



**THE RETREAT OF MOUNTAIN GLACIERS IN CENTRAL ASIA
UNDER GLOBAL WARMING CONDITIONS AND ITS IMPACT ON
WATER RESOURCES**

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Abstract: This article analyzes the processes of glacier retreat in the mountainous regions of Central Asia under conditions of global climate change and their impact on the region’s water resources. During the study, the state of glaciers in the Tien Shan and Pamir-Alay mountain systems, as well as the dynamics of changes in their area and volume, were examined. Based on remote sensing data and geographic information systems (GIS), the spatial characteristics of glacier degradation were identified. The results show that the rapid melting of glaciers initially leads to a temporary increase in river discharge; however, in the long term, it intensifies water resource scarcity. It was also determined that glacier retreat increases the risk of mudflows, landslides, and other natural hazards. The research findings serve as a scientific basis for developing sustainable water resource management and climate change adaptation strategies in Central Asia.

Keywords: Global warming, climate change, Central Asia, mountain glaciers, glacier retreat, water resources, Tien Shan, Pamir-Alay, river discharge, GIS, remote sensing.

Introduction

In recent decades, global climate change has had a significant impact on natural geographical processes in all regions of the Earth. In particular, glaciers located in mountainous areas are considered one of the most sensitive natural components to climate change. Central Asia is a region characterized by the Tien Shan and Pamir-Alay mountain systems and arid and semi-arid



climatic conditions, where glaciers are regarded as one of the main sources of freshwater.

Mountain glaciers of Central Asia play an important role in the nourishment of the Amu Darya, Syr Darya, Zarafshan, Ili, and other rivers. As a result of global warming, the rapid retreat of glaciers poses a serious threat to the water regime, seasonal discharge, and long-term water supply of these rivers. This situation directly affects agriculture, energy production, drinking water supply, and regional ecological stability [1].

The main objective of this article is to analyze the dynamics of glacier retreat in the mountain regions of Central Asia under conditions of global warming and to scientifically assess the impact of this process on the region's water resources.

Research Methods and Results

This study is aimed at identifying the processes of glacier retreat occurring under the influence of global warming in the mountainous regions of Central Asia and their impact on water resources, and a comprehensive physical-geographical approach was applied. Several modern scientific methods were used in an integrated manner in the research.

First, using the climatic-statistical analysis method, trends in changes in average annual air temperature and precipitation recorded over the past 50–70 years in the territory of Central Asia were examined. Based on these data, the main climatic factors affecting the condition of glaciers were identified.

Using the remote sensing method, spatial changes in glaciers in the Tien Shan and Pamir-Alay mountain systems were analyzed. Satellite imagery made it possible to identify the retreat of glacier boundaries, the emergence of fragmented small glaciers, and the complete disappearance of glaciers in certain areas.

Geographic information system (GIS) technologies were widely used in the study. Based on GIS, the distribution of glaciers by altitudinal zones, their

connection with river basins, and spatial differences in the contribution of glacier meltwater were modeled. This method made it possible to more accurately assess the spatial distribution of water resources.

In addition, through hydrological observation analysis, seasonal and annual variations in river flow formed by glacier melt in the basins of the Amu Darya, Syr Darya, and Zarafshan rivers were studied. The impact of the decreasing contribution of glacier meltwater on river flow was determined.

Furthermore, using a comparative-geographical method, the rates of glacier retreat in Central Asia were compared with those in other mountain regions (for example, the Alps and the Caucasus), highlighting regional characteristics. This combination of methods ensured the scientific reliability of the research results [2].

The study results indicate that global warming processes are leading to a rapid retreat of glaciers in the mountainous regions of Central Asia. Over the past decades, the increase in average annual air temperature has caused a significant reduction in the total area of glaciers in the Tien Shan and Pamir-Alay mountain systems [3].

It was found that small and medium-sized glaciers are particularly vulnerable to climate change, with some of them reaching the stage of complete disappearance. In high-altitude areas, the upward shift of the snow line reduces the accumulation zone of glaciers, limiting their potential for regeneration [4].

Hydrological analyses showed that rapid glacier melting initially led to a temporary increase in river flow. However, in the long term, the reduction in glacier volume is causing a decrease in summer minimum flow in the basins of the Amu Darya and Syr Darya. This situation creates serious problems for irrigated agriculture, hydroenergy production, and drinking water supply.

Moreover, glacier degradation has been shown to increase the number of natural hazards in mountainous areas. The formation and potential breach

of glacial lakes increase the likelihood of floods, posing a threat to settlements and infrastructure located at the foot of the mountains.

The results indicate that if global warming continues at the current rate, water scarcity in the Central Asian region will intensify in the future, negatively affecting the ecological and socio-economic sustainability of the region.

Discussion

The study results confirm that global climate change processes have a direct and significant impact on glaciers in the mountainous regions of Central Asia. The increase in temperature and changes in the seasonal distribution of snowfall are disrupting the accumulation processes of glaciers. In particular, the upward shift of the snow line reduces the accumulation zone of glaciers, decreasing their long-term stability.

When compared with studies conducted in other mountain regions, the results show that glaciers in Central Asia are more sensitive to climate change due to their location in arid and semi-arid climatic conditions. This situation is explained by the fact that the region's water resources largely depend on glacier and snow melt. As a result, glacier retreat intensifies the seasonal and annual variability of river flow [5].

Although glacier retreat initially leads to a temporary increase in river discharge, in the long term it exacerbates water scarcity, which is a scientifically important conclusion. This process is associated with what is called the "glacier peak water" phenomenon, after which river discharge may sharply decrease. This situation necessitates a re-evaluation of water resource management strategies in Central Asian countries.

Moreover, glacier degradation increases geo-ecological risks in mountainous areas. The formation and potential breach of glacial lakes heightens the risk of floods, contributing to an increase in natural disasters.

This poses serious threats to settlements and infrastructure located in mountain foothills.

In this regard, strengthening glacier monitoring at the regional level, widely implementing remote sensing and GIS technologies, and developing science-based and cooperative approaches to transboundary water resource management remain urgent tasks [6].

Conclusion

The conducted studies show that under global warming conditions, the retreat of mountain glaciers in Central Asia has a significant and long-term impact on the region's water resources. The increase in temperature and changes in snowfall patterns lead to a reduction in glacier area and volume, weakening the feeding sources of rivers.

Although rapid glacier melting initially increases river flow, in the long term it intensifies the risk of water scarcity. This situation creates serious problems for agriculture, hydroenergy production, drinking water supply, and ecological stability. At the same time, glacier degradation in mountainous areas increases natural hazards, including floods and landslides.

In conclusion, the preservation of mountain glaciers in Central Asia and the sustainable use of water resources are crucial for ensuring ecological security and sustainable development in the region. Expanding scientific research, developing monitoring systems based on modern technologies, and strengthening regional cooperation are key directions for mitigating these challenges.

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