Central Asian Journal of Water Research (2017) 3(1): 43-53
Special Issue on Water Hazards in Central Asia

Evaluation of hydrological processes (floods, high water, lateral erosion and mudflows) in the Kara-Unkyur River Basin (Kyrgyzstan)

Moldobekov B. D.
Central-Asian Institute for Applied Geosciences (CAIAG)
(b.moldobekov@caiag.kg)

Abdibachaev U. A.
Central-Asian Institute for Applied Geosciences (CAIAG)

Kalashnikova O. Ju.
Central-Asian Institute for Applied Geosciences (CAIAG)

Abstract
Almost in all river basins of Central Asia, with the onset of spring, the probability of natural disasters, such as floods, high water and related lateral erosion, increases. Especially, these phenomena often occur in large river basins of Fergana Valley, Kyrgyz ridge and Trans-Ili Alatau. The aim of this study was to identify vulnerable areas affected by erosion processes in the course of disastrous floods and high water in order to take preventive measures for protection of settlements, their territories and infrastructure. To identify vulnerable areas affected by erosion processes in the Kara-Unkyur River Basin, a complex of field methods of ground-based observation was implemented with the use of Remote Sensing (RS) data. Based on the obtained data, a degree of manifestation of exogenous geological processes was analyzed and evaluated. Recommendations for decision-making were elaborated and submitted to the state authorities (Ministry of Emergency Situations of the Kyrgyz Republic, MES).

Keywords: catastrophic floods, erosion processes, Kara-Unkur River, remote sensing, hydrological processes.

1. Introduction

Occurrence and development of hazardous hydrological events, such as floods, high water and lateral erosion, are determined by a set of natural conditions and a sum of development factors. Present-day development of these phenomena in the Kara-Unkyur River Basin is understudied, although it causes harm to population and economic entities of the Kyrgyz Republic. In 1988, the following events were recorded and reflected in the report of "Kirgizgiprozem": in Bazar-Korgon district, in April 1987, mudflows destroyed the road at 17, 19, 23, 25 kilometers of the automobile road Sovetskoye (Bazar-Korgon) - Arslanbob, and swept away the bridge over the Kara-Unkyur-Sai river on the Frunze-Osh road. According to MES, the water level of the Kara-Unkyur river in the Nooken district increased in the second decade of April 2017. The flood washed away the dam built in 1970-1980s. 300 meters of the river bank was washed out, which resulted in flooding of farmlands in the Sakaldy rural district, as well as in a risk of flooding of residential houses. More than 800 families were evacuated. These examples show that the study of the development of hazardous phenomena in the river basin is still relevant, particularly, when quantitative characteristics of river valley floods and the state of protective measures change in unstable climate conditions.

For the last two decades, in the study basin, none of hazardous hydrological processes have been evaluated; moreover, there is no unified geodatabase of hazardous processes, which allows collection, systematization, storage, update of information on damages, and visualization by means of appropriate software applications that supports geoinformation systems including remote sensing data. The main purpose of the study was to identify vulnerable areas affected by erosion processes in the course of disastrous floods and high water, and to perform spatially-temporal analysis of remote sensing data and compare them with the results of field studies. All work related to processing of Landsat optical data was performed using ArcGIS software application, with the additional Spatial Analyst module designed for raster data analysis.

Figure 1. Consequences of floods in the Kara-Unkyur-Sai River, June 5, 2010.

2. Study area

Kyrgyz Republic (KR) is a highland with a complex terrain, and a system of that is dissected by ridges extending in a sub-latitudinal direction from east to west, with intermountain troughs of various sizes and heights [1, 2]. Climatic conditions of the Republic are generally determined by its mid-latitude geographical location, complexity of mountainous terrain, and with such characteristic features as continental dry air, low clouds and high solar radiation. All climatic elements are changing both in latitudinal and vertical (altitudinal) directions [1, 3, 4]. Mudflows and high-waters resulting in floods and bank erosion cause 29.65% of all registered emergencies. Most of them occur in the Jalal-Abad (35.5%), Osh (22.4%), and Batken (21.5%) regions. In the Talas, Chuy, Issyk-Kul, Naryn regions, they comprise 6.4% - 4% [16]. The investigated Kara-Unkyur River Basin (Figure 1) occupies a total catchment area of 1300 km^2, geographically located in the south of the Kyrgyz Republic and is a part of the

