$ Naryn R.- Uchterek SG + 0,06 (3)

In this methodology, antecedent discharge for the month April is important predictand that gives the indication of groundwater storage. Therefore, discharge for the month of April for the closed hydroposts was reconstructed using correlation matrix as shown in (Table 3).

Table 3 - Correlation matrix of discharge in rivers of Naryn basin for April before 1991.

№	Name of River	1	2	3	4	5	6	7	8
1	Naryn R. – Naryn City	1.00	0.77	0.81	0.62	0.69	0.55	0.25	0.35
2	Naryn R. – Uchterek SG		1.00	0.78	0.69	0.68	0.34	0.42	0.53
3	Chong-Naryn			1.00	0.60	0.52	0.36	0.16	0.37
4	Uzunakhmat R.				1.00	0.73	0.34	0.34	0.53
5	Chichkan R.					1.00	0.28	-0.10	0.52
6	Atbashy R.						1.00	0.41	0.07
7	Alabuga R.							1.00	-0.10
8	Torkent R.								1.00

Following equations were obtained for the estimation of discharge in April considering higher correlation coefficients:

1. Q_4 Atbashy = 0,19*Q_4 Naryn R.- Naryn SG + 3,1 (4)
2. Q_4 Alabuga = 0,06*Q_4 Naryn R. – Uchterek SG + 11,3 (5)
3. Q_4 Torkent = 0,03*Q_4 Naryn R.- Uchterek SG + 2,4 (6)

For the estimation of water availability for vegetation period we used MODIS snow cover data. Original MODIS snow cover data was processed using MODSNOW Tool which enables to remove possible cloud cover for the day of forecast (April 30). MODSNOW Tool delivers cloud free snow cover maps in ESRI ASCII format. Further, snow cover area of each sub-basin relative to total sub-basin area was estimated using ArcGIS software /8/ for the following sub-basins:

1. Naryn - Toktogul Dam
2. Naryn –Uchterek SG
3. Upper Naryn River - Naryn City
4. Uzunakhmat – Ustasai R. (mouth)
5. Chichkan –Bala-Chychkan R. (mouth)
6. Torkent – Torkent Village
7. Atbashy – Acha-Komandy R. (mouth)
8. Alabuga – Koshtube Village

The MODSNOW processed snow cover maps in ASCII format were converted into raster format. As an example, snow cover map is illustrated in Figure 2 for April 30, 2015.

Next, snow cover area for a subbasin was computed using the Spatial Analyst Tool (Extraction, Extract by Mask). This was done using the records in attribute table for snow and snow free grids by taking the relationship of each class to total area in this subbasin.

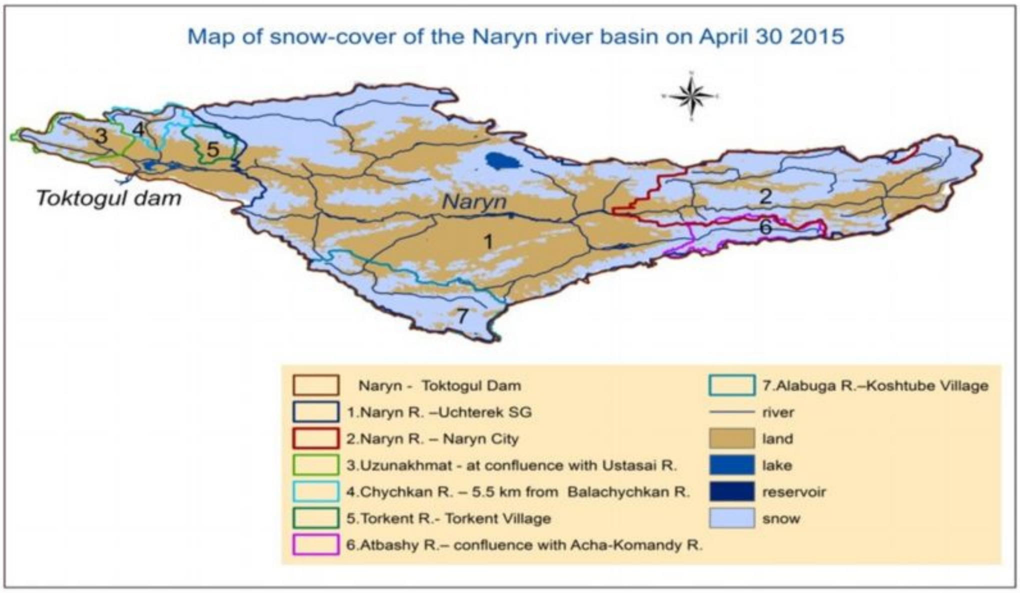

Figure 2. Snow cover map developed using ArcGIS for 30 April 2015

Table 4 - Snow cover areas on April 30, 2015 for different subbasins

№	Name of river – Stream Gauge	Snow cover areas
1	Torkent R. – Torkent Village	51%
2	Atbashy R. – Acha-Komandy R. (mouth)	97%
3	Alabuga R. – Koshtube Village	78%

Computed relationships of May-September mean discharge with snow cover area and antecedent discharge for April showed coefficient of correlations of 0.62-0.77 (Fig 3).

For the computation of runoff for summer period following equations were obtained for already closed hydroposts:

1. $Q_{5\text{-}9}$ Atbashi = 0,826*Q_4 Atbashi + 0,23*Sn_4 + 6,2 (7)
2. $Q_{5\text{-}9}$ Alabuga = 1,048*Q_4 Alabuga + 0,465*Sn_4 + 8,6 (8)
3. $Q_{5\text{-}9}$ Torkent = 1,655*Q_4 Torkent + 0,371*Sn_4 - 6,02 (9)

Using obtained equations 7, 8 and 9, water availability forecasts for May-September in 2015 was carried out. Following results are obtained:

In river At-Bashy, mean discharge for May-September was 38.4 m^3/s or 125 % from long term mean.

