Chapter 16
Investigation of the Various Aspects of the Kafirnigan River Basin, Tajikistan

Z. Z. Nasriddinov, M. Abdusamatov, A. S. Kodirov, J. B. Niyazov, and N. S. Mirakov

Abstract The article is devoted to and carried out in the framework of the PEER NAS USAID project "Integrated Water Resources Management and Strategic Environmental Assessment of Kabul and Amu Darya Rivers". The goal of this article is to assess the environmental and socio-economic situation in the Kafirnigan River basin in face of demographic growth, climate and hydrological regimes changes. In this research, the methods of comparative analysis, field observations, physical and chemical assessments of water quality and GIS technologies are applied. The basis of research and study of these factors is to propose options for managing the water resources of the Kafirnigan River basin and improving the living conditions of the local population. The article pays attention to modern processes of formation and use of water resources on the example of the Kafirnigan River basin of the Republic of Tajikistan. The article discusses the scientific basis of using remote sensing data, in particular, the Normalized Difference Vegetation Index (NDVI), primarily to assess land degradation at various scales and in a wide range of applications, including the stability of agroecosystems. The assessment of environmental and socio-economic of the Kafirnigan River basin shows that the standard of living of the population has different features depending on the zones of formation, dispersion and transit of the flow. Due to the fact that the flow formation zone is located around the city of Dushanbe—the capital of Tajikistan, the majority of the population has greater economic income than other areas of the Kafirnigan River basin.

Keywords Kafirnigan River · Water resources · IWRM · NDVI · Socio-economic assessment

---

Z. Z. Nasriddinov (✉)
Tajikistan Mining Metallurgical Institute, 6 Moskovskaya Str., Dushanbe, Tajikistan

M. Abdusamatov · A. S. Kodirov · J. B. Niyazov · N. S. Mirakov
Institute of Water Issues, Hydropower and Environment, 14a Aini Str., Dushanbe, Tajikistan

Z. E. Kulenbekov and B. D. Asanov (eds.), *Water Resource Management in Central Asia and Afghanistan*, Springer Water, https://doi.org/10.1007/978-3-030-68337-5_16

16.1 Introduction

In general, Central Asian states have sufficient water resources, but uneven distribution, intensive population growth, increased water use and other factors contribute to water scarcity in many parts of the region. The introduction of water-saving technology (drip, subsurface, sprinkling), the reuse of collector-drainage and wastewater, the use of automated devices for surface irrigation and the improvement of management methods are some of the mechanisms for water saving by increasing the efficiency of irrigation systems [1].

The inefficiency of the existing water management system, the deterioration of the irrigation and drainage system built in the past century, as well as the transition to a market economy and the involvement of water users in water management confirm the need for a transition to Integrated Water Resources Management (IWRM). In this regard, IWRM issues in pilot zones (rivers, target villages) are also relevant, as one of the main tasks of IWRM is to promote the efficient use of water in the interests of sustainable welfare of the society and environmental safety [2].

To address the issues, water resources monitoring, improving the water accounting system, using new devices in determining the physical and chemical properties of soil and water, and determining the rate (flow) of water, both in canals and in rivers, are important. Another important condition is the assessment of the ecological and socio-economic situation (SES) using modern technologies. The purpose of the research is to assess the environmental and socio-economic situation in the settlements of the Kafirnigan River Basin of the Republic of Tajikistan.

Amu Darya and Syr Darya are the largest rivers of Central Asia. The sources of these rivers originate in the mountains of Tajikistan, Kyrgyzstan, Afghanistan and China. The Amu Darya takes its name after the confluence of the Panj and Vakhsh rivers in Tajikistan, the Syr Darya after the confluence of the Kara Darya and Naryn rivers in Kyrgyzstan. The major tributaries of the Amu Darya are the Panj, Vakhsh, Zeravshan and Kafirnigan rivers, whose share in the total water resources of this basin is 82.5% presents data on the formation of surface runoff in the Aral Sea basin [3].

Comparing the data in Table 16.1 based on river flow in Central Asia, it can be seen that water is mainly used for irrigation and other needs in the states located in the middle and lower reaches of the rivers: Kyrgyzstan—4.3%, Tajikistan—11.8%, Uzbekistan—51.5%, Turkmenistan—21.2%, Kazakhstan—9.5% and Afghanistan—1.7% [4].

