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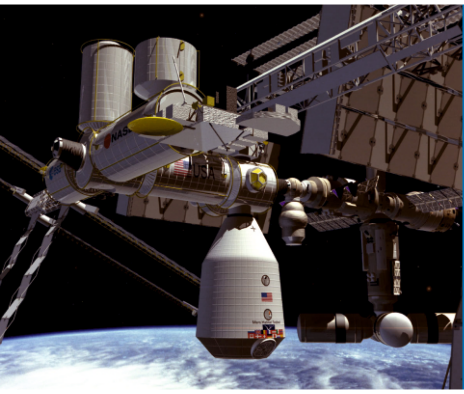

# ВЕСТНИК
## Алматинского университета энергетики и связи

Special Issue

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## "Disaster Management & Emergency Responses to Flooding" Conference, 7-13 August 2016, Almaty, Kazakhstan

The event brought together scientists, engineers and practitioners from across academia, industry, and non-government organizations to discuss, share and promote current research and recent developments across all aspects of engineering in disciplines such as Civil, Environmental, Hydrological, Geological, Social, Political Sciences, Earth Observation Satellite or Remote Sensing Technologies. The workshop was focused on three specific themes related to forecasting, decision making and response to natural disasters:

I) natural hazards from floods and seismic activity to landslides

II) Remote Sensing (Satellite) for monitoring and prediction of natural disasters

III) Disaster Risk Reduction and Resilience (DRRR)

Theme I dealt with natural hazards with a particular focus on flooding from seasonal glacial ice melt and seismic distortions resulting in landslides, with field work tracking and sensors applications, data collection and modelling.

Theme II dealt with remote sensing for real-time monitoring and prediction analysis, applications of the different international satellite and local data, including Kazakhstan KazEOSat-1 and -2. Satellite data processing, data collection, modelling and visualization with web GIS tools application were also discussed.

Theme III dealt with Disaster Risk Reduction and Resilience (DRRR) and response. Cooperation strategies related to DRRR were discussed by public emergency preparedness researchers, emergency agencies, scientists, multidisciplinary social-political science and engineering science experts.

The papers presented in the conference are published in this special issue of VESTNICK of AUPET.

### Acknowledgements:

This conference and proceedings were supported by the British Council Researcher Links Workshop Grant awarded under the Newton – Al-Farabi Partnership Programme, by the Royal Academy of Engineers awarded under the Industry Academia Partnership Programme, and by the Committee for Emergency Situations of the Ministry of Internal Affairs of the Republic of Kazakhstan, Almaty city KazSeleZashita.

# Special Issue

VESTNICK OF ALMATY UNIVERSITY OF POWER ENGINEERING AND TELECOMMUNICATIONS

# CLIMATE CHANGE IMPACTS ON GLACIER AND RIVER RUNOFF IN WESTERN PART OF ZHETYSU (DZHUNGAR) ALATAU

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**Abstract.** Our glaciological studies were conducted for the periods of 1956-1989, 1989-2001 and 2001-2012 and are based on Landsat TM/ETM+ data analysis. A well-established semi-automated band ratio technique was applied for glacier mapping. The result showed a comparatively higher shrinkage rate (-1.02%) than rates in other glacierized areas of Central Asian mountains, including Altai, Tien Shan and Pamir. We also analyzed long-term climatic and runoff fluctuations for the different sub-basins of the Karatal River. A positive trend in annual discharge was detected in almost all the glacierized tributaries of the Karatal River during the last half of the century.

**Key words:** glacier shrinkage, glacier mapping, river runoff, Karatal river basin.

## Introduction

Global climate has changed on both regional and global scales, with a mean increase in annual temperature of 0.74 from 1906 to 2005 and a predicted increase of 1.1 °C−6.4°C by 2100 [1]. This increase in surface temperature has important consequences for the hydrological cycle, particularly in regions where the water supply is provided mostly by melting ice or snow. Even a low fraction of change in glacial cover within a basin has tremendous impact on hydrology. Various research studies based on remote sensing methods found that the shrinkage of Central Asian glaciers has accelerated in the last several decades [2, 3,4]. Especially, glaciers that are located on the peripheral regions of the Tien Shan [5, 6] have changed.

