

# Problems of Protection and Preservation of Mountain Glaciers: Risks and Solutions (on the example of glaciers in Kyrgyzstan and Tajikistan)

**Temirbek S. Bobushev**

Science and Research “Kyrgyz Economic University named after M.Ryskulbekov”,  
58 Togolok Moldo Street Bishkek, Kyrgyz Republic 720033

*Received 06-05-2025*

*Revised 18-05-2025*

*Accepted 04-06-2025*

**Published 10-06-2025**



Copyright: ©2025 The Authors. This is an open access article under  
the CC BY-NC-ND license

<https://creativecommons.org/licenses/by-nc-nd/4.0/>

## Abstract:

The accelerated melting of mountain glaciers is closely linked to issues of environmental risks, first of all, as well as to decision-making in the field of research into ethical dilemmas and the technical feasibility of such solutions for the conservation of mountain glaciers. Unfortunately, such solutions in determined problems are quite often limited in its wider applying in practice. The importance of solutions on the preservation of mountain glaciers is explained by the problems in related areas, such as electricity production and water using on the both in transboundary environment and within the country. At the same time, in our opinion, public acceptance of strategies and policies for the preservation of mountain glaciers is extremely important against just generalization of problems noted.

Research problems in reducing the melting of mountain glaciers are based on important ethical issues, namely the intergenerational responsibility for the conservation of mountain glaciers and transnational water resource management. Ultimately, the proposed article will offer the results of discussion and decision-making in the following research areas: socio-economic development and pattern of air pollutants emission, introducing the dynamic monitoring model, transnational governance and cooperation in a field of water resources using, and improved designing the ethical and legal frameworks for the conservation of mountain glaciers.

**Key words:** mountain glaciers, environmental risks, water resources, ethical standards in glacier protection, conservation of mountain glaciers.

## Introduction:

Every time we apply to information in the open publishing about the current state of mountain glaciers, we most often come across a conclusion about what will happen if the melting of mountain glaciers and ice caps accelerates. Indeed, the glaciers are retreating and melting twice as fast as in the last two decades. But what are the reasons

for this acceleration, and what problems do they create? As it known, the glaciers begin to form when snow remains in the same place all year round, where it accumulates enough to turn into ice. Each year, new layers of snow bury and compress previous layers. Ice melting is essentially a physical process that causes water to

undergo a phase transition from solid to liquid. This occurs when the internal energy of a solid (i.e. the ice) is increased, usually by applying heat or pressure, which raises the temperature of the ice or substance to the point of melting.

What can be done to slow down the melting of mountain glaciers? There are several ways to slow down the melting of glaciers. The direct methods are increasing the reflectivity of the ice surface or albedo. As for other methods, they can be combined into groups of indirect methods, which contributing to the melting of glaciers. This is about the reducing of greenhouse gas emissions, which along with volcanism and climate change processes, build-up a group of causes of global warming characterized by an indirect effect on the dynamics of mountain glaciers. From the above, we can come to the following preliminary conclusion: in practical aspect of science, a “mixing” of processes and their consequences on different levels or scales is quite often observed. Therefore, despite the “popularity” of indirect methods using to analyzing the glacier melting, it is necessary to adhere to the real situation of mountain glaciers, which need of serious protection and conservation as natural water reservoirs, sources of climate transformation in mountainous areas, natural resources that should not only be used rationally at present, but also be preserved for using by future generations.

### **Materials and Methods:**

The melting of mountain glaciers is accompanied by their retreat in environment. It occurs for several reasons depending on the geographical location, including the ablation, evaporation, wind erosion and calving.

Ablation is a natural and seasonal part of the life of a glacier. As long as snow accumulation equals or exceeds the melting and ablation, the glacier will remain in equilibrium or even grow. To stop the melting of ice, it is necessary to protect it from warm air, which is heated from the surface of the glacier by solar radiation. In order to reduce the amount of solar radiation, it is necessary to increase the albedo or reflectivity coefficient of

the glacier surface. Changes in the albedo of the mountain glaciers’ surface are closely depend on the transparency or dustiness of the atmosphere. Unfortunately, the measurement is currently limited mainly to urban areas [19, 2020].

Taking into account the reduction in the area of the Aral Sea, which ultimately led to the emergence of significant open areas on the site of the former sea, it is necessary to concentrate research toward the studying, analyzing and assessing the processes of atmospheric dustiness and formation of dust storms, which main flows are often directed towards the mountain glaciers.

