Remote Sensing and GIS for Thematic Mapping of the Ak-Suu and Isfana River Basins in Kyrgyzstan

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Abstract
Geographic information systems (GIS) play a significant role in the thematic mapping to collect, store, analyze, visualize and deliver geospatial data today. The Ak-Suu and Isfana rivers flow into the Syrdarya river, which is used for irrigation and other purposes in Uzbekistan, Tajikistan and Kazakhstan. Thematic mapping of the river basins allow efficient use of natural and water resources in the region to mitigate the existing conflicts over water use by four Central Asian neighboring countries. SRTMGL1 DEM is applied in terrain modeling and river basin boundary delineation. Multispectral Landsat 8 and Sentinel-2 images were used in land use and glacier mapping. DEM, glacier, ecosystem, emergency and soil maps are designed and updated based on the cartographic materials, remote sensing, infrastructure and statistical datasets.

1. Introduction

Geographic Information System (GIS) - an information system designed to collect, store, analyze and graphically visualize spatial data and related information about the objects represented in the GIS. Using modern means of remote sensing, geographic information systems are capable of delivering this information quickly and efficiently. Moreover, the modeling tools available in modern GIS software systems allow real-time forecasting of the development of a situation, for example, showing a consistent expansion of a flood zone or forest fire. Data sources for GIS are maps, plans, diagrams, presented both in specific object formats and in traditional raster and vector formats. GIS content is carried out by entering various primary materials, including the results of measurements on the ground, geological surveys, mapping, aerial and satellite imagery, and special subject information. The Ak-Suu and Isfana rivers flow into the Syrdarya river, which originates as the Naryn river in the mountains of Kyrgyzstan. Its total length is around 2800 km and it flows through Uzbekistan, Tajikistan and Kazakhstan where it drains into the Aral Sea. These rivers create conflicts over water allocation in international catchments shared by three countries, governed by weak international water management institutions, and exposed to severe climatic changes (Bernauer and Siegfried, 2012).

Given the multifaceted nature of the use of the river flow, many countries and regions are introducing an integrated approach to water resources management at the basin level. This allows for more effective implementation of the principles of integrated water resources management in river basins, lakes and aquifers (Orifov, 2019 and Savina, 2014). The main goal of this research work is to create different thematic maps for the Ak-Suu and Isfana river basins using modern geographic information technologies and remote sensing data for effective management of the region's water resources.

The different formats and data types from various sources were used in this work. The determination of the necessary cartographic materials and remote sensing data was carried out by carefully studying the existing digital maps and thematic layers that are in the public domain, in the geodatabases of government agencies and other international projects. Medium and high-resolution free satellite images were used to map land use, glaciers, river network and irrigation systems. Paper pasture maps and electronic local municipality (Ayil aimak) maps were obtained from local experts and other organizations and institutions. Data from map services such as Google Map, Google Earth and OpenStreetMap was also actively used.

2. Data and Methods

2.1 Study Area

The Ak-Suu and Isfana rivers are transboundary rivers that originate from the Turkestan ranges of the Gissar-Alai mountain system from south to north. These rivers provide irrigation water to a significant part of the Ferghana Valley, which has the highest population density in Central Asia (Kenjabaev and Frede, 2016). The Ak-Suu River

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has glacial-snow feeding and is formed on the territory of Kyrgyzstan and partially on the territory of Tajikistan. The Isfana River has mainly underground recharge and is fully formed on the territory of Kyrgyzstan. Both rivers flow into the Syrdarya River and then go towards the Aral Sea. The policy of downstream countries turning into intensive irrigation economy ultimately led to the desiccation of the Aral Sea, with highly adverse social, economic and environmental consequences in the region (Micklin, 1988).

The absolute height of the region ranges from 300 to more than 5100 meters above sea level. The climate of the region is sharply continental with large temperature fluctuations during the day and in the seasons of the year (Shabunin, 2018). Some spatial and statistical data on river basin irrigation systems were developed and implemented as part of the SmartWaters - Water, Education and Partnership project, CAREC, USAID (CAREC, 2020). To familiarize with the geographical conditions, conditions and features of land use, the river network and irrigation systems in the Isfana and Ak-Suu river basins, fieldwork was carried out in 2018-2019 (Figure 1).