In spite of the glaciers' importance to the economy, after the collapse of the USSR in the 1990s, regular glacier mass balance and other ground-based glaciological measurements were discontinued in the Karatal River basin, as well as in the entire Zhetysu Alatau mountain range.

In this study, the glacier area shrinkage and the effects of dramatically decreased glacier runoff for the sub-basins of Karatal river with different glaciation area are assessed. The three main parts of this study include detection of long-term trends of runoff, precipitation, and air temperature; estimation of glacier change; and the assessment of the effects of glacier and climate changes on runoff.

## Study area

We focused on the Karatal River Basin, which is the largest basin in Zhetysu Alatau. It covers an area of 19,100 km2; and the total area of the four sub-basins studied here is 4370 $km^2$ (Figure 1).

The Karatal river basin is located on the outer ranges of Zhetysu Alatau, where the elevations of the highest mountain ridges range between 3800 and 3850 m above sea level [7]. Most glaciers found here are small in size (less than 1 $km^2$). In addition, the Karatal basin is close to urban areas, which are located approximately 60 km from the lowest glaciers [8].

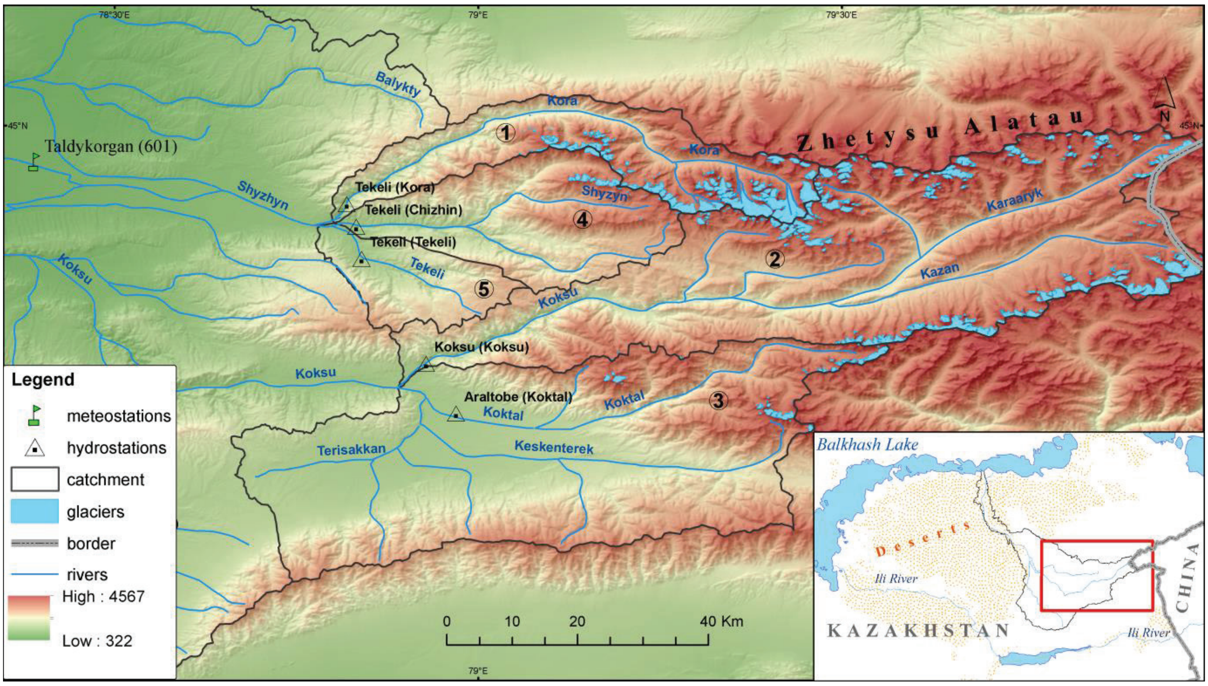


Figure 1 - Location of the study area; map based on SRTM3-DEM; sub-basins with glacier: 1 – Kora; 2 – Koksu; 3 – Koktal; 4 – Chizhin; 5 – Tekeli; Weather station – Taldykorgan (air temperature, precipitation)