In frameworks of conducting research, special attention should be paid to the socio-ecological and economic consequences of the reduction the area of mountain glaciers and, in general, the reduction of water resources. The level and volumes of water resources depend not only from climate change, but from inappropriate or irrational using, especially in the agricultural production sector. It is so clear that the gradual disappearance of glaciers means a reducing of water consumption by the population, hydroelectric power generation capacities and finally, the reduction of the volume of water available for irrigation needs. In other words, at present, a choice must be made among the followings: to preserve the reserves of mountain glaciers and water resources for optimal socio-economic development or to continue to pursue the policy of traditional cultivation of some industrial crops that consume huge amounts of water and ultimately lead not only to a reduction in water resources, but to the destruction of land and subsequent erosion, water losses and water pollution. In searching for solutions to the above-stated issues, it is necessary to use geoengineering and environmental technologies on a new innovative basis, the essence of which is technical feasibility and public support for the proposed solutions.

### **Results and Discussions:**

#### *1. Causes of Glacier Melting*

Since global climate change is one of the main risks of mountain glacier shrinkage, the main

problem that climate researchers tried to solve back in the 19th century was to explain the causes of glaciation.

The global context is given by the Climate Indicators (temperature, ice and glaciers, greenhouse gases and ocean) [20,2025] for which data are available for the majority of the year.

Globally, an average of around 14 m reduction in ice thickness has been observed since satellite records began in 1976. Figure 1 illustrates the tendencies of rapid reducing the mass balance of glaciers as a negative effect of climate changes.

Both globally and across Europe, glaciers have seen a substantial and prolonged loss of ice mass since the mid-19th century. The current situation

since 1976 is the followings: global glaciers' ice lost at (-9,200 km<sup>2</sup>), and European glaciers' ice lost at (-915 km<sup>2</sup>) [22,2023] or 9.94%.

The cause of glaciation, including in high mountain regions, may be associated with several simultaneously acting factors, such as astronomical cycles, atmospheric composition, plate tectonics and ocean currents. The determined reasons should be attributed to factors of a global level or scale. However, in the "life" of mountain glaciers, in our opinion, local and sometimes regional reasons may have a greater impact, a discussion of which will be proposed below.

The role of changes in the Earth's orbit in climate control was firstly proposed by James Croll [3, 2025].

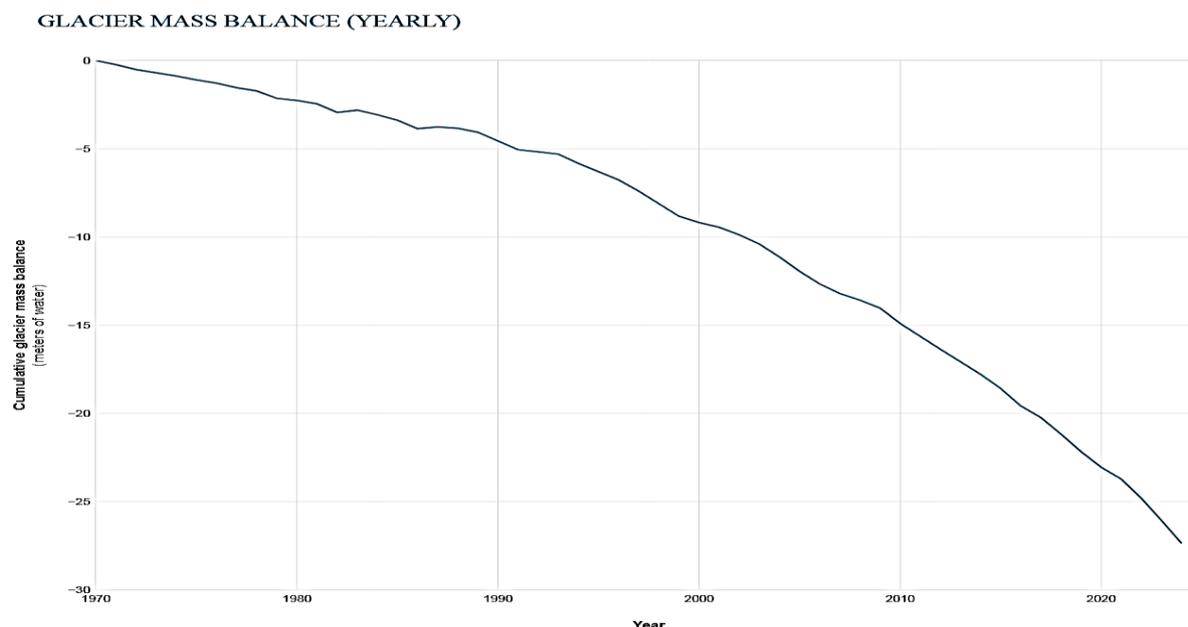


Figure 1. Tendencies of cumulative glaciers mass balance (meters of water) in 1970-2023.

Source: 22, 2023.