Figure 1: Irrigation channel with aqueduct

2.2 Remote Sensing Data

Information on the terrain is necessary for the implementation of various geographic information projects. The most important sources of spatial information are digital elevation models (DEM). In this work, we used the digital terrain model SRTM Version 3.0 Global 1 arc second dataset (SRTMGL1) based on data from radar interferometric imaging of the study area on February 11, 2000 from the Endeavor satellite (NASA, 2020a). SRTMGL1 DEM scenes were obtained from the US Geological Survey (USGS) geoportal - https://earthexplorer.usgs.gov for the study area, limited in latitude from 39°28′50,854′′N to 40°17′10,75′′N and in longitude from 69°9′37,722′′E to 69°46′35,908′′E.

Landsat satellite imagery plays a very large role in environmental studies and in solving a huge number of different scientific and applied problems. Landsat satellites are owned by NASA, the United States National Space Agency, which has been realizing the Landsat project since 1972 with the goal of capturing the entire globe for scientific research (NASA, 2020b). The highest quality Landsat images were studied and obtained with minimal cloud cover for the study area for August, which is the most optimal season for studying glaciers in the Ak-Suu and Isfana river basins. The following Landsat satellite images, with radiometric and geometric correction using digital elevation models, were obtained from the USGS website for 1977, 1997 and 2017, i.e. with an interval of 20 years. All satellite images have the cartographic projection system WGS_1984_UTM_Zone_42N (NASA, 2020b).

Landsat images used in this research are:

- Landsat 2 cloud free images from August 25, 1977:
  - LM02_L1TP_165032_19770825_20180423_01_T2.
  - LM02_L1TP_165033_19770825_20180423_01_T2.
- Landsat 5 cloud free images from August 6 and 29, 1997:
  - LT05_L1TP_154032_19970829_20180611_01_T1.
  - LT05_L1TP_153033_19970806_20180708_01_T1.
- Landsat 8 images with small cloud coverage from August 13, 2017:
  - LC08_L1TP_153032_20170813_20170824_01_T1.
  - LC08_L1TP_153033_20170813_20170824_01_T1.

For mapping the land use and visual interpretation of objects the next multispectral images of Sentinel-2A - operational Earth Observation (EO) satellite of the European Space Agency (ESA, 2020), were used:

- Sentinel-2A cloud free images from August 5, 2018:
  - S2A_MSIL1C_20180805T060631_N0206_R134_T42SWJ_20180805T081709.SAFE.
  - S2A_MSIL1C_20180805T060631_N0206_R134_T42SWJ_20180805T081709.SAFE.

2.3 Cartographic Materials

The digital thematic maps of the Ak-Suu and Isfana river basins were created based on the river network model and paper maps, including the Leilek district irrigation map and schemes of the irrigation infrastructure of Water User Associations (WUAs) - "Too-Zhailoo", "Omur-Suu", "Sarkent-Suu" and "Aikol"-Sarkent ", as well as land use maps of Ayil Aymaks "Ak-Suu", Sumbula" and "Isfana". Mapping of the research area was carried out using topographic maps at a scale of 1: 100,000 and other available cartographic materials. Spatial analysis using high-resolution satellite imagery showed that the floodplains of the Ak-Suu and Isfana rivers have undergone strong changes in recent years when compared with topographic map data due to changes in land use and expansion of the boundaries of settlements. The use of high-resolution satellite imagery needed in digitizing and updating the settlement and basin boundaries as well as the irrigation network (Arshad et al., 2014).

To study the dynamics of changes in the area of glaciers, available datasets were collected in the form of paper and digital maps of glaciers, rivers and lakes from various sources (Hydrometeoizdat, 1974 and Shabunin, 2018) (Figure 2) and topographic maps. The location of water wells for irrigation in the target territories is collected from the sources of local communities and WUAs. As a result, all available data were analyzed and entered on the maps, which may have some security limitations while providing open access to the geodatabase (e.g. coordinates of water wells are not open to public). Emergency data was obtained from the Ministry of Emergency Situations of the Kyrgyz Republic (MES KR).