## Data and methods

### Remotely sensed data and glacier mapping technique

Landsat TM and ETM+ images were used to measure glacier delineation. We applied a well-established semi-automated approach using the TM3/TM5 band ratio to produce glacier outlines. Misclassified areas, such as snow patches, cast shadows and lakes, were corrected manually using false-colour composite (TM bands 5, 4, and 3) on the Landsat imagery. All of the images were obtained during cloud-free conditions and for the ablation period when the extent of snow cover was minimal in order to reduce potential uncertainly in glacier boundary delineation because of seasonal snow cover. Changes in the extent of glaciers were assessed with regard to images from 1989, 2001 and 2012, and analysed according to the surface area. Landsat TM and ETM+ scenes were co-registered to the 2001 Landsat ETM+ scene, and root-mean-square error (RMSE) was within 0.5 pixels.

### Hydro-meteorological data and trend analysis

In order to determine and analyse the potential drivers of glacier changes and investigate the changes in river runoff over the past decades, a trend analysis using the Mann-Kendall test [9] was carried out for the time series of runoff at selected hydrological stations.

An accumulative deviation test was applied to detect trends in air temperature at the Taldykorgan weather station. Test results showed that the temperature had a step change point occurrence in 1977. Therefore, the data series was divided into two periods before and after 1977.

The rank-based nonparametric Mann-Kendall test is commonly used to assess the significance of monotonic trends in a hydro-meteorological time series. In this test, the standard normal statistic Z is estimated and compared with the standard normal deviate $Z_{\alpha/2}$. The test statistic Z is not statistically significant if $-Z_{\alpha/2} < Z < Z_{\alpha/2}$. Correspondingly, this test shows a statistically significant trend if $Z < -Z_{\alpha/2}$ or $Z_{\alpha/2} < Z$ . The confidence level fixed at $\alpha = 0.95$ and critical z values for two-sided test are −1.96 and +1.96.

## Results

### Glacier shrinkage

Our glaciological studies were conducted for the periods of 1956-1989, 1989-2001 and 2001-2012 based on Landsat TM/ETM+ data analysis.

In 1989, we found 243 glaciers with a total area of 142.8 km$^2$ that by 2012 had shrunk to 214 glaciers with a total area of 109.3 km$^{2.}$ This indicates a decrease of 33.5 km$^2$ over 23 years or -1.02% per year. We also analyzed the shrinkage rate of glaciers based on their differences in size, altitude and aspect of slopes, as well as other topographic parameters in four sub-basins, where glacier shrinkage varied from 18% to 39% (Table 1).

Table 1 - Changes in Glacier area

| Region | Area change (%) /annual rate (%) | | | | | Mean size ($km^2$) in |
|---|---|---|---|---|---|---|
| | 1956-89 | 1989-01 | 2001-12 | 1956-12 | 1989-12 | |
| Terisakkan | -40/-1.22 | -23/-1.96 | -20/-1.8 | -63/-1.13 | -39/-1.68 | 0.403 |
| Koksu | -31/-0.93 | -15/-1.24 | -13/-1.14 | -48/-0.86 | -26/-1.11 | 0.506 |
| Chizhin | -44/-1.32 | -15/-1.24 | -9/-0.79 | -56/-1.0 | -22/-0.97 | 0.445 |
| Kora | -28/-0.61 | -14/-1.03 | -7/-0.63 | -35/-0.62 | -18/-0.80 | 0.873 |
| Total | -28/-0.86 | -14/-1.20 | -11/-0.96 | -45/-0.81 | -23/-1.02 | 0.588 |
| Glaciers <0.1 $km^2$ in 1956 | -34/-1.04 | -68/-5.63 | -22/-1.99 | -83/-1.49 | -75/-3.25 | 0.031 |

**Runoff Trends**

Trends in monthly and annual runoff for the sub-basins of Karatal river were analysed. Discharge trend analysis was calculated for three periods: full-observed time and for periods before and after 1977 (step change year) for each hydrological station. Annual runoff of almost all of the sub-basins showed an increasing trend for annual, melting and frozen seasons for the entire observed time (Figure 2 A). An increasing discharge trend was statistically significant in more glacierized catchments (Kora, Koksu and Koktal). Runoff trends for the melting season were similar to those in the annual cycle. Less glacierized (Chizhin) and non-glacierized sub-basins (Tekeli) show a lower increasing trend in the melting season and annual time frame.