According to Croll, the Earth, rotating around the Sun, does so not in a circular, but in an elliptical orbit, which creates different volumes of solar radiation reaching the Earth's surface. During periods of cooling, as well as the least amount of heat coming from solar radiation, ice masses can form. Subsequently, these ideas by Croll were significantly supplemented by Milankovitch's calculations [11, 1938]. However, unfortunately, the proposed theories of the formation of glacial surfaces on the Earth did not receive their support

at that time [17, 2027]. The study of ice cores made it possible to combine both theories and explain the theories of the formation of ice masses. Such research involves the studying the carbon dioxide content of both the atmosphere and glaciers, which is used as a main driver of climate change and can be called the "carbon explanation".

A major problem in studying the ice conditions is how ice will be changed with climate change and what these interacting processes will be.

The fact is that for a glacier to survive, it must have a constant and stable accumulation zone, containing: 1) an outcrop of rock in the accumulation zone, the upper glacier area (relief factor) and 2) the possibility of retreat of the upper edges of the glacier around the accumulation zone (glacier location factor). Naturally, as above-noted, the albedo values in the area of the glacier surface and dustiness of the atmosphere in these regions are of particular importance.

## 2. Dynamics of glaciers in Kyrgyzstan and Tajikistan

The four Central Asian countries, including Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan are located in inland arid regions and characterized by an average annual precipitation of approximately 100–400 mm and a severe water shortage. Glaciers developed in high mountainous areas of these countries are important water resources in the Central Asian region, and glacier meltwater contributes up to 40–60% of river recharge. Affected by global warming, the

glaciers in the Central Asia are experiencing rapid retreat.

Glaciers in Kyrgyzstan cover an area of over 8,000 km<sup>2</sup>, which is almost 4% of the total area of the country. Glaciers in Tajikistan cover an area of at least 9,000 km<sup>2</sup>, which is almost 6% of the total area of the republic [7, 2017]. Over the past decades, under the influence of climate change, as a result of melting, the area of some large glaciers has begun to shrink, which has contributed to their significant retreat.

The latest Randolph Glacier Inventory (RGI) 7.0 dataset, although is providing detailed information on glaciers in the Central Asia, primarily relies on remote sensing images from 2002, thereby failing to capture the current state of glaciers. Subsequently, the manual visual revision method is used to verify the glacier boundaries more specifically. Finally, the relevant information of glaciers is supplemented with reference to the RGI specifications. The results show that there are 22,662 glaciers in four Central Asian countries, with a total area of 12,873.33 km<sup>2</sup> and figures 2-3 below reflect the current situation on glaciers quantity and cumulative area [23, 2024].

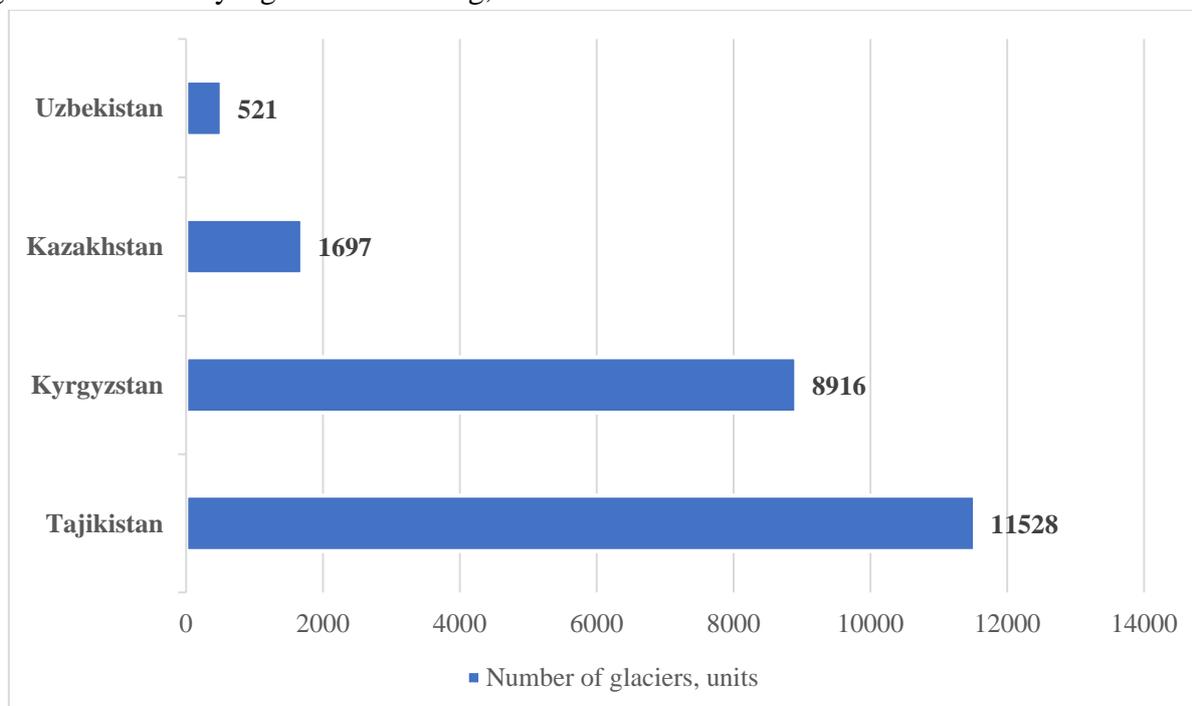


Figure 2. Distribution of total number of glaciers in Central Asia in 2023, units.  
Source: 23, 2024