Regardless of the water availability in each country in Central Asia or a particular river basin, the issues of protection and rational use of water resources are relevant. Thus, IWRM issues in pilot zones (target villages) are also important components for planning purposes. Along with other principles of IWRM (such as participation of women, the public in the process of water resources management, etc.), the introduction of water-saving irrigation technologies and the protection of aquatic ecosystems are very important priorities. In Tajikistan, the Kafirnigan River was chosen as a pilot project, it flows through the territory of 4 districts (Vahdat, Rudaki, Kabadian,

Table 16.1 Surface water resources of the Aral Sea basin

Country	Amu Darya basin (km^3/year)	Syr Darya basin (km^3/year)	Aral Sea basin	
			(km^3/year)	(%)
Kazakhstan	–	4.50	4.50	3.9
Kirgizstan	1.90	27.4	29.30	25.3
Tajikistan	62.9	1.1	64.00	55.4
Turkmenistan	2.78	–	2.78	2.4
Uzbekistan	4.70	4.14	8.84	7.6
Afghanistan	6.18	–	6.18	5.4
Central Asia	78.46	37.14	115.6	100.0

and Shaartuz) of Tajikistan. Vakhdat district is a zone of flow formation, Rudakinsky district is a dispersion zone and Kabadion and Shaartuz districts are transit zones of the Kafirnigan River basin.

16.2 Study Area

The total length of Kafirnigan River is 387 km, the catchment area of the basin is 11.6 km^2. The average discharge of the river is 164 m^3/s; however, depending on the season and weather conditions, the flow varies from 30 to 1200 m^3/s. The glacial region of the Kafirnigan River basin is located in the South of the Tien Shan mountain system (on the southern slopes of the Gissar Range, extending from the eastern part of the Zeravshan Range). The highest altitude is about 5000 m above sea level. The energy potential of the river is estimated at 2883 kW [5].

Hydrologically, the Kafirnigan river basin is relatively well studied. The Kafirnigan River has a snow-glacial type of feed, and high water lasts from March to September with the maximum flow of water in June (headwater) and from February to the end of August with the maximum flow in April downstream. The average annual turbidity of the water in the lower reaches is more than 1500 g/m^3 [5].

In zones located above 3000 m, the climate of the Kafirnigan River basin is characterized by cold summers and moderately severe snowy winters. The Kafirnigan River combines many other large and small rivers and tributaries. This river passes through irrigated land in central and southern Tajikistan before it reaches the Amu Darya River. The Kafirnigan River is very diversely used by local dekhkan (farmer) farms and has a rich historical resource management mechanism that is interesting and relevant to study with a view to developing integrated management and environmental assessment methods to further implement or adjust action plans to the region [5].

16.3 Methodology

During the fieldwork in the Kafirnigan River basin, the newest devices available to the project were used: a Land Mapper ERM-02, which measures electrical resistance and soil conductivity allowing for rapid mapping and monitoring of agricultural land as well as geological, hydrological and environmental studies; an RS485 electromagnetic velocimetry; a water flow meter; weather stations; a PH-meter for the determinant of water acidity and temperature; and a satellite GPS-receiver (Trimble R1) to determine the exact geographic location of the objects of study.

Through the interpretation of satellite imagery, it is possible to analyze many processes occurring on Earth. The presence of a collection of images from different years, months and consideration of the development of phenomena of interest over the long term. One of the predominant objects of the study of Earth from space is plant communities. In particular, great attention is paid to the dynamics of the areas and structure of the wooded territory. Changes occurring in forests can be associated with clear-cutting logging, forest fires, and the loss of forest stands from other negative natural and anthropogenic factors. These types of changes in forest communities can be identified by the data of multi-zone images [6].

A characteristic feature of vegetation and its state is spectral reflectivity, which is characterized by large differences in the reflection of radiation of different wavelengths [7]. Knowledge of the relationship between the structure and the state of vegetation with its spectral-reflective abilities allows for the use of satellite images for mapping and identifying vegetation types. Based on the combination of brightness values in certain channels, informative for highlighting the object under study, and calculating the "spectral index" of an object using these values, an image is constructed corresponding to the index value in each pixel. This allows for the selection of the object under study and evaluation of its state [8]. Spectral indices used to study and assess the state of vegetation have the generally accepted name of vegetation indices and allow for the automation of the process of identifying various plant communities and assessing their qualitative characteristics.