The discharge trend for the first period, before step change year (1977), showed a slightly negative trend in the annual and melting cycle. A positive trend was found for only two stations, Chizhin and Tekeli. However, the trends for cold months and the frozen season were different. The discharge trend was increased in Koktal and decreased in Chizhin and both trends were statistically significant (Figure 2 B).

Runoff data for the second period (after 1977) indicated trends that are more positive. In the Koksu sub-basin, where most of the glaciers were located (108.6 $km^2$ in 1956), trend analysis exhibited a statistically significant increase for melting, frozen and annual cycles. Three sub-basins, which were more glacierized, showed a slight increasing trend, while less glacierized sub-basins had small decreasing trend during the melting season (Table 4 C).

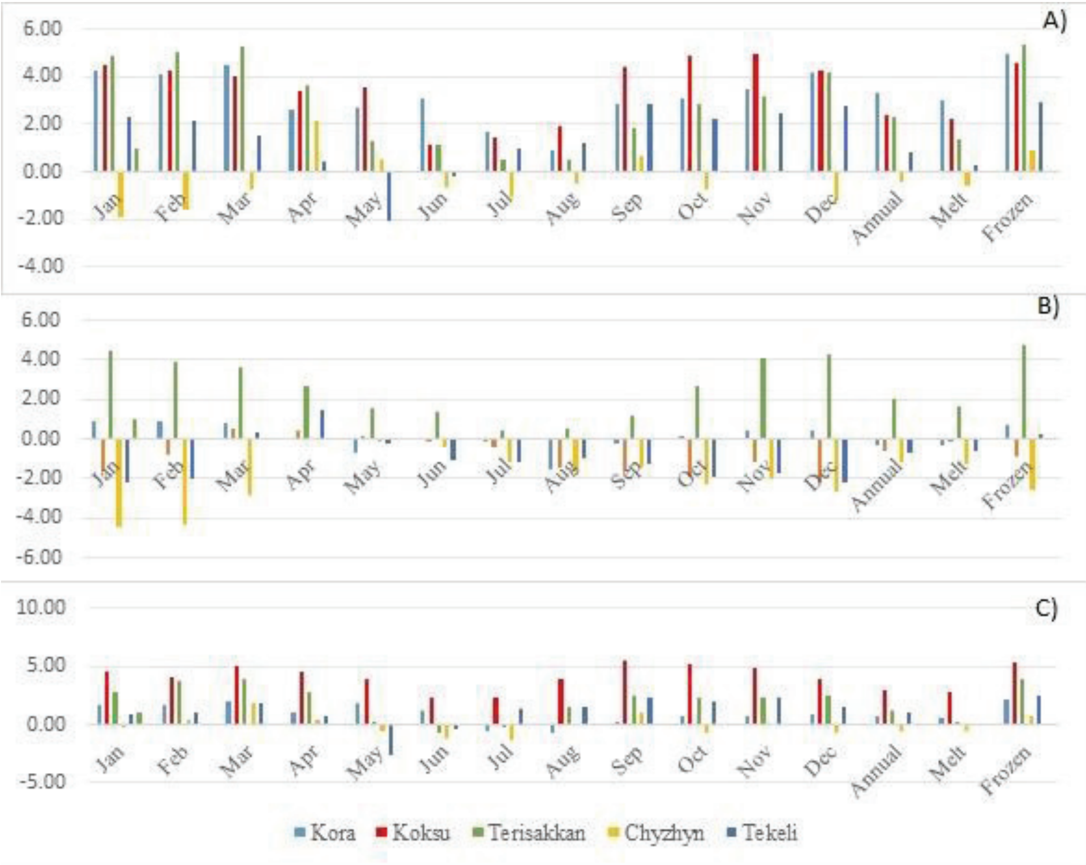


Figure 2 - Kendall test Z statistics for trends of monthly, annual and seasonal runoff for the Karatal river sub-basins: (A) for entire period, (B) and (C) for the periods before and after the 1977 (step change) year, respectively. Critical value of $Z < -1.96$ and $>+1.96$ (two-sided)

## Discussion

The linear trend analysis of mean temperature indicated that the average rate of temperature increase was 0.43 °C $(10a)^{-1}$, while the summer (JJA) temperature rose 0.28 °C $(10a)^{-1}$ (see Figure 3). From 1960 to 2007, records at the same station displayed a slight decrease in annual precipitation. Increasing temperature leads to: (1) increased energy available for ice and snow-melt, (2) decreased snow accumulation, and (3) lower albedo of the glacier surface [10, 11]. The temperature increase caused the rainfall rate to increase, rather than snowfall in the high altitude glacierized areas, leading to a reduction of accumulation and the acceleration of ablation, especially during the summer. Due to a significant increase in annual temperatures between 1960 and 2007, and a stable annual precipitation trend, which did not compensate for the rising temperature, intensive glacier melting occurred.