There are different opinions on this matter, some scientists believe that the process of melting glaciers is practically irreversible, and the industrial era only accelerates this process, others believe that the process of melting glaciers is a normal natural process and it is almost impossible to do anything to prevent this process, you just need to monitor the glaciers. Paying tribute to the different opinions regarding the reduction of mountain glaciers, we believe that it is necessary not to limit ourselves only to observations, but also to analyze the possibility of a certain slowdown of this process, including using innovative technologies for preserving glaciers. For these purposes, first of all, it is necessary to determine the reasons for the priority of factors that have a direct impact on the melting of glaciers.

The fact that the direct significance in the matter of preserving the mountain glaciers, the role of glaciers is mainly in the formation of the flow of large rivers of the country as established idea. At the same time, the glaciers make up to 10-20% of the large rivers' flows of the country, and 80% of such water of the glaciers of Tajikistan goes to neighboring countries.

Based on the all-above stated, it turns out that the functioning of the glacier is not considered as a natural heritage, but only as a source for its using and indirect development. If we add here the losses of water for irrigation needs, the huge consumption of water for the production of industrial crops, water pollution, etc., then mountain glaciers are "to blame" for the reduction of water resources' using?

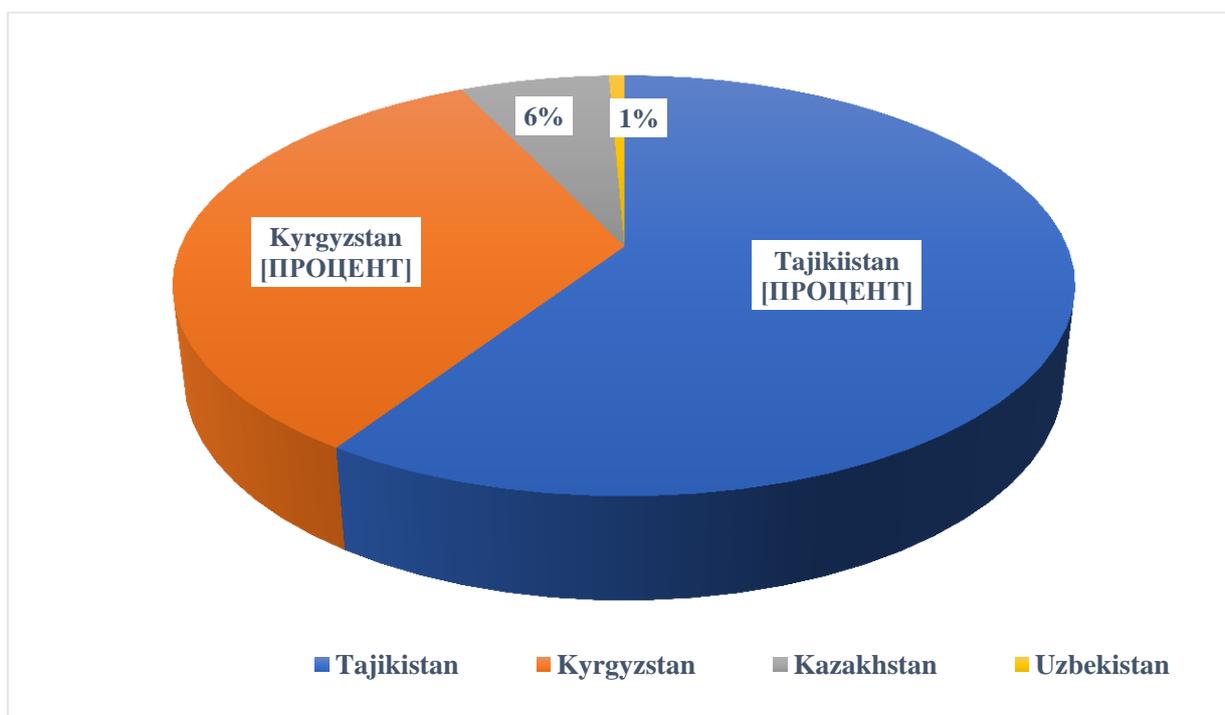


Figure 3. Total Area of glaciers in Central Asia in 2023, km<sup>3</sup>.

Source: 23, 2024.