3. Results and Discussion

When creating thematic maps, cartographic materials from various sources, satellite images, satellite positioning data, results of field investigation and interviews with specialists, as well as outcomes of other studies were used. Data processing was performed using ArcGIS 10.4, ENVI 5.1, QGIS 3.4, and SNAP software packages. A geodatabase was created with geospatial datasets in the zonal coordinate system WGS_1984_UTM_Zone_42N (EPSG: 32642) selected as the main reference system. After processing the collected data from field work, including GPS measurements, the existing inaccuracies in the geographical location of the primary cartographic materials were determined. Office work was carried out to refine the geographic referencing of satellite imagery and other types of actions to improve spatial data quality. The provision of uniform formats and contents of electronic maps was agreed upon during regular meetings with all stakeholders.

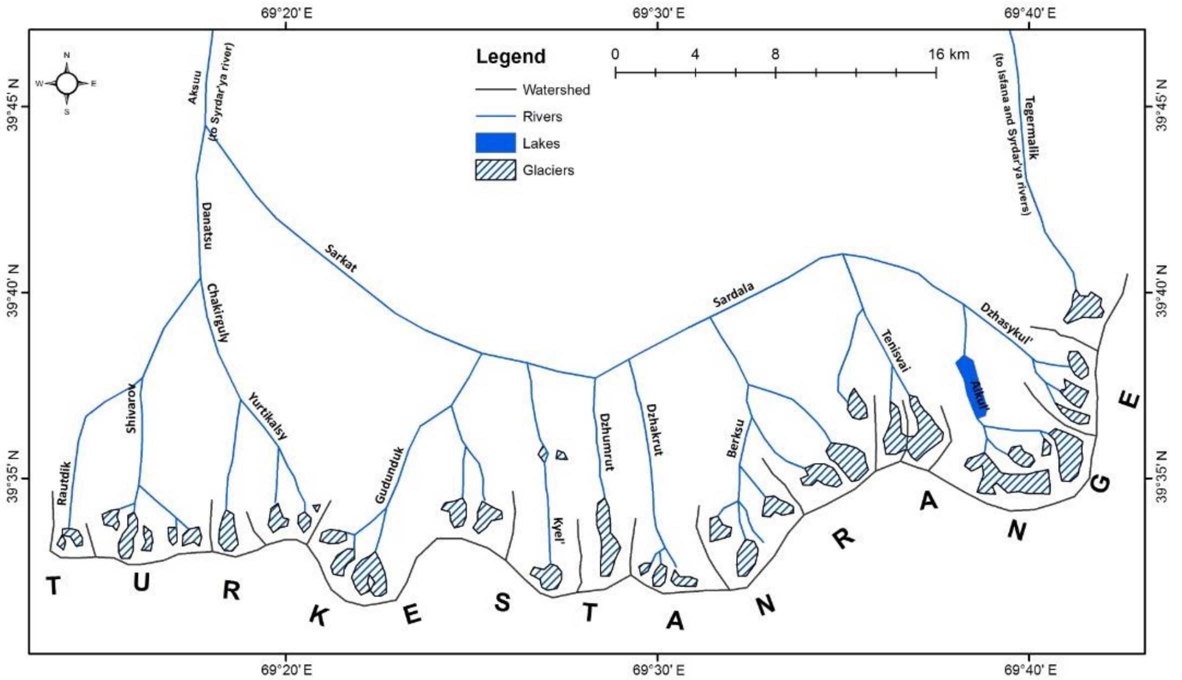

Figure 2: Map of glaciers in the Ak-Suu and Isfana river basins, 1974

3.1 Development of DEM and Basin Boundaries of the Ak-Suu and Isfana Rivers

The remote sensing data based on Digital Elevation Models (DEMs) are the most important sources of spatial information in hydrological research today. DEM of the study area was generated by mosaicking scenes SRTM1N39E069V3 and SRTM1N40E069V3. The river network of the research area and river basin boundaries were created on DEM using tools of the ArcGIS 10.4 Hydrology module. Using DEM, the topography of the study area was analyzed and river basins are delineated (Figure 3). The Ak-Suu river originates in Kyrgyzstan and Tajikistan recharged from several large and small glaciers, the Isfana River basin starts from the Tegermalik Glacier in Kyrgyzstan and they flow north and flow into the Syrdarya river. Spatial analysis showed that river basins start from 318 m above sea level (the mouth of the Ak-Suu river in the Farkhad Reservoir, Uzbekistan) to 5101 m above the Baltic Sea level (the beginning of the Isfana river, Mount Akchukur at the Kyrgyzstan-Tajikistan border).