Bazar-Korgon district, in the Jalal-Abad region. This river forms its flow in the north-western end of the Fergana ridge. From the river head to the Bazar-Korgon village it is called Kara Unkyur, and downstream – Tentek-Sai. Near the Bazar-Korgon village, the riverbed is usually dry due to water uptakes for irrigation.

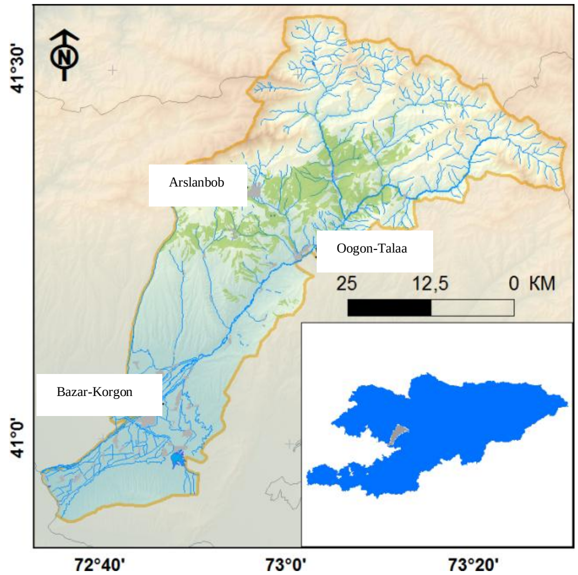

Figure 1. Investigated water basin of the Kara-Unkyur River, on the blue map - highlighted in grey

The natural basin conditions are rather subdued relief, densely covered by walnut-fruit forests and bushes, which create conditions for suppression of widely spreading mudflow origination sites in the area. However, the main watercourse of Kara-Unkyur is hazardous mudflow. Here, mudflow origination sites are located both on the left and right slopes. Large floods occur in a wide flood bed (300-400 m) near the Bazar-Korgon village.

3. Methodology and initial data

3.1. Methodology

As for the methodology of survey and description of the mudflow origination sites in field works, the authors of this publication adhered to specific rules and conditions that are well described in the papers of Lomtadze V. D. (1976), Bondarik G. K. (1986), Perov V. F. (2012), as well as other researchers [6, 7, 8, 9, 10, 11]. Currently, the issues of use of materials obtained from satellites in geological, geotechnical and other investigations are covered in many publications of various well-known journals. Satellite optical images were processed and relevant information was acquired in accordance with the recommended basic and special steps and GIS tools for processing of remote sensing (RS) data and digital terrain model (DTM) [12, 13, 14, 15, 16]. Effect of climatic factors (accumulation of snow cover in winter and precipitation) on high water and mud floods was analyzed using statistical methods in accordance with the hydro-forecasting guide and available experience in using surface and satellite information for other river basins of the Kyrgyz Republic [17, 18, 19]. Snow cover information was proceed in GIS; its interpretation and removal of cloud cover from MODIS images were made by using the MODSNOW-Tool [20].

3.2. Initial data

Initial data in this study are presented in Table 1. Small-scale thematic maps are used as they are freely available.