16.4 Results and Discussion

The RK900-05 Weather Station device installed by the research team in the Kafirnigan River basin (RIKA-Wireless Home Weather station) measured 12 parameters (precipitation, evaporation, humidity, wind speed, lighting, etc.) and showed reliability in work. A comparison of the data from the RK900-05 with the data from the station of the Agency for Hydrometeorology of Tajikistan (Esanbay station) for 2018 showed that they were very close. Figure 16.1 shows the average monthly temperature and precipitation data in 2017 obtained from the RK900-05 Weather Station.

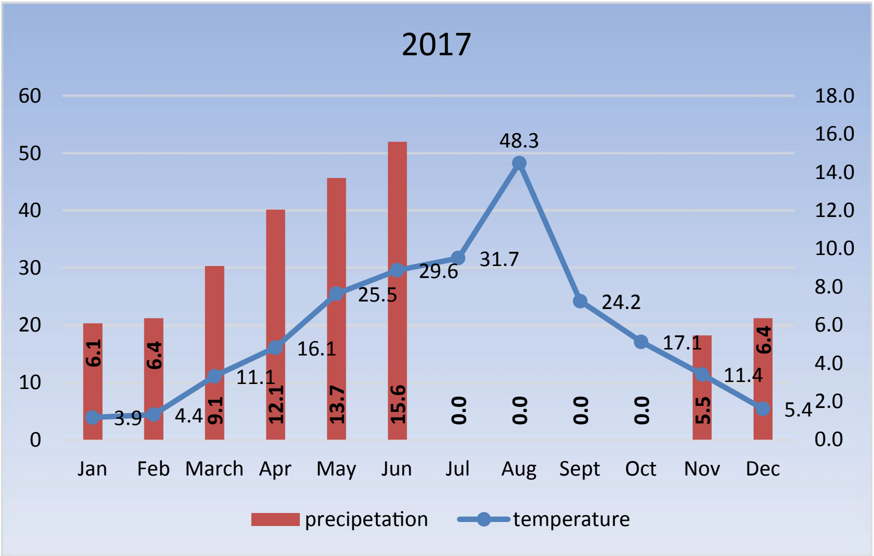

Fig. 16.1 The average monthly temperature and average monthly rainfall for 2017 precipitation (mm); temperature (°C)

The calculation of most of the vegetation indices is based on the two most stable sections of the spectral reflectivity curve of plants and are not dependent on other factors. The red zone of the spectrum (0.62–0.75 μm) accounts for the maximum absorption of solar radiation by chlorophyll, and the near-infrared zone (0.75–1.3 μm) accounts for the maximum reflection of energy by the leaf's cellular structure (Fig. 16.2).

Thus, high photosynthetic activity is associated, as a rule, with a large phytomass of vegetation, and leads to lower values of reflection coefficients in the red region of the spectrum and large values in the near infrared. The relationship of each other allows researchers to clearly separate the vegetation from other natural objects [9]. One of the most well-known vegetative indices was chosen for this study—the Normalized Difference Vegetation Index (NDVI).

To identify objects on the Earth's surface, it is useful to combine different channels to obtain images in natural colors (if red, green, and blue channels are used) or pseudo-color images (if another combination of channels is used). For example, with LANDSAT ETM +, the combination of channel numbers 3-2-1 gives a realistic image in natural colors. However, pseudo-color images are more suitable for many purposes. For example, channel number combinations, such as 4-3-2, 7-4-2, or 4-5-3, are widely used to determine vegetation or water surfaces, respectively [10].

