

ANNOTATION

to the dissertation for the degree of Doctor of Philosophy (PhD) in the specialty
6D071100 – Geodesy

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ASSESSMENT OF THE STATE OF MOUNTAIN CRYOSPHERE COMPONENTS USING SATELLITE TECHNOLOGIES

General characteristics of the work

The dissertation is devoted to the study of the state of the components of the Zhetysu Alatau mountain cryosphere, including glaciers and rock glaciers, using satellite technologies. The main focus is on assessing the state of glaciers, their mass balance, and inventory of rock glaciers in the context of climate change. The results of the study are important for understanding the dynamics of glacier change and their impact on the region's water resources, and also offer methods that can be applied to other mountainous regions of Central Asia.

Relevance of the topic

The relevance of the research is due to the need to assess and monitor the dynamics of changes in glacier area, the geodetic mass balance of glaciers in the entire mountain range and inventories of rock glaciers, due to the insufficient completeness of ground-based data.

Changes in glacier area. The first detailed inventory of the Zhetysu Alatau glaciers – "Catalog of Glaciers" (Catalog of Glaciers of the USSR, 1980), based on aerial photographs from 1956, was published in 1980. In 2004, Cherkasov P.A. compiled a second glacier inventory using topographic maps at a scale of 1:25,000, based on aerial photographs taken in 1972, and two more separate studies were conducted in the 1990s and 2000s. The main results of research during this period were descriptive in character and preserved only in unpublished reports.

Inventory of active rock glaciers. Rock glaciers are widespread in the Zhetysu Alatau mountain system and are one of the main indicators of permafrost levels. The number of studies that provide data on rock glaciers is limited. However, rock glaciers in the Zhetysu Alatau part of the Zhetysu Alatau almost have not been studied in the past few decades.

Glacier mass balance studies. Despite the relatively large number of glaciers located in this area, glacier mass balance data remain scarce. To fill the gap in direct glaciological observations and cover larger mountain areas, glacier volume changes have been estimated at various catchment scales, from local to regional studies using

remote sensing data. However, detailed regional mass balance time series with high temporal resolution are still lacking for the Zhetysu Alatau.

In this regard, a detailed study of glaciers and stone glaciers, knowledge of the current state of the components of the mountain cryosphere of the Zhetysu Alatau under climate change conditions, and the comparison of the characteristics of glaciers and stone glaciers with other parts of the Tian Shan are crucial for understanding the regional state of the cryosphere of the Tian Shan mountain system as a whole.

The aim of the work is to study and assess the state of glaciation of the mountain ranges of the Zhetysu Alatau with the calculation of geodetic mass balance based on satellite technologies and an inventory of rock glaciers.

Tasks solved in the work

1. Creation of a database of archival and current satellite data. Assessment of the historical state of glaciation of the Zhetysu Alatau mountain ranges.

2. Glacier mapping based on remote sensing data using a semi-automated band ratio technique. Assessment of the accuracy of glacier mapping;

3. Identification and mapping of active rock glaciers using optical and radar images;

4. Determining the equilibrium line altitude (ELA) for the glaciation of the Zhetysu Alatau;

5. Creation of bistatic digital elevation models (DEM) using remote sensing data. Correction of elevation values taking into account the difference of microwave penetration in X, C bands using SRTM-X and SRTM-C data;

6. Assessment of glacier height and mass balance changes using remote sensing data. Assessment of glacier mass balance using numerical methods.

Object of study – Components of the cryosphere of the Zhetysu Alatau mountain ranges.

Subject of study – States of components of the mountain cryosphere of the Zhetysu Alatau mountain ranges.

The research methods allow achieving the aim set in the dissertation and revealing the essence and content of the obtained scientific results. The following methods were used to solve the tasks:

- The band ratio threshold method was used to determine the glacier area, based on the analysis of multispectral optical images in combination with visual interpretation, provides sufficient accuracy in delineating glacier boundaries;

- two basic approaches were used for rock glacier inventories: geomorphological (using DEM and high-precision optical data) and kinematic (radar interferometry data (InSAR));

– to calculate the change in glacier surface elevation, a mathematical comparison of two DEMs was carried out: historical (SRTM) and current (SRTM).

Description of the main results of the study:

- interpretation of glaciers in all seven river basins for Zhetysu Alatau was carried out, the rate of glacier area reduction was analyzed using satellite data;
- catalog of stone glaciers of Zhetysu Alatau was created according to the data of archives of optical images. Classification of rock glaciers by activity index using InSAR technology, processing by SBAS (Small Baselines Subset) method was carried out;
- changes in the height and mass balance of glaciers on a regional scale for Zhetysu Alatau were assessed using Earth remote sensing data;
- the obtained results of scientific research on Zhetysu Alatau can be scaled to estimate the mass balance for all glacial mountain systems of Kazakhstan. The developed methodology of satellite data processing allows to determine the spatial and temporal dynamics of glacier volume and their impact on river flow as one of the main sources of renewable natural resources;
- the proposed methods and recommendations allow us to reduce the labor intensity and cost of studying the state of glaciation in the mountainous regions of Central Asia.