Table 1. Initial data

No.	Data name	Source
1	Remote sensing data	Landsat, with optical resolution 15-30 m/pixel. Survey scene: 1994/06/20, 1998/05/30, 2001/07/17, 2002/05/26, 2010/06/16, 2013/06/08, 2014/06/11, 2017/04/25, RapidEye with optical resolution 6 m. Survey scene: 2014/August ASTER (DEM) (30 m)
2	Topographic map	Scale 1:100 000
3	Geological map	Scale 1:500 000
4	Geomorphological map	Scale 1:500 000
5	Engineering-geological map	Scale 1:500 000
6	Surface water map	Scale 1:500 000
7	Groundwater map	Scale 1:500 000
8	Maps of slopes, slope exposure and flow direction	With Spatial Analyst tools, the values of slopes and slope exposure were retrieved from DTM (30 m) and maps were generated in ArcGIS 10.1 application
9	Field investigation data	Obtained using GPS receivers
10	Snow cover data from satellite images	MODIS, spatial resolution for snow cover 500 m. For a period 2000-2015.
11	River basin (catchment) map	With ArcGIS Hydrology Tool, the area of Kara-Unkyur river basin was retrieved from ASTER (DEM).
12	Data on water flows and precipitation in the river basin	Kyrgyzhydromet data from the hydrological station of the Kara-Unkyur (Tentek-Sai) river – the Charbak village, Meteorological station Ak-Terek.

4. Discussion of results

The main cause of floods and mudflows in piedmont of the Kara-Unkyur River Basin (Bazar-Korgon district) is heavy rains. During cold-air outbreak, mudflow forming rains are 20 mm per day, disastrous mudflows are 30 mm per day and more. Accumulation of precipitation during cold season (October-March) and 2-3 days prior moisture also have an impact on the intensity of mudflows. In rare cases of torrential rains, mudflows are formed on the first day. In March-May, cold-air outbreak and altitude cyclones often cause great drops in air temperature, however the critical temperature for mudflow formation is +4°C up to 1800 m altitudes, and +2°C up to 2200 m altitudes. In April-May, mudflows can form in all types of precipitation-forming synoptic processes, however they are most probable during wave actions, north-western outbreaks and high-altitude cyclogenesis, especially in May when highly hazardous mudflows can occur. In June-August, mudflows generally occur with high-altitude cyclogenesis and northern outbreaks [21, 22, 23]. It should also be noted that with high-altitude cyclogenesis, distribution of precipitation is very uneven and the meteorological stations located in the study area do not always record heavy precipitation, especially occurring in June-July.

Over the past 12 years, 25 cases of continuous precipitation of 60-122.3 mm in two days were recorded. Continuous precipitation is generally observed once a year and usually occurs in April or May. An exception was in 1998, when 3 cases of heavy precipitation occurred in May. 2 more cases occurred in April and May of 1994, 1996 and 2005, in April and July of 2002, in April and June of 2014 (Figure 2). In most cases, mudflows and floods occurred during continuous rains (Figure 3).

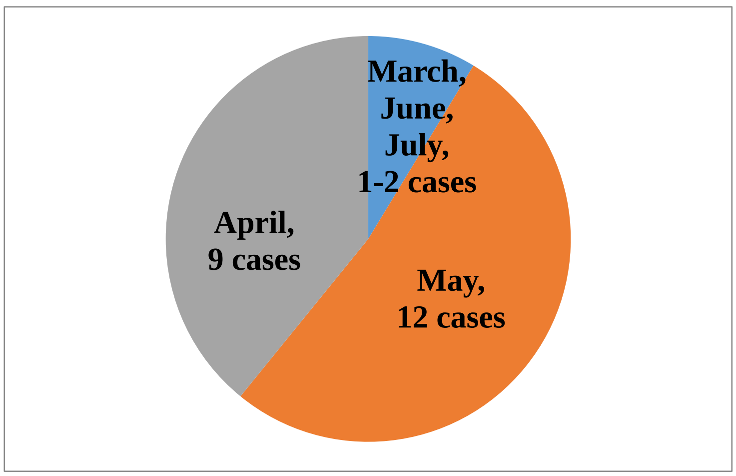

Figure 3. The number of cases of continuous precipitation, records from the Ak-Terek meteorological station from 1992 to 2014