Semiautomatic extraction of objects of interest (vegetation, water mirrors, etc.) includes the construction of a ratio of different channels. The construction of the relationship eliminates the relationship between the ranges, thus eliminating unnecessary data and retaining very specific information. This approach is suitable if it is

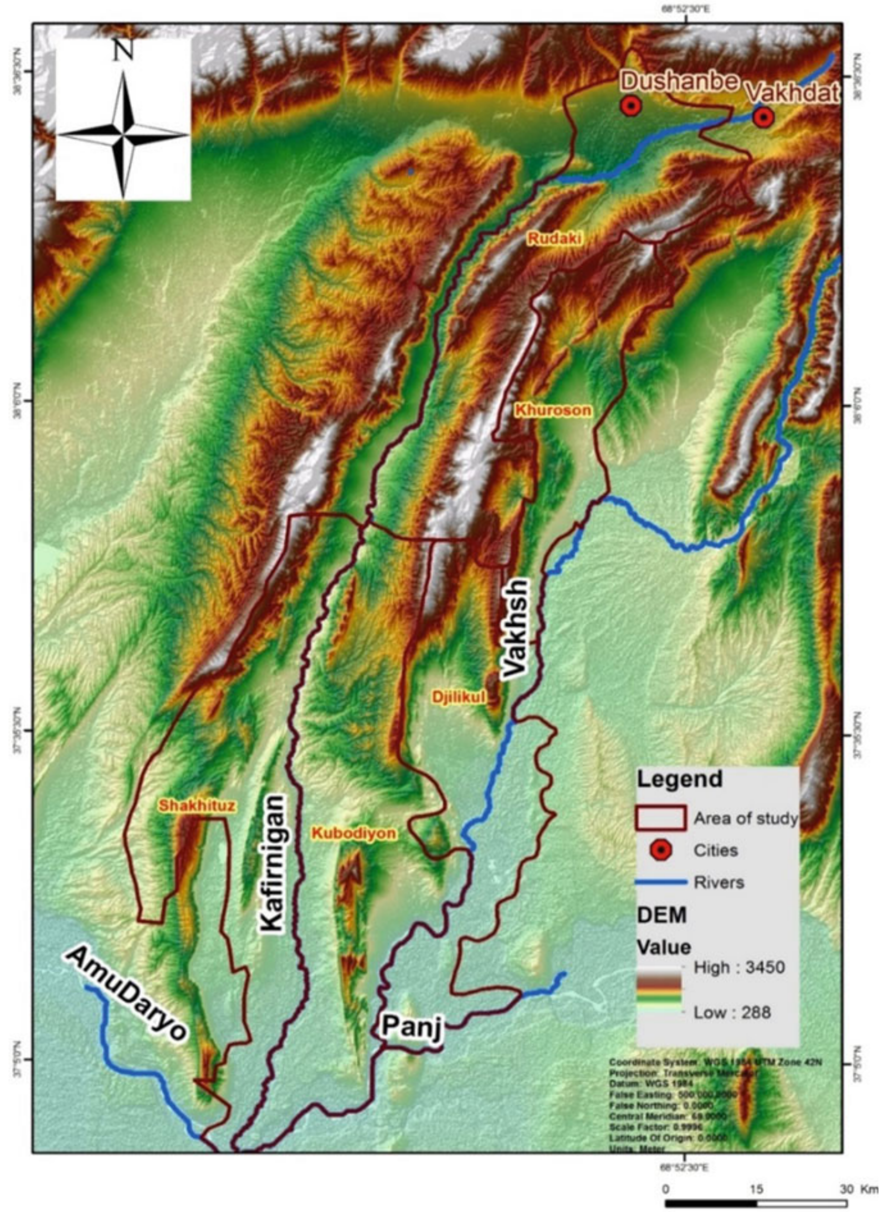

Fig. 16.2 The research area of the Kafirnigan River basin

necessary to select a specific type of object which is strongly reflected in one channel and weakly in another.

Allocation of vegetation-covered areas is widely distributed by calculating the normalized differential vegetation index NDVI:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}},$$

where NIR is the reflection in the near-infrared region of the spectrum, RED—reflected in the red region of the spectrum.

According to this formula, the density of vegetation (NDVI) at a certain point in the image is equal to the difference of the intensities of the reflected light in the red and infrared ranges, divided by the sum of their intensities.

The range of NDVI values varies from -1 to 1, in which the highest values indicate the presence of lush vegetation and low values indicate rare vegetation cover. NDVI values should be classified in order to clearly identify vegetation areas. It is necessary to determine equal values for the classified visualization of NDVI separately for each satellite scene in order to calculate the difference between the scenes (Fig. 16.3).