### 3. Analysis of the reasons for the melting of glaciers

The conducted analysis of data on sources and distribution of emissions that have a significant impact on the melting process of mountain glaciers shown that the largest contribution is made by wind-blown dust at 33% and heating of individual residential buildings at 31%. After two

first, followed by emissions from the energy sector at 9%, waste at 7%, industrial production at 4% and transport at 3% [10, 2021].

As we can see, most part of the air pollutions belongs to dust, which, depending on the season, to varying degrees reaches mountainous areas and settles on the surface of mountain glaciers. Therefore, the solution to this problem involves

the following measures: control over dust sources and applying the technologies to “capture” dust and reduce its volume [13, 2018]. For these purposes, it is necessary to take into account the wind rose, the expansion of green areas throughout the country, as well as the transformation of the architecture of streets and houses, fields and roads, engineering structures, which could “contain” the spread of dust particles and limit their entry on the surface of mountain glaciers [12, 2023]. It has also been recognized that the most effective long-term approach to slowing the rate and extent of glacier melt is to reduce heat-trapping emissions. In this case, the optimal strategy involves reducing and eliminating greenhouse gas emissions while preparing for the inevitable negative consequences.

Thus, global warming accelerates glacier melting through several mechanisms. It increases the number of warm days, increases ice temperature, and reduces the storage of cold in glaciers. The glacial snow line shows a strong correlation with annual temperature, such that global warming increases the height of the glacial snow line [8, 2024]. An upward shift in the snow line accelerates glacier melting by reducing snow and ice accumulation, which reduces glacier mass. As the snow line rises, the accumulation area decreases, exposing lower albedo surfaces, such as old ice or dirty ice, which absorb more solar radiation and accelerate melting [16, 2023]. In general, mountain glacier protection includes the both greenhouse gas mitigation approaches to control temperature rise, and artificially increasing glacier albedo.

#### 4. *Use of glacier protection technologies*

Geoengineering technologies for the protection and preservation of mountain glaciers involve aerosol spraying in the stratosphere to reduce temperatures during the summer months. However, unfortunately, such methods are still not sufficiently developed. Despite the “temptation” of using this technology, its limited using is associated with the solution of many issues, such

as: the development of financial mechanisms and technological innovations, in close connection with the solutions of detailed scientific research tasks in international cooperation. At the same time, overcoming the named obstacles will allow making decisions on mitigating the melting of glaciers and gradually slowing their reduction.

In the context of global warming and increasing drought in the foothills, an approach to preserving mountain glaciers has long been used in the mountainous regions of Pakistan and can be called traditional practices or “glacier weddings”. The essence of this technology is transportation of ice to places where shrinking glaciers have been detected. The ice masses are compacted into a pit, which is either a natural cave or a specially dug hole. The ice mixture then produces an optimal combination of enough pure ice to freeze more water, with enough debris to act as insulation to protect the frozen water from the sun's heat and warm air. It is possible that this combination allows the ice mass to accumulate more snow, grow and form a glacier. Experience with this traditional technology in Pakistan has shown the positive climatic and ecological effects, with increased water availability recorded as a result of ice transport and “seeding” [2, 2025].

The experience of ice growth in the glacier area and introducing the traditional approaches to preserve glaciers in Pakistan have also attracted the interest of scientists of some European countries. Similar studies have been continued in Spain and the Swiss Alps [6, 2016]. Such studies in Austria, China, France, Germany, Italy and Switzerland on the preservation of snow and ice using various ecological materials and methods, using foam, sawdust, wood chips, and especially geotextiles, have shown that placing geotextiles on the snow surface in spring reduces glacier melting, which can significantly reduce the ablation rate in a shorter period of time [14, 20210].

By the way, the applying of this technology does not involve covering the surface of mountain glaciers with geotextiles, but scattering pieces of

such geotextiles, like pieces of broken glass, which can increase the reflection of solar radiation many times over and help reduce the rate of melting of mountain glaciers [18, 2020].

##### 5. Socioeconomic development and emission structure

Since the problem of glacier shrinkage, one of the reasons for which is greenhouse gas emissions, let us turn to materials on the production of hydropower and structure of emissions. Kyrgyzstan's economy is the second lowest emitter in Central Asia, with the intensity of CO<sub>2</sub> emissions in GDP being about 12% higher than the world average. Kyrgyzstan's energy sector contributes approximately 60% or 9.1 MT CO<sub>2</sub> from total greenhouse gas emissions, with residential energy consumption and heat and power production accounting for more than 70% of energy sector greenhouse gas emissions [4, 2024].

Compared to Kyrgyzstan, Tajikistan's economy has the lowest CO<sub>2</sub> emissions in the Central Asian region, with a CO<sub>2</sub> emissions intensity of GDP about 4% higher than the world average. Tajikistan's energy sector contributes approximately 75% or 7.4 MT CO<sub>2</sub> of total greenhouse gas emissions, while transport and thermal power generation account for more than 60% of total energy sector greenhouse gas emissions [5, 2024].