Evaluation of snow cover area during intensive snow melting serves as an indirect indicator affecting the volume of surface runoff of involved material. The snow cover maps of the river basin for the period 2000-2014 were drawn based on the processed MODIS satellite images. Formation of snow cover in the study basin is notable for great diversity in the reviewed period. For the development of snow cover maps, the dates of snow cover melting were taken into account based on the results of long-term observations from the Ak-Terek meteorological station (April 3). Snow cover destruction maps are constructed – as of March 31. Average value of snow cover area in the Kara-Unkyur River Basin as of March 31 – 46% of the total basin area. In 2003, 2004, 2011 and 2014, snow cover area ranged from 50% to 58%, in 2001 and 2013 the minimum values were 26-30% of the total basin area. In March 2012, the maximum values of snow cover area of 69% were observed. Maximum water flows of the Kara-Unkyur river (Tentek-Sai) are given in Table 2 that usually occur in April-May. Due to non-functioning of a hydrological station from 2004 to 2009, no observations of water flows were carried out. Data for the vegetation season of 2004 were recovered, data for 2005-2009, unfortunately, could not been recovered. Table 2 presents the data on snow cover area according to MODIS satellite images, the number of cases with heavy precipitation, the number of cases with mudflows occurred in the Jalal-Abad region, water flows in the Kara-Unkyur river in high-water period (April-September), maximum water flows and their dates. In the years with the least number of mudflows and low-water in the Kara-Unkyur river (e.g., 2001), the lack of snow storage by the beginning of high water and the smallest number of heavy precipitation were observed, and vice versa, in the years with considerable snow storage and heavy precipitation, the large number of mudflows and high water were observed on the Kara-Unkyur river.

Table 2. Water flow of the Kara-Unkyur river

Year	**Snow cover area as of March 31 / number of cases of heavy precipitation**	**Number of cases of mud floods***	**Water flows in Kara-Unkyur river**		**Date of maximum water flow**
			Average-vegetation, m3/s	**Maximum, m3/s**	
2000	43 / 9	16	38,4	98,5	12.05
2001	30 / 4	2	20,9	41,5	20-21.05
2002	45 / 11	47	55,5	116	28.05
2003	56 / 16	23	54,4	141	26-28.04
2004	58 / 11	8	55,4	-	-
2005	42 / 13	10	-	-	-
2006	46 / 9	5	-	-	-
2007	49 / 8	17	-	-	-
2008	41 / 11	21	-	-	-
2009	38 / 10	32	-	-	-
2010	47 / 14	47	63,1	149	23.05
2011	54 / 9	27	-	-	-
2012	69 / 14	75	-	-	-
2013	30 / 9	29	-	-	-
2014	26 / 7	12	-	-	-
2015	51 / no data	16	-	-	-
average	46 / 9	24			

* - data of the Ministry of Emergency of the Kyrgyz Republic

The forecast of maximum and average-vegetation water flows is made based both on the analysis of precipitation accumulation from October to March, from October to April (according to the Ak-Terek meteorological station) and on the snow cover data from satellite images, using the developed procedure of CAIAG (Central Asian Institute of Applied Geosciences). The correlation coefficient (R^2) of an average-vegetation water flow and maximum water flows in the Kara-Unkyur river with snow cover area according to MODIS data is 0.66 and 0.86, respectively. Using multispectral satellite images of Landsat and Rapid

Eye, the post-event analysis of terrain was performed. So, for the Landsat scenes, it was applied in the RGB composition with various channel combinations. To interpret the objects exposed to mudflow deposits and underfloods, a combination of 453 was used followed by information extraction and reclassification (Remap). Figure 4 presents a series of Landsat scenes showing the areas with high surface humidity detected.