The use of automatic selection indices includes some explanations: in addition to determining the actual vegetation-covered zones, the results of automatic selection using NDVI will always contain two types of errors: (a) zones are defined as vegetation-covered when they are not exactly those, and vice versa: (b) zones are defined as not covered with vegetation, when in fact they are clearly covered with vegetation. To calculate these errors, an accuracy estimate can be performed using ground survey data or images obtained through visual interpretation.

During field studies, a survey was conducted among residents of the Vahdat (Tangai and Ramit village), Rudaki (Sarikishti village) and Kabadiyan (Tartki village) districts, according to a pre-compiled questionnaire that covered different socio-economic situations (SES). One of the indicators was the activity of the Water Users Association (WUA) in the studied areas. According to the information which was received from the Agency for Land Reclamation and Irrigation of Lands under the Government of the Republic of Tajikistan, as of September 1, 2017, there are 383 WUAs operating in the republic which serve 387,559 ha of irrigated land. Of this number, in the studied area of the Kafirnigan River basin, only 45 WUAs serving 52,176 ha were in operation. On average, 1 WUA accounts for 1159 ha of irrigated land in the Kafirnigan River basin.

WUA efficiency is still low. They do not have trained specialists and they are not provided with transport and earthmoving equipment. Not all WUAs have a material base, including offices. Another important indicator of SES was the family cattle breeding of the studied basin (Table 16.2).

An analysis of family cattle breeding shows that, in the areas of runoff formation and the middle flow of the Kafirnigan River (Vahdat and Rudaki districts), the population has less livestock (about 20% of the families) than in the area of the dispersion (irrigation) districts of Kabadiyan, where are more than 90% of residents have livestock.