Scientific novelty

1. Scientific and methodological principles for studying the state of the Zhetysu Alatau cryosphere using satellite technologies have been developed;
2. The mass balance of glaciers of the entire Zhetysu (Dzungarian) Alatau has been calculated on a regional scale using Earth remote sensing data with high temporal and spatial resolution;
3. The inventory of active stone glaciers of Zhetysu Alatau was carried out using differential interferometry and high resolution multispectral optical images and derived products in the form of DEM. Modification of the methodology for identification of rock glaciers was carried out and for the first time classification by origin was carried out for the studied area;
4. The lower and upper boundaries of the cryolithozone for the Zhetysu Alatau have been determined;
5. The degradation rates of glacier areas of the Zhetysu Alatau have been calculated using satellite data.

Theoretical and practical significance of the work

The significance of the work is due to the development and creation of scientific and methodological foundations for studying the components of mountain cryosphere, contributing to a more detailed study and understanding of the impact of climate change in general on water resources.

Scientific significance - testing and implementation of the international methodology for inventorying glaciers and rock glaciers for the Zhetysu Alatau can be scaled up to study the components of mountain cryosphere in other high-mountain regions of the Republic of Kazakhstan and Central Asia.

Practical significance - digital catalogs of glaciers and rock glaciers were created according to the model of the international standard organizations International Permafrost Association (IPA), Global Land Ice Measurements from Space (GLIMS) and International Centre for Integrated Mountain Development (ICIMOD), which can be included in the system of international data catalogs, increasing the availability of the scientific community to fill the information gap in the study region. The results of the research can be used as additional data by specialists for the tasks of building and calculating hydrological models.

The validity and reliability of scientific provisions, conclusions and recommendations are confirmed by: the application of the theory of measurement errors to study the accuracy of various methods of collecting geospatial data, statistical methods, including calculations to determine the mean-square errors of the areas of glaciers and rock glaciers, as well as methods of comparative analysis of climate data to determine the influence of temperature trends and precipitation on the increased rate of reduction of glacier areas.

Connection of the topic with the research plan and various State programs.

The work was carried out within the framework of the project of the Science Committee of the Ministry of Higher Education and Science of the Republic of Kazakhstan: "Region-wide glacier mass balance assessments and inventory of active rock glaciers in the Zhetysu Alatau using remote sensing data" for 2020-2022 (AP08856470).

Scientific provisions submitted for defense:

1. For the first time, numerical values of the degradation rate of the glaciers of the Zhetysu Alatau were obtained using satellite data;
2. For the first time a catalog of stone glaciers of Zhetysu Alatau was created according to the data of complex analysis of optical and radar satellite data, and derived DEM products;

3. Modification of the methodology for identification of rock glaciers was carried out and for the first time classification by origin was performed for the studied area;

4. For the first time, an assessment of the geodetic mass balance of mountain glaciers of the Zhetysu Alatau was carried out using satellite data, taking into account the characteristics of the study area;

5. For the first time, factors influencing the reduction in the volume of glaciers of the Zhetysu Alatau were determined.

Publications and approval of the work. There are 5 published works on the topic of the dissertation. 3 articles were published in peer-reviewed journals included in the Scopus and Web of Science databases. Of these, 2 articles in the journal "Remote sensing" (percentile 91, Q1) and one article (review) in the journal "Water" (percentile 84, Q1). Also, 2 articles were published in journals approved by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan and 2 reports were made and 1 abstract was submitted at international scientific and practical conferences, forums and congresses. The research was carried out within the framework of the grant project on the topic "Region-wide glacier mass balance assessments and inventory of active rock glaciers in the Zhetysu Alatau using remote sensing data" (IRN AP08856470), based on Institute of Ionosphere LLP.

The personal contribution of the doctoral student to the preparation of each article:

Nurakynov S.M. made a significant contribution to the preparation of articles on the study of glaciers and rock glaciers of the Zhetysu Alatau, focusing on the use of satellite data and modern technologies for analyzing changes in the cryosphere. His participation included data collection and processing, development of analysis methods, and preparation of texts for publications.

In the article "The First Inventory of Rock Glaciers in the Zhetysu Alatau: The Aksu and Lepsy River Basins" S.M. Nurakynov participated in the inventory of rock glaciers of the Zhetysu Alatau, in particular, in the collection and analysis of data on rock glaciers in the Aksu and Lepsy River basins. He modified the methodology of identification of rock glaciers and for the first time, for the studied area, carried out classification of rock glaciers by origin. He was also engaged in the processing and interpretation of the obtained radar data using InSAR technologies.

In the article "Accelerated glacier area loss in the Zhetysu (Dzhungar) Alatau Range (Zhetysu Alatau) for the Period of 1956–2016", S. M. Nurakynov is the main author, assessing the dynamics of glacier area change in the Zhetysu Alatau. He

participated in the analysis of satellite data, calculation of glacier area changes for the period from 1956 to 2016, and application of remote sensing methods to assess glacier shrinkage in this region. He made a major contribution to the development of the methodology for assessing the rate of glacier degradation and to the preparation of the article results.

In the article "Application of Artificial Intelligence in Glacier Studies: A State-of-the-Art Review", S. M. Nurakynov is the main author of the review devoted to the application of artificial intelligence in glacier studies. He collected and analyzed existing studies on the use of artificial intelligence technologies for glacier analysis, as well as developed the structure of the article and wrote a review on the current state of this field.