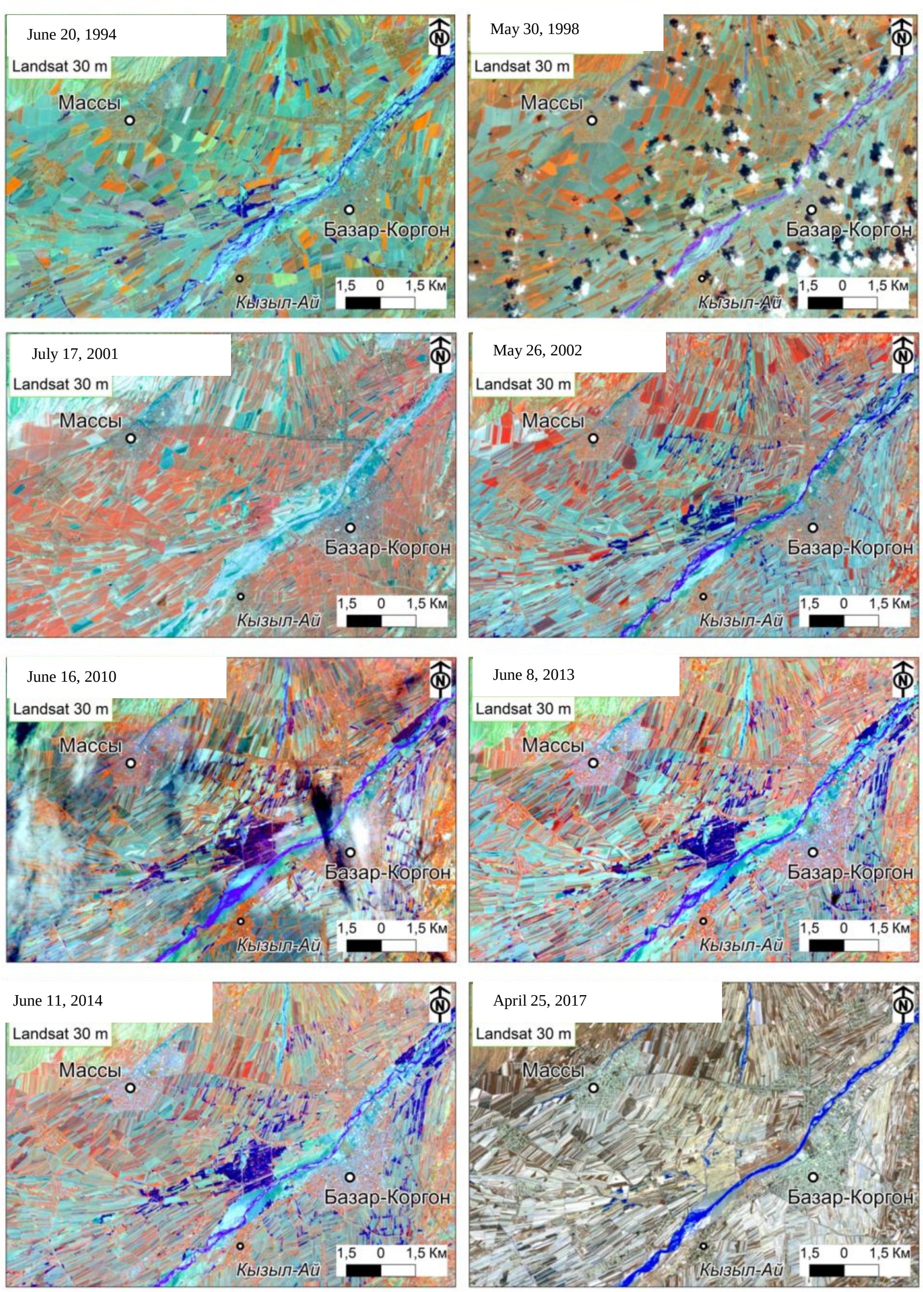

Figure 4. A series of Landsat scenes for 1994-2017. RGB 453 combination. Areas with high humidity are highlighted in blue. Dark spots on a segment of the scene for 2010 are cloud shadows

It should be noted that the authors did not perform any analysis of the scenes from 2003 to 2009 due to incorrect surface display because of a technical fault in *Scan Line Corrector* (SLC) in ETM+ tool of Landsat 7 satellite [24]. According to the obtained results, based on the Landsat data, the so-determined “high humidity areas” were retrieved and calculated, and presented in Table 3.