Thus, hydropower is the only significant renewable energy source in the region, providing from 76% to 88% of electricity in Tajikistan and Kyrgyzstan, the production of which largely depends on the dynamics of water flows in rivers, one of which is glacial water. At the same time, the hydropower sector, compared to the agricultural, industrial and transport sectors, produces much fewer emissions, which should also be considered as indirect factors in the melting of mountain glaciers.

##### 6. Using the glacier dynamics model

The studying of dynamics of mountain glacier's functioning is a process consisting of a number of

interrelated parameters; therefore, it is possible to represent such correlations as a Glacier Dynamic Model (GDM). It is known that the model of mountain glacier dynamics is a simplification that allows us to identify and test the sensitivity of the glacier to a number of variables, such as seasonality in average annual temperature, precipitation intensity or bed topography, albedo readings, etc. By the way, data on real glaciers are required to parameterize the model, which can use values for similar glaciers in other countries, e.g. the albedo, as well as to determine other variables for the glacier under study.

For example, long-term studies of the dynamics of broadband albedo for snow and ice, as well as the dynamics of retreat of glaciers. Lysy, Davydov and Sary-Tor glaciers were investigated in Kyrgyzstan from 1994 to 2018. The length of retreat of above-mentioned glaciers was, at average, 700-800 meters, which contributed to the loss of glacier area: on Lysy at 1.7 km<sup>2</sup> (39.6%), on Sary-Tor and Davydov at 3.6 km<sup>2</sup> or 30.3% [15, 2018]. Subsequently, starting since 2005, the melting rate of these glaciers was slowed down significantly compared to the previous years. It was noted that in accumulation zone at altitude of 4,200 m and up to altitude of 4,799 m, there is constant snowing; therefore, the albedo values were higher, and the highest albedo values had recorded in 2018.

Unlike the territory of Kyrgyzstan, Tajikistan has more than 14,000 glaciers, 19 of which are large. It makes Tajikistan the leader in quantitative parameter of mountain glaciers in Central Asia. Although the glaciated area makes only 6-8% of the country's territory, they contain about 460 km<sup>3</sup> of fresh water [1, 2025].

The process of accelerating glacier melting is currently generally associated with global warming, as a result of increased emissions of pollutants into the atmosphere. However, taking into account the fact that Tajikistan's share of total greenhouse gas emissions is only 0.04%, it seems that other sources of melting of Tajikistan's mountain glaciers should also be analyzed

especially. If we take, as an example, the state of Tajikistan's largest glacier as the Vanjakh glacier, known as the Fedchenko glacier, then during the observation period of the glacier's dynamics from 1933 to 2021, the following changes were revealed: the glacier retreated by more than 1.5 km during this period, and the area of glaciation decreased by almost 5 km<sup>2</sup>.

The observed cyclicity in dynamics of this glacier allows us to suggest that the reduction in the area of the glacier may be closely related to climate change, in which the warming process is not always a priority, but may record a period after which a period of cooling may be expected. Large glaciers, like large lakes, can serve in this case as indicators of changes in the dynamics of solar radiation, the study of which should be carried out in conjunction with the dynamics of large glaciers, such as the Vanjakh glacier.

As we can see from the example of the above-mentioned glaciers, the greenhouse gas emissions may not always be the direct causes of the reduction of mountain glaciers. Each mountain glacier is unique and studying of its dynamics requires a multifactorial analysis of all its components in form of a GDM.

Ultimately, collecting the relevant data for this model may require the creation of large volumes of Meta data, due to the difficulties of conducting research and gathering the actual data due to updated methodology, but this research problem need to be disclosure in another article.

#### *7. International and regional cooperation on Water Resource Management*

The preserving of mountain glaciers, a special attention should certainly be given to cooperation and complex rational using of water resources in national and interregional scale. Hence, co-management should be understood as a shared interest and shared responsibility for the water resources using. Since most of the river flow, including the glacial waters is distributed outside Kyrgyzstan and the downstream countries, in particular, Tajikistan, should also be responsible for the correct using of water.

This means reducing water losses, gradually replacing agricultural crops that consume large amounts of water, using technologies for the economized water using (e.g. in irrigation, etc.)

Decision-making in this context requires not only the development of transnational water resource management policies, but also the adoption of ethical and legal norms for the conservation of mountain glaciers. The target of such strategies is to provide policymakers with effective guidance in crafting effective and equitable mitigation strategies for the melting of mountain glaciers in the conditions of global climate changes. Climate change, population growth, infrastructure problems, uneven distribution of water resources among the Central Asian countries and other problems create many constraints on the equitable using of water resources. In the current circumstances, it is necessary to adopt new water resource management strategies, when the Water, as a valuable natural resource, can and should be considered a commercial product. For these purposes, we can recommend an article devoted to the problems and possibilities of forming a water resources market in Central Asia, which may be interesting and useful in continuing the discussion in this direction [1, 2025].