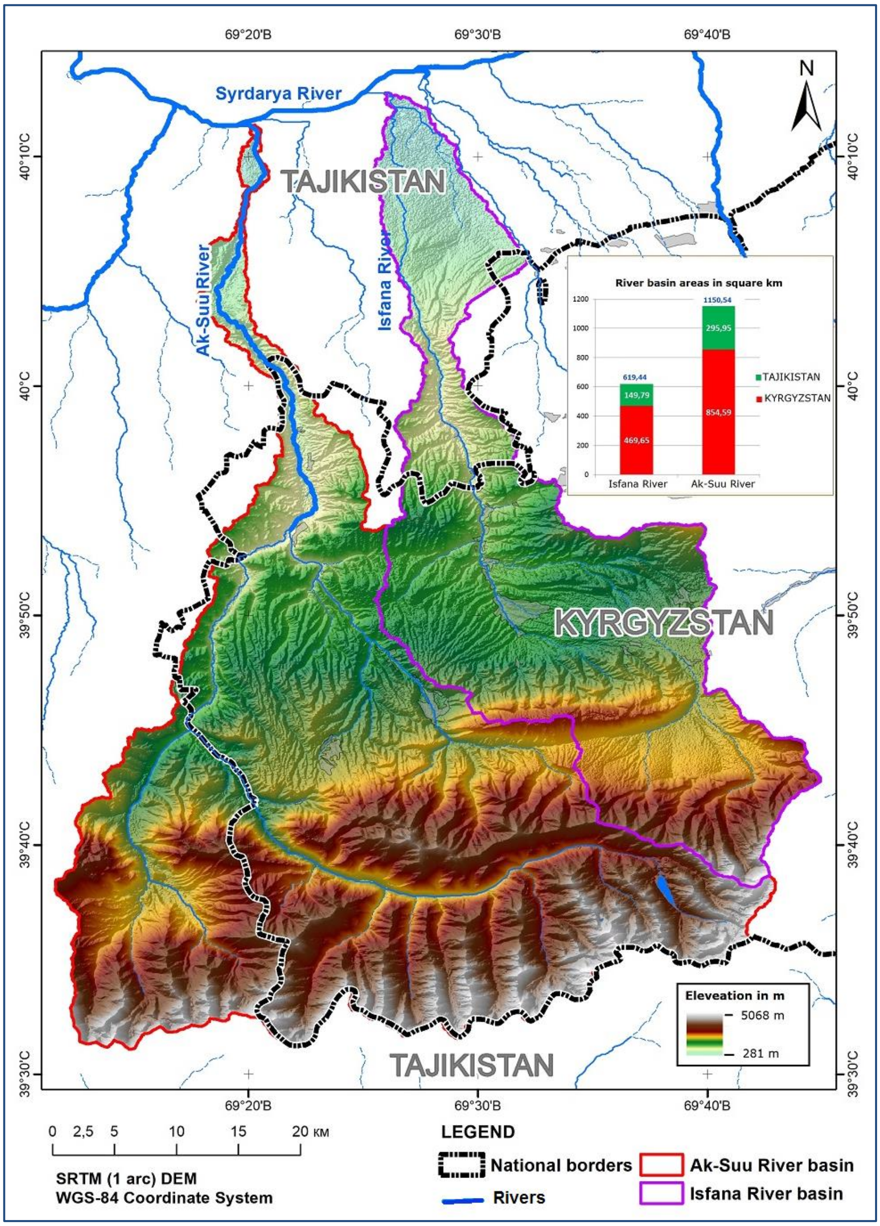

Figure 3: DEM and relief map of the Ak-Suu and Isfana river basins

The results of the river basin models indicate that the total area of the Ak-Suu and Isfana river basins are 1769.98 km^2 (Ak-Suu - 1150.54 km^2, Isfana river - 619.44 km^2). 1324.38 km^2 of these are accounted for in the Kyrgyz Republic (Isfana - 470.89 km^2, Ak-Suu - 853.49 km^2), and the rest belongs to the Republic of Tajikistan. State and administrative borders of the study area are not officially defined in the framework of this research.