Table 3. “High humidity areas”

Date of scene of a satellite image YYYY/MM/DD	Area in hectares
1	**2**
1994/06/20	600,1
1998/05/30	599,6
2002/05/26	1233,1
2010/06/16	3334,4
2013/06/08	2275,3
2014/06/11	2605,1

From Table 3 (values in column 2) it follows that from 1994 to 2010 the area tends to increase and the maximum value falls on 2010, however according to Table 2 (column 3), 47 cases of mudflows were recorded in 2002 and 2010. The values of area surely differ between these scenes, and the authors assume (based on the field work survey) that after mudflows in 2002 some engineering and protective structures were destroyed or lost their capability. In the investigated territory, there are 60 areas of development of mudflows and lateral erosion (M&LE) that carry a threat for residential houses and infrastructure of settlements, with a total coverage area of 724.8 ha and about 83% of the areas are located on the right bank of the Kara-Unkyur river. During field surveys of the area, 60 mudflow areas and lateral erosion areas were described and systematized; they are accumulated on the northern slopes and nearby exposures – 4, southern and nearby exposures – 24, eastern and western exposures – 15 and 17 respectively. M&LE areas are mostly located, in percentage, under the terms of engineering-geological zoning, in the deposits of "Molasse-Cenozoic" formation – 49.2%, "Intermountain troughs" formation – 27.1%, "Mountain slopes" formation – 22%, and "Terrigenous-Carbonate" formation – 1.7%. Under the terms of gradation of surface water flow, 71.2% of the areas are located in formation zone “0.1-5.1 l/s km^2”, zone “20.1-25 l/s, km^2” – 15.2% and in zone “Area of flow dissipation”– 13.6%. In "Low-mountain <1200 m" zone, 79.7% of M&LE areas are located; in "Mid-mountain 1200-2500 m" zone, there are 20.3% of their total amount. According to the classification of their impact on structures, they are divided into three groups: "Low-power" (small washouts, partial clogging of culvert holes) – 32.2%, "Moderate-power" (large washouts, full clogging of holes, damage and demolition of foundationless structures) – 39%, and "High-power" (highly-destructive power, demolition of bridge trusses, destruction of bridge supports, stone structures, roads) – 28.8%. According to the classification of maximum amount of one-time wash-out, M&LE areas are divided into: “less than 1.0 ths m^3" – 66.1% "1.0 ths – 10 ths m^3" – 23.7%, and "0.1 – 1 mln m^3" – 10.2%.

5. Conclusion

1. The main cause of mudflows and lateral erosion in the Kara-Unkyur river valley is precipitation (accumulation of snow cover during an autumn-winter-spring period, temperature scenario and heavy rains).
2. MODIS and Landsat data provides strong support in retrieving of specific values for analysis and visualization based on evaluation of hazardous phenomena associated with hydrological processes.
3. It is necessary to further investigate the use of remote sensing, analyze and retrieve "high humidity areas" based on Rapid Eye satellite images, for correlation with the results obtained from the Landsat data.

6. Acknowledgment

The studies were conducted in 2014 in the frame of the project "Comprehensive assessment of natural risks in the Kara-Unkyur water basin" with financial support from the UNDP office in Kyrgyzstan. The authors thank "Kyrgyzhydromet" for the provided information, T. Konokov, A. Serenkov for collection and processing of field data, and the driver Zh. Osmonov.

7. References

1. Atlas of the Kyrgyz SSR, published by GUGK, 1987.-T.I.-157 p., (in Russian).
2. Isaev D. I., Glushkov M. I., Aliev Z. A., Danilina A. P., Tokombaev Sh. Landscape of Kyrgyzstan, published by Frunze Ilim, 1964.-154 p., (in Russian).
3. Mamatkanov D. M., Bajanova L. B., Romanovskii B. B. Water Resources of mountainous Kyrgyzstan at the present stage, published by Bishkek Ilim, 2006-276 p., (in Russian).
4. Climate of the Kyrgyz SSR, Rjazanzeva Z. A. (ed.), published by Frunze Ilim, 1965.-291 p., (in Russian).
5. Criteria of hazardous hydrometeorological events and the procedure for filing a storm note about their occurrence. Procedure document. Main Department of Hydrometeorology of the Ministry of Emergency of the Kyrgyz Republic. Bishkek, 2002, pp.4-5, (in Russian).
6. Lomatdze V. D. Engineering geology. Special engineering geology, Subsoil, 1978. -496 p. UDK 624.131.1, (in Russian).
7. Bondarik G. K. Methodic of engineering-geological studies. Subsoil, 1986.-333 p., (in Russian).
8. Perov V. F. Mudflow studies, published by the Geographical faculty of Moscow State University, 2012-272 p., (in Russian).
9. Abdibachaev U., Moldobekov B. D., Ibatulin H. V. New cadastration of landslide risks based on the example of the Alay district of the Osh region of Kyrgyzstan. // Remote and field studies in Central Asia: materials of international conference, 2014, 193-197 p. ISBN 978-9967-11-449-4, (in Russian).