The area changes of the glaciers investigated in the Karatal river basin confirmed an expected and widely published trend of glacier retreat [11, 12]. However, our results for this region indicated the highest shrinkage rate for the period of 1989-2012 compared to other glacierized areas of Central Asia, including all parts of Tien Shan and Pamir. The effect on runoff changes was different in glacierized sub-basins of Karatal river. The relatively high glacierized Kora area (14% glaciation) showed the highest positive trend, while the smaller glacierized Koktal area (5%) demonstrated a smaller trend, with the statistically significant magnitude of 3.32 and 2.31, respectively (Table 2). In the catchment with only 2% glaciation (Chizhin), the trend was even negative with a magnitude of -0.43. Apparently, the tipping point (peak water) for this catchment might be already passed [12, 13].

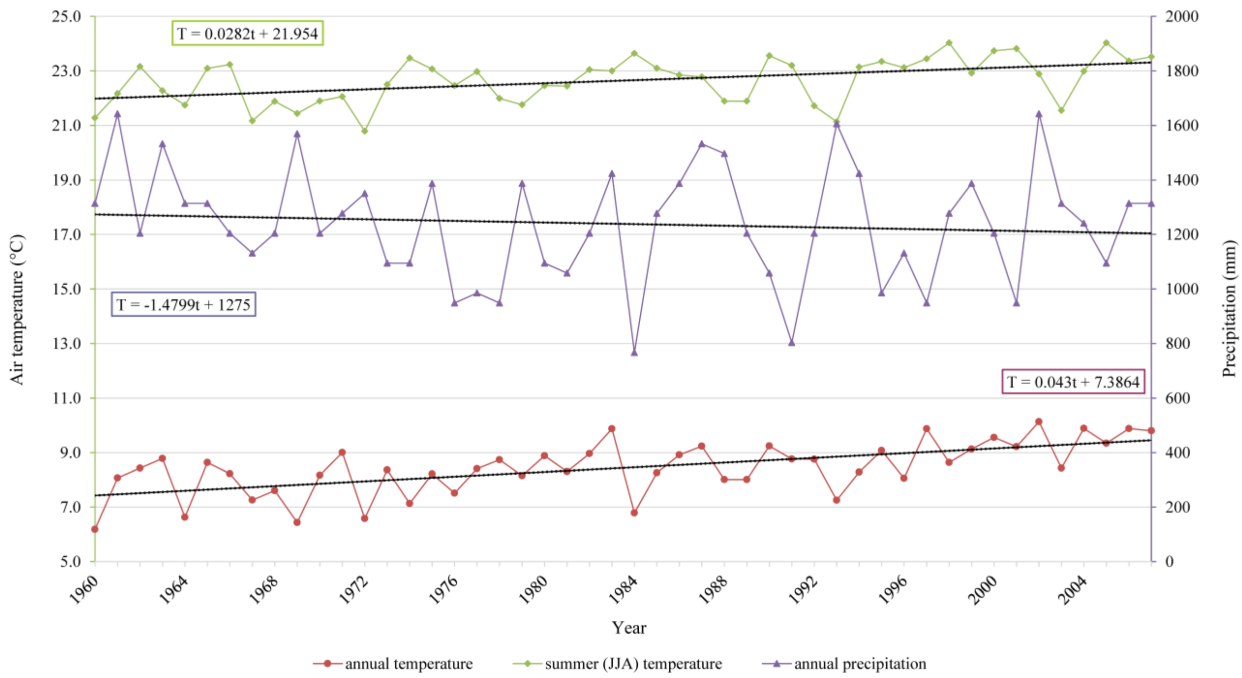


Figure 3 - Annual and summer (JJA) temperature and annual precipitation of Taldykorgan station [4]