3.2 Digital Mapping of the Glaciers by Using Satellite Images

The formation of the runoff and the hydrographic network in the territory of Kyrgyzstan is greatly influenced by the orographic structure and topography, climatic conditions and the presence of glaciers. The main source of feeding for the Ak-Suu river is the melted snow and glacial waters. The contribution of glacial runoff to the total river runoff and the regulating effect of glaciers on runoff is the greater, the greater the relative area of glaciation equal to the ratio of the area occupied by glaciers to the total area of the river basin for this closing range. Due to the large masses of water accumulated in the thickness of the glacier, they have a regulatory effect on river flow. An analysis of the data showed that it is necessary to create electronic maps with a larger scale for a detailed study of glaciers in the Ak-Suu and Isfana river basins. Further, images of the Landsat and Sentinel satellite systems were used for the study of glaciers. The Normalized Difference Snow Index (NDSI) is designed to apply MODIS (or Moderate Resolution Imaging Spectroradiometer aboard the Terra satellite) data (Bands 4 and 6) and Landsat TM (Bands 2 and 5) to identify snow cover while ignoring cloud cover (Yan et al., 2020 and Hall and Riggs, 2011). Since it is based on a ratio, it also reduces the atmospheric effects:

$$NDSI = (Green - SWIR) / (Green + SWIR),$$

Equation 1

where *Green* is pixel value from the *Green* band; *SWIR* is pixel value from the S*hort Wave Infrared*.

Landsat 5 (TM) images are classified according to the following formula:

$$NDSI = (TM\ Band\ 2 - TM\ Band\ 5) / (TM\ Band\ 2 + TM\ Band\ 5),$$

Equation 2

where *Band 2* is *Visible Green,* 0.53 - 0.61 micrometers; *Band 5* is *Short Wave Infrared (Short Infrared),* 1.55 - 1.75 micrometers. As a result of visual analysis of a Landsat 5 satellite image with natural color, the threshold value of the NDSI snow cover index was determined ≥ 0.4 (Cea et al., 2007).

Landsat 8 (OLI) imagery is classified using the following formula:

$$NDSI = (ETM\ Channel\ 3 - ETM\ Channel\ 6) / (ETM\ Channel\ 3 + ETM\ Channel\ 6)$$

Equation 3

The threshold value NDSI > 0.3 was determined by comparing and visual analysis of the snow cover classification results from Sentinel-2A images as of August 5, 2018 (Figure 4). After calculating NDSI from Landsat images and analyzing the accuracy of snow cover classification, the raster surfaces were reclassified (-1-0.39999 as NoData and 0.4-1 as 1 for Landsat 5 images and -1-0.29999 as NoData and 0.3-1 as 1 for images Landsat 8) Using visual interpretation of satellite images with ultra-high resolution obtained from other systems (Sentinel-2A, WV-2) and map services (Google Earth, SAS Planet), it was determined that the classification accuracy is 80-90% snowy or icy surface on the ground. Such accuracy results are quite good as compared to similar researches (Kumar et al., 2021 and Nijhawan et al., 2016).

The resulted from the reclassified raster surface was converted into vector layer features for further aggregation of polygons (aggregation distance of 30 m, the minimum polygon area of 1000 m^2 and the minimum hole area of 1000 m^2). The next graphical improvement procedure - the smoothing of polygons with a distance of 100 m is performed. Next, the areas of all polygons with snow cover in the Isfana and Ak-Suu river basins were summarized. Taking into account the fact that satellite images were obtained in the middle and at the end of August, the obtained areas can be considered the approximate area of glaciers with a minimum content of snowfields. The glacier areas for the study periods were calculated as:

- 7.188 km^2 as of August 13, 2017;
- 12,428 km^2 as of August 29, 1997 (decrease of 42% over 20 years (Figure 4).

3.3 Land Use Maps of the River Basins

The territories of the Ak-Suu, Sumbula and Isfana Ayil aimaks (municipality) as well as forest land and the State Nature Park “Sarkent” are located in these river basins. Land use mapping was realized using topographic maps, forestry, land-use and pasture maps. Supervised classification of Landsat 8 OLI and Sentinel-2A imagery was employed to update the land-use change patterns of the study area.