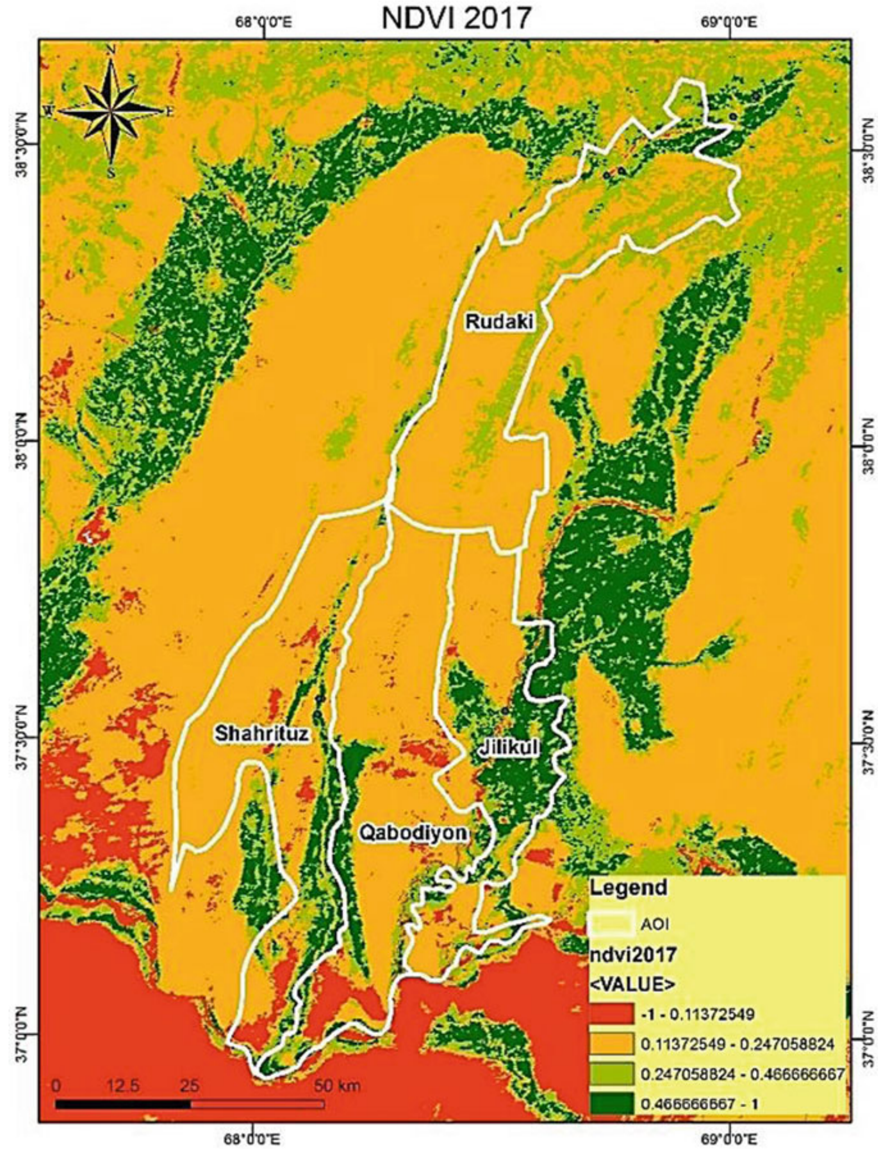

Fig. 16.3 NDVI for the Kafirnigan River basin, 2017

The water quality of the Kafirnigan River mainly complies with the norms of maximum permissible concentration (MPC). In the flood period, there is an excess of MPC for suspended substances. Water samples for chemical analysis were taken from three points (upper reaches, middle part, and dispersion zone) in 2018, and

Table 16.2 Families involved in cattle breeding (%)

Polling place	Cattle	Sheep	Goat	Horses	Chickens	Their absence (%)
Vahdat, Tangai and Ramit villages	5	5	5	0	5	80
Rudaki, Sarikishti village	5	5	5	0	5	80
Kabodiyon, Tartki village	20	10	10	2	50	8

these showed that the pH was within the normal range (6.85–7.21), as was TDS (300–600 mg/l). Of the heavy metals in water, the presence of molybdenum (Mo), cadmium (Cd), nickel (Ni), chromium (Cr), and others that did not exceed the permissible rate was noted.

16.5 Conclusion

Studies conducted in the Kafirnigan River basin have shown the need for introducing water-saving technologies, integrated water resources management, improving the ecological status of rivers, socio-economic conditions of the population, improving the efficiency of irrigated land, planning and introducing efficient use of water resources of the partner countries. And the use of GIS technology allows you to determine the vegetation index (NDVI), which reflects the total amount of vegetation and is used to assess its condition and build environmental-climatic maps.

Acknowledgements This research was accomplished thanks to the financial support of the USAID and PEER regional project.

References

1. Kodirov AS (2015) The role of water users associations in improving water management (on the example of the Gissar Valley). In: Proceeding of dedicated to the international decade for action “water for life, 2005–2015”. TajikNIIGiM, Dushanbe, pp 142–147
2. Tushaar Sh, Barbara VK (2006) Is India ripe for integrated water resources management? Fitting water policy to national development context. Econ Polit Week 41(31):3413–3421
3. Nuraliev K, Abdusamatov M, Latipov RB (2011) Water resources of Tajikistan: initiatives, strategy and perspectives. Asia-Print Publishing House, Dushanbe, 219 p
4. Kodirov AS (2016) Formation and dynamics of the hydrological regime of the Vakhsh river basin of the Republic of Tajikistan. Diss Cand Tech Sciences. Kodirov A.S., Dushanbe-Bishkek, 24 p
5. Catalog of glaciers SSRR, vol 14, Central Asia, Issue 3, Part 5, L. Hydrometeoizdat (1980)
6. Terekhin EA (2013) The method of mapping perennial changes in forests based on the analysis of their spectral characteristics over the series of satellite data of different times. In: Study of earth from space, № 5, pp 62–69

7. Antonov VN, Sladkikh LA (2009) Monitoring the state of crops and forecasting the yield of spring wheat according to the ERS data. Geomatics № 3:50–53
8. Cherepanov AS, Druzhinina EG (2009) Spectral properties of vegetation and vegetation indices. Geomatics № 3, WITH 28–32
9. Crippen RE (1990) Calculating the vegetation index faster. Remote Sens Environ 34:71–73. Bartalev SA (2005) Methods of using time series of satellite images of high spatial resolution for assessing the extent and dynamics of deforestation of taiga forests. Bartalev SA, Kuryatnikova TS, Stibig KhYu. Modern problems of remote sensing of the earth from space. T. 2. № 2 WITH 217–227
10. Landsat Data Continuity Mission. Press Kit (2013) [Electronic resource]. URL: www.nasa.gov/pdf/723395main_LDCMpresskit2013-final.pdf