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Glacier Change and Analysis in the Middle Section of Qilian Mountains from 2014 to 2024

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Abstract

This research uses remote sensing technology and GIS methods to conduct a detailed analysis of the glacier area changes in the middle section of the Qilian Mountains from 2014 to 2024. The study area, located in the middle section of the Qilian Mountains, is a crucial water conservation area and ecological security barrier in the northwest region. By preprocessing multiple remote sensing images, extracting glacier boundaries, and calculating the area, the study reveals the dynamic changes in the glacier area during this period. The results show that the glacier area in the middle section of the Qilian Mountains has shown a significant retreat trend during this period. Although the speed and extent of the glacier retreat vary across different years and regions, the overall trend is clear. This change not only affects the regional water resource balance but may also have profound impacts on the local ecological environment and climate system. Combining observational data, this study not only provides a scientific basis for the protection and rational use of glacier resources in the middle section of the Qilian Mountains but also offers valuable insights into glacier research under the backdrop of global climate change.

Keywords

middle sections of Qilian Mountains, glacier reduction, remote sensing image, ecological impact

1. Introduction

Glaciers are important parts of the cryosphere; they store more than 70% of the world's fresh water and play important roles in the global water cycle. In the ocean, glaciers are key for maintaining sea level; on land, glaciers regulate river runoff to varying degrees (Radić & Hock, 2014). Owing to the acceleration of global warming, the rate of global glacier melting has accelerated in recent years. The average annual melting mass has exceeded 1 trillion tons since 2010, and the long-term forecast is not optimistic. Scholars estimate that by the end of this century, the total number of glaciers will decrease by 18%-36% (Hock & Huss, 2021).

Glaciers in China are divided into two types according to their physical properties. One is continental glaciers, whose representative distribution areas are the Qiangtang Plateau and Qilian Mountains; the other is marine glaciers, whose representative distribution areas are the Himalayas and the Nyainqentanglha Mountains., etc (Yang & Li, 2007). The Qilian Mountains, located in the northeastern Qinghai–Tibet Plateau, China, are important water conservation areas in the Hexi Corridor. Taking the Shule River Basin in the western section as an example, glacial meltwater accounted for more than 40% of the multiyear average value of annual runoff in this basin (Ren & Chang, 2022). Therefore, it is highly important for water resource supply, climate regulation and ecological environmental balance in surrounding areas.

The most recent study on the remote sensing monitoring of glaciers in the middle section of the Qilian Mountains focuses on the relationship between the snow line in the middle section of the Qilian Mountains and climate change, as discussed by Zhao et al. (2015), which is based on 2000–2012 remote sensing image products and relevant meteorological data. Owing to the intensification of the global warming effect, the Qilian Mountains glaciers are also facing the risk of shrinking and disappearing. The study of glacier changes in the central section of the Qilian Mountains over the past decade is helpful for understanding the latest dynamic change characteristics of glaciers in this region and for predicting future glacier change trends. The development of reasonable risk prevention measures provides a scientific basis that is more suitable for the current situation.

A comprehensive literature review reveals that current research on the status of the middle section of the Qilian Mountains in the past decade is relatively scarce. This study aims to investigate the changes in glaciers in the central section of the Qilian Mountains during 2014–2024 through remote sensing monitoring and image analysis, especially the use of the latest released image product of Landsat 8-9 OLI/TIRS C2 L2 in 2024, and we attempt to elucidate the main reasons and the potential ecological impacts of the changes to facilitate further scientific research and policy formulation in the future.

2. Overview of the Study Area

2.1 Geographic Location of the Middle Section of the Qilian Mountains