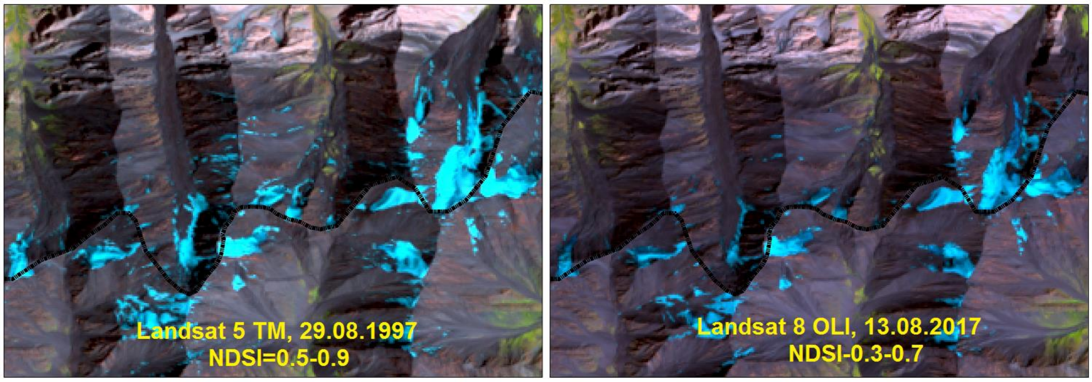

Figure 4: 3D model of the Ak-Suu and Isfana river basins

The open geospatial data and web-based tools of the Google Map and OpenStreetMap were used. Separate land-use maps were designed for each of the Ak-Suu, Sumbula and Isfana Ayil aimaks to enlarge the scale of the maps for the purpose of better visibility (Figure 5a).

3.4 Ecosystem Maps

The mainstreaming ecosystem services into policy and decision making is dependent on the availability of spatially explicit information on the state and trends of ecosystems and their services (Sumarga et al., 2014). Ecosystem maps of the study area are needed for local communities, state institutions and WUAs for the efficient agriculture, environmental and water resource management. The land use, forestry, pasture and topographic maps, high resolution satellite imagery were used in mapping ecosystems of the Ak-Suu and Isfana river basins (Figure 5b). Spatial analysis using high-resolution satellite imagery showed that the floodplains of the Isfana and Ak-Suu rivers have undergone significant changes in recent years when compared with old maps due to changes in land use and the expansion of settlements. The river network and irrigation infrastructure in the study area updated by processing and classification of remote sensing data. The location of wells for irrigation in the target territories is collected from the sources of local communities and WUAs. As a result, all available well locations are analyzed and displayed in the thematic maps with restricted access.

3.5 Emergency Maps

The study area has been located in the Batken oblast (province) of Kyrgyzstan and prone, on average, 25-26 emergencies occurred during the year. Emergencies caused by mudflows and floods account for 63.0%; landslides and rockfalls 4.3%; earthquakes 3.6%; avalanches of 0.4%; hazardous meteorological events 9.3%; industrial accidents and major fires 10.0% (MES KR, 2017). According to the Ministry of Emergency Situations of the Kyrgyz Republic (MES KR) there are 3 active landslides, more than 40 sites prone to mudflows and floods, there are an groundwater raised site and two places with the risk of landslides and rockfall in the Isfana and Ak-Suu river basins (Figure 5c). The Ay-Kul Lake in the Ak-Suu river basin has the 3rd category of outburst flood hazard.

The greatest danger in the research area is mudflows. The causes for the formation of mudflows are the seasonal melting of snows, torrential rains, and the presence of moistened mud-forming deposits. The mudflow hazard period begins in the month of March, covers the entire warm part of the year, including September. The most probable time for mudflows and floods (April-June) is associated with periods of snowmelt and heavy rainfall (MES KR, 2017).

3.6 Soil Maps

The soil map is developed on the base of 1: 500000 scale “Soil map” from the Book “Natural Resources of the Kyrgyz SSR”, published in Tashkent in 1987 (Figure 5d). The grey-brown desert soils (Calcic Gypsisols) are dominated in the both river plains and mountain meadow soils are widespread in the alpine zones.

4. Conclusion

Thematic maps have been composed of standard content such a mathematical basic element with projection, map scale and grids, a digital terrain model, hydrography, land cover/land use, transportation infrastructure and other additional elements. Preparation of thematic maps is a complex the procedure, which is realized today by using GIS and cartographic web services. Development and updating of the thematic digital maps for the Ak-Suu and Isfana river basins are realized by using old paper maps, state-of-the-art geospatial datasets, remote sensing materials and statistical information.