In addition to using economic approaches, all Central Asian countries should take care to reduce dust storms, which, as is known, ultimately head towards mountainous areas and settle on the surface of mountain glaciers, leading to increased melting and subsequent reduction in the area of mountain glaciers.

#### *8. Ethical and legal norms for the preservation of mountain glaciers.*

There is no secret that glaciers, including mountain glaciers, are melting. The only question is what to do to slow down or, if possible, reduce the development of this process. Since our discussion is taking place in a scientific and educational environment, it would be right to express ideas on preserving glaciers from a scientific point of view. The most important measures to protect and conserve mountain

glaciers include: mobilizing the efforts of all human society at the global level to prevent further melting of glaciers, preserve their ecosystem functions and ensure sustainable use of water resources, improving scientific understanding and promoting cooperation, as well as raising awareness and advocacy for action in this direction, and, finally, strengthening political and ethical frameworks and financial support.

Since almost half of the ideas for preserving glaciers involve the participation of all citizens and the population of countries, then, naturally, special attention should also be paid to the development of ethical norms for understanding and preserving glaciers. For example, local community efforts can be directed towards the use of geotextiles, since they, by reflecting sunlight and reducing the surface temperature of the glacier, due to their high reflectivity, can contribute to increasing the albedo and generally reducing the melting of the glacier.

People's activities at the national, regional and international levels should be aimed at "creating" barriers to dust storms by greening open spaces and, of course, adopting strategies for the rational use of water resources, reducing water losses to a minimum. Perhaps the time has come to develop international standards for all Central Asian countries to regulate water use. Such an interstate program should include measures to develop the necessary volumes of water use (with the transformation of the structure of agriculture taking into account forecasts of water availability), identifying water losses and a system of fines for such losses. Decisions on legislative and economic measures must be included and accepted by all countries in our region. At the end, I would like to note that we cannot wait for outside help, we must make decisions ourselves.

### **Conclusion:**

One of the causes of climate change is generally believed to be the increase in greenhouse gases in the atmosphere, which alter temperatures and precipitation patterns. Human-induced emissions that affect climate include heat-trapping gases

such as carbon dioxide (CO<sup>2</sup>), methane, and nitrous oxide, as well as particles such as black carbon, which have a warming effect, and sulfates, which have a general cooling effect.

However, if we could understand the causes of climate change, thanks to which we have "achieved" such a serious impact on the global biosphere, we could try to solve the problems we face. And first of all, to determine the threshold or critical levels, the overcoming of which creates an irreversible character. In addition to anthropogenic global climate change, local patterns of climate change can also be influenced by other anthropogenic factors (such as crop irrigation) and natural variability in natural ecosystems.

Climate change can threaten the use of natural resources, the goods and services they produce, and the jobs and livelihoods of those who depend on them. For example, climate change is likely to affect farming, tourism, and recreation. Rural communities that have developed around the production of various crops, such as wheat or cotton, depend on the climate to support their way of life. Combined with some decline in rural populations, climate change could fundamentally alter many of these communities. Rising temperatures change weather patterns over time and disrupt the normal natural balance. Therefore, it is no coincidence that the manifestation of water imbalance is rightfully one of the most important risks in Central Asia, influencing the activities of agriculture, the energy sector and the destruction of biodiversity. It also poses many risks to humans and all other life forms in our region. Of course, we would like the results of our research and our discussions to give more hope, but the question is not whether these results are positive, but whether our research and discussions can help us at least accurately describe the problem we are facing.

The main information review on climate change in our countries is series of national communications on climate change, in which the majority of content of these reviews is devoted to issues of manifestation the impact of climate change on

economic activity. At the same time, practically it is covered issues directly related to the analysis and assessment of climate change itself from anthropogenic impact. The publications mentioned contain virtually no information on climate and weather indicators that can and should be used to analyze modern climate change. Another significant drawback of the available review materials is the lack of technical reviews of databases in general on the climate condition and individual critical objects, which could also be used as larger-scale and spatial indicators of certain areas on climate change (e.g. lakes and mountain glaciers). In this case, science and applying the scientific approaches can help in clear understanding the observed climate changes and formulate conclusions to assess the consequences of such change on mountain glaciers.