In river Torkent this was 30.4 m^3/s or 158 % from long term mean.

In river Alabugy this was 73.9 m^3/s or 148 % from long term mean.

With this, above long term mean discharge (125-158 %) was expected in 2015 and responsible water resources organizations, energy companies and emergency companies were recommended to take mitigating measures.

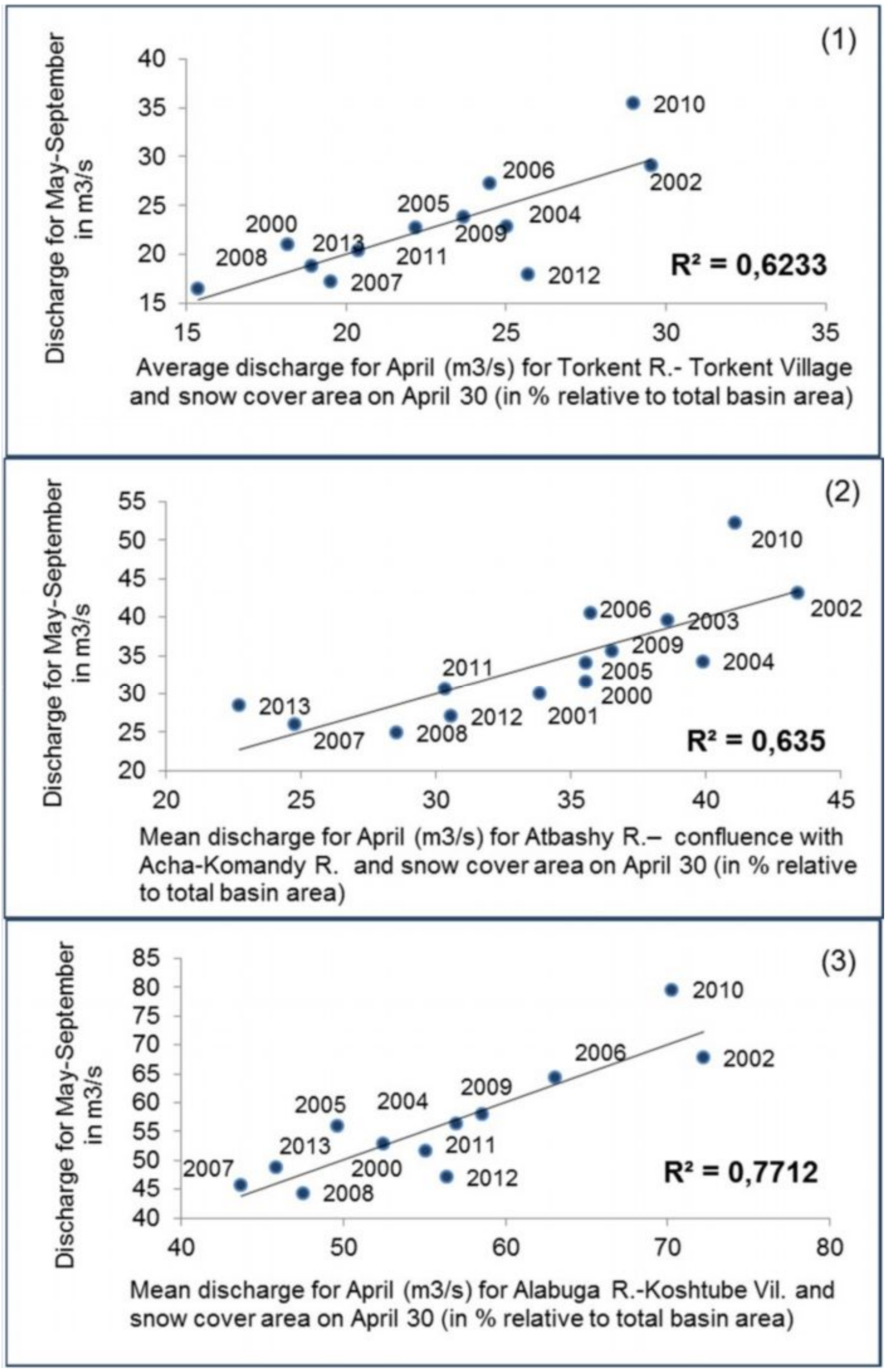

Figure 3. Relationships of mean discharge for the period of May-September for rivers Torkent (1), Atbashy (2), Alabuga (3) and snow cover area for April 30 and discharge for April.

Conclusion

The method using MODIS snow cover area data to forecast water availability for the gauges that were closed after 1991 gave good results (R^2 = 0.62-0.77).

Information on snow cover from MODIS is available free of charge and has daily temporal resolution which enables obtaining and using such data for forecasting discharge in the river basins.

GIS allows to interpret information obtained from remote sensing for further application in different subbasins.

The here proposed method can be applied to the river basins with major seasonal snow type of runoff formation as well as for the basins with mixed, snow and glacier runoff formation.

One of the main advantages of the method is the possibility of forecasting discharge in rivers located at high elevation basins (between 2,4-3,7 km in this study), where obtaining information on snow accumulation or precipitation in winter period is problematic without using satellite data.

Water related organizations, energy companies or state emergency organizations can benefit by using such methodology which enables to identify whether the season will water scarce or water excess year and take measures according to that.

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