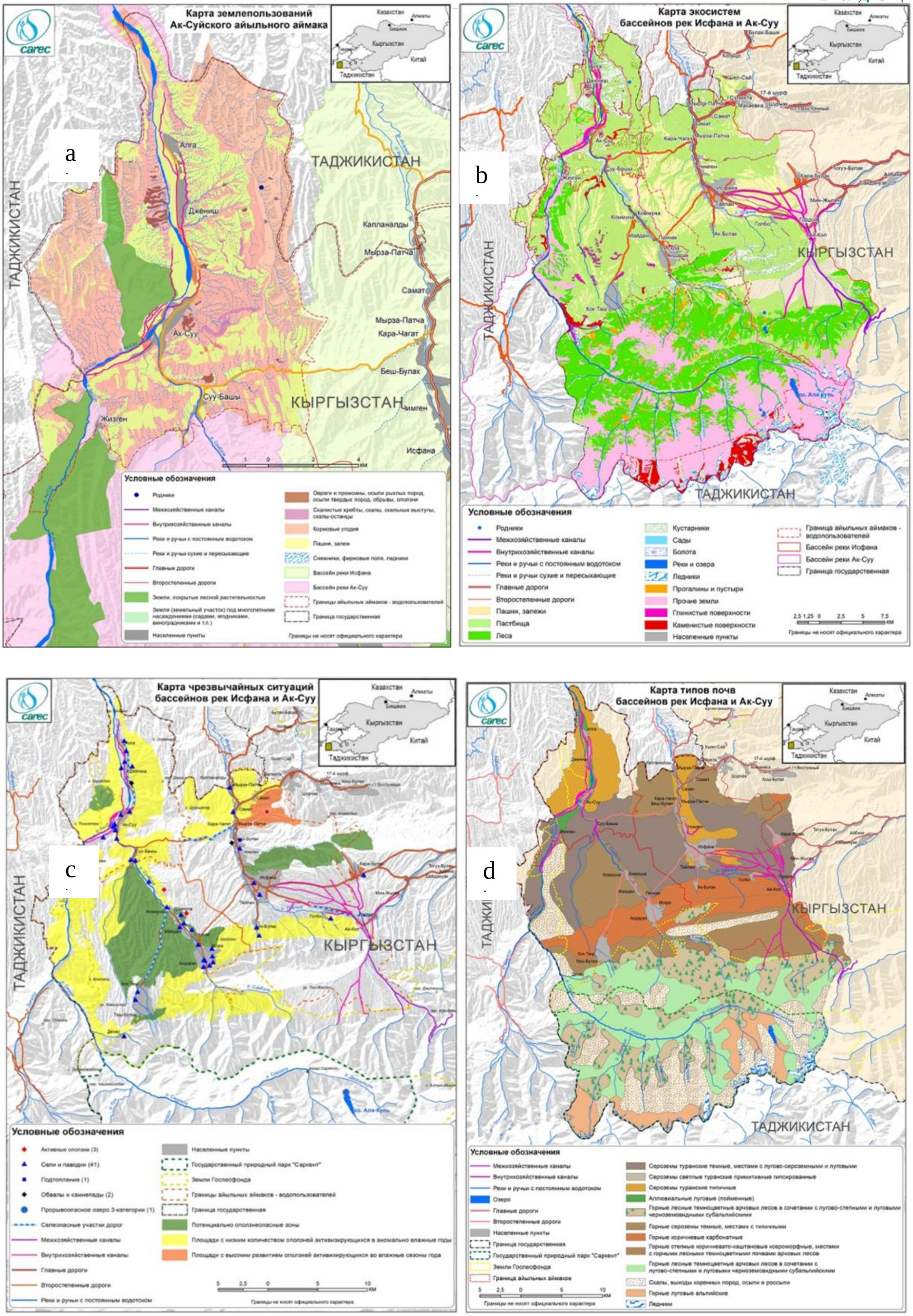

Figure 5: Thematic maps of the Ak-Suu and Isfana river basins: a) Land use map; b) Ecosystems map; c) Emergency map; d) Soil map

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