10. Ormukov Ch. A., Abdibachaev U. A., Moldobekov B. D. Inventory and evaluation of mudflow risks in the region of the city Sjuljukta of the Bartken region of Kyrgyzstan. // Remote and field studies in Central Asia: materials of international conference, 2014, 193-197 p. ISBN 978-9967-11-449-4, (in Russian).
11. Nijazov R. A., Minchenko V. D., Tashmatov H. M. Monitoring of exogenous geological processes, published by Tashkent "Fun", 1991. 180 p., (in Russian).
12. Roessner S. Behling R., Abdybachaev U. Multi-temporal optical and radar satellite remote sensing for spatial-temporal analysis of landslide activity at a regional scale in southern Kyrgyzstan. // Remote and field studies in Central Asia: materials of international conference, 2014, 80-85 p. ISBN 978-9967-11-449-4.
13. Podobnikar Tomaz, Methods for visual quality assessment of a digital terrain model. S.A.P.I.E.N.S. 2.2 /2009:VOL.2/No.2 Special Issue.
14. A series of issues "GEOMATIC" from 2008 to 2015. http://geomatica.ru/eng/archive.html (in Russian).
15. Kopackova V., Rapprich V., and etc. Slope dependent morphometric analysis as a tool contributing to reconstruction of volcano evolution. Earth and Environmental Sciences. 219-240 p. 2011. http://cdn.intechopen.com/pdfs/24557.pdf.
16. Monitoring, forecasting of dangerous processes and phenomena on the territory of the Kyrgyz Republic. MES KR. 2013 and 2014, ISBN 978-9967-23-948-4, (in Russian).
17. Guidance on hydrometeorological forecasts, issue 1, Gidrometeoizdat, 1989, (in Russian).
18. Karamoldoev J. J., Kalashnikova O. Ju. . Evaluation of correlation links of the vegetation runoff of the rivers of Upper Naryn. The materials of the international conference, KRSU 20 years. 2013, (in Russian).
19. Kalashnikova O. Development of long-term forecast methods for the flow of mountain rivers and the inflow of water into the reservoir using the example of the Naryn River, publishing by Science and new technologies and innovations of Kyrgyzstan. Bishkek No. 5, 2015, (in Russian).
20. A. Gafurov, S. Ludtke, K. Unger-Shayesteh, S. Vorogushyn, T. Scho¨ne, S. Schmidt, O. Kalashnikova, B. Merz. MODSNOW-Tool: an operational tool for daily snow cover monitoring using MODIS data. Environ Earth Science (2016) 75:1078.
21. Draft guidelines for the forecast of mudflow hazard in the foothills of the Fergana Valley. Proceedings of SANII, Goskomgidromet, 1984. p.13., (in Russian).
22. Salihova D. H. Aerosynoptic method of short-term forecast of snow-rain floods in the Kashkadarya river. Theoretical and applied meteorology, published by "Fun" Uzb SSR,1975, volume 2, (in Russian).
23. Salihova D. H., Ljahovskaja L. F. Forecast of mudflow hazard in the Surkhandaria River Basin, works of SINII, Kyrgyzhydromet, 1982, volume.89(170), pp.121-125, (in Russian).

24. http://landsat.usgs.gov/Landsat_7_ETM_SLC_off_data_products.php «estimated 22 % of any given scene is lost because of the SLC-off failure».