Table 2 - Characteristics of sub-basins and changes in annual runoff

| | Glaciation, % | Z of trend in annual runoff | Mean runoff (m3/s) | Basin area($km^2$) |
|---|---|---|---|---|
| Kora | 14 | 3.32 | 14.1 | 484 |
| Koksu | 7 | 2.38 | 39.2 | 1590 |
| Terisakkan | 5 | 2.31 | 9.3 | 293 |
| Chyzhyn | 2 | -0.43 | 11.6 | 479 |
| Tekeli | 0 | 0.86 | 2.2 | 193 |

*Critical value of Z < −1.96 and >+1.96 (two-sided)

The tipping point is a phenomenon when runoff during warm temperatures will at first increase due to the higher temperatures and result in more meltwater.

This effect is gradually reduced when the glacier area begins to decline as a result of continued glacier mass loss. Tekeli sub-basin, which has no glacier, showed a slight increasing trend, but the absolute water volume of the rising trend was very small. Based on runoff trend analysis, the runoff in the sub-catchments was controlled by temperature provoking the melting of glaciers which had existed for decades and centuries.

## Conclusions

Our results, with the shrinkage rate of about -0.8% to -1% per year for the periods of 1956-1989 and 1989-2012 for this study area, showed the highest decreasing rate compared to other glacierized areas of Central Asian mountains, including Altai, Tien Shan and Pamir. Climatic conditions play a primary role on glacier status. Two main climatic factors, statistically significant temperature increases and slight precipitation decreases, were the main cause in the glacierized area loss in the Karatal river basin.

River runoff demonstrated a significant increasing trend during the last half of the century at the expense of glaciers' melting intensification against a background of slight decreasing precipitation at the same time.

The increase of global temperature had a significant impact on the river runoff fluctuations for even small glacierized areas (5% - 14% of the total basin).

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## ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА ЛЕДНИКИ И РЕЧНОЙ СТОК В ЗАПАДНОЙ ЧАСТИ ЖЕТЫСУСКОГО (ДЖУНГАРСКОГО) АЛАТАУ

**Аннотация.** Наши гляциологические исследования проводились на периоды 1956-1989, 1989-2001 и 2001-2012 на основе анализа данных Landsat TM/ETM+. Для картирования ледников использован налаженный полуавтоматический метод Band ratio technique. Результаты показали, что скорость сокращения ледников (-1.02%), сравнительно быстрее чем в других оледенённых горных территориях Центральной Азии, включая Алтая, Тянь-Шаня и Памира. Мы также проанализировали долгосрочную колебанию климата и речных сток для различных под-бассейнов реки Каратал. Была обнаружена положительная тенденция почти во всех оледенённых притоках реки Каратал за последние полвека.

**Ключевые слова:** сокращение ледников, картографирование ледников, речной сток, Каратальский речной бассейн.

## ЖЕТІСУ (ЖОҢҒАР) АЛАТАУЫ БАТЫС БӨЛІГІНДЕГІ МҰЗДЫҚТАРДЫҢ ЖӘНЕ ӨЗЕН СУЫНЫҢ ӨЗГЕРІУІНЕ КЛИМАТТЫҢ ӘСЕРІ

**Аңдатпа.** Біздің гляциологиялық зерттеулер 1956-1989, 1989-2001 және 2001-2012 жылдар аралығына Landsat TM/ETM+ мәліметтерін талдау негізінде жасалды. Мұздықтарды картографиялауда кең таралған жартылай автоматты Band ratio technique әдісі қолданылды. Алынған нәтижелер мұздықтардың - 1,02%

жылдамдықта қысқарғандығын және бұл көрсеткіш салыстырмалы түрде Орталық Азия таулы аймақтарындағы (Алтай, Тянь-Шань және Памир тауларын қоса есептегенде) мұздықтардан жылдам қыскарып жатқандығын қөрсетті. Сонымен қатар, Қаратал өзеніндегі әртүрлі салалардағы өзен суы мен климаттың ауытқулары талданды. Соңғы жарты ғасырда Қаратал өзенінің салаларында судың көбейгендігі байқалды.

**Кілттік сөздер:** мұздықтардың қысқаруы, мұздықтарды картографиялау, өзен ағысы, Қаратал өзені бассейні.