#### Bibliography:

1. Bobushev, T.S. Water Resources Market: formation the opportunities and searching for solutions (in case of the Central Asia). *Emerging Markets: Central Asian Studies Journal*, 2025.
2. Central Asian Bureau for Analytical Reporting. *Cabar. Asia*. 30.01.2025.
3. Croll, J. *elDiario.es*. On the Physical Cause of the Change of Climate During Geological Epochs. 1864. The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science. 5 April 2025.
4. Energy Policy Brief: Kyrgyzstan, UNECE, 2024.
5. Energy Policy Brief: Tajikistan, UNECE, 2024.
6. Fischer, A., Helfricht, K., Stocker-Waldhuber, M. Local reduction of decadal glacier thickness loss through mass balance management in ski resorts. *Cryosphere* 10 (6), 2941–2952, 2016.  
Retrieved from: <https://doi.org/10.5194/tc-10-2941-2016>.

7. Glaciers of Tajikistan. Archive copy, 2017.  
Retrieved from: <https://tajikistan.orexca.com/rus/glacier.shtm>
8. Larocca, L.J., et al. Arctic glacier snowline altitudes rise 150 m over the last 4 decades. *Cryosphere* 18 (8), 3591–3611, 2024.  
Retrieved from: <https://doi.org/10.5194/tc-18-3591-2024>.
9. Lockley, A., et al. Glacier geoengineering to address sea-level rise: a geotechnical approach. *Adv. Clim. Change Res.* 11 (4), 401–414, 2020.  
Retrieved from: <https://doi.org/10.1016/j.accre.2020.11.008>.
10. McDuffie, E.E., Martin, R.W., Spadaro, J.W., Burnett, R., Smith, S.J., O'Rourke, P., Hammer, M.S., van Donkelaar, A., Bindl, L., Shah, V. and Jaegle, L. Source and fuel sector contributions to ambient PM2.5 emissions and associated mortality at different spatial scales. *Nature Communications*, Vol. 12(1), p.3594, 2021.
11. Milankovitch, M. *Astronomische Mittel zur Erforschung der erdgeschichtlichen Klimate (Astronomical 330 Means for Investigating the Earth's Historical Climates)*. *Handbuch der Geophysik*, Vol. 9, Sec. 8, Berlin, 1938.
12. Minunno, R., Andersson, N., Morrison, G.M. A systematic literature review considering the implementation of planetary geoengineering techniques for the mitigation of sea-level rise. *Earth Sci. Rev.* 241, 104431, 2023.  
Retrieved from: <https://doi.org/10.1016/j.earscirev.2023.104431>.
13. Moore, J.C., Gladstone, R.V., Zwinger, T., Wolovick, M.J. Geoengineer polar glaciers to slow sea-level rise. *Nature* 555, 303–305, 2018.  
Retrieved from: <https://doi.org/10.1038/d41586-018-03036-4>.

14. Olefs, M., Lehning, M. Textile protection of snow and ice: measured and simulated effects on the energy and mass balance. *Cold Reg. Sci. Technol.* 62 (2–3), 126–141, 2010. Retrieved from: <https://doi.org/10.1016/j.coldregions.2010.03.011>
15. Rakhmatilla u Z., Usubaliev, R. A., Mitusov, A. V. Broadband albedo and glacier size changes in the Ak-Shyrak massif from 1994 to 2018, Tien Shan, Kyrgyzstan, 2018. Retrieved from: <https://doi.org/10.29258/CAJWR/2019-R1.v5-1/1-12.rus>
16. Ren, S., Jia, L., Menenti, M., Zhang, J. Changes in glacier albedo and the driving factors in the Western Nyainqentanglha Mountains from 2001 to 2020. *J. Glaciol.* 69 (277), 1500–1514, 2023. Retrieved from: <https://doi.org/10.1017/jog.2023.45>
17. Salavich, R., D., Bennett, B.F., Hope, O.P., Tribett, W.R. and Canty, T.P. *Earth's climate system.* Springer Climate, 2017.
18. Senese, A., Azzoni, R.S., Maragno, D., D'Agata, C., Fugazza, D., Mosconi, B., Trenti, A., Meraldi, E., Smiraglia, C., Diolaiuti, G. The non-woven geotextiles as strategies for mitigating the impacts of climate change on glaciers. *Cold Reg. Sci. Technol.* 173, 2020. Retrieved from: <https://doi.org/10.1016/j.coldregions.2020.103007>
19. Shukurov, I. and Alireza, M. Dustiness and Aerodynamics of Air in Central Asian Cities. *IOP Conference Series: Materials Science and Engineering.* 753 042013, 2020.
20. Wang, F., Xie, Y., Wang, L., Liu, S., Jin, X. Mitigating ice sheets and mountain glaciers melt with geoengineering. *Science of the Total Environment*, Volume 963, 178450, 2025. Retrieved from: <https://doi.org/10.1016/j.scitotenv.2025.178450>
21. Copernicus Climate Change Service. *Climate indicators*, 2023.
22. European State of the Climate (ESOTC), *Glaciers*, 2023.
23. A dataset of glacier inventory in four Central Asian Countries during 2022–2023, *Science Data Bank*, 18/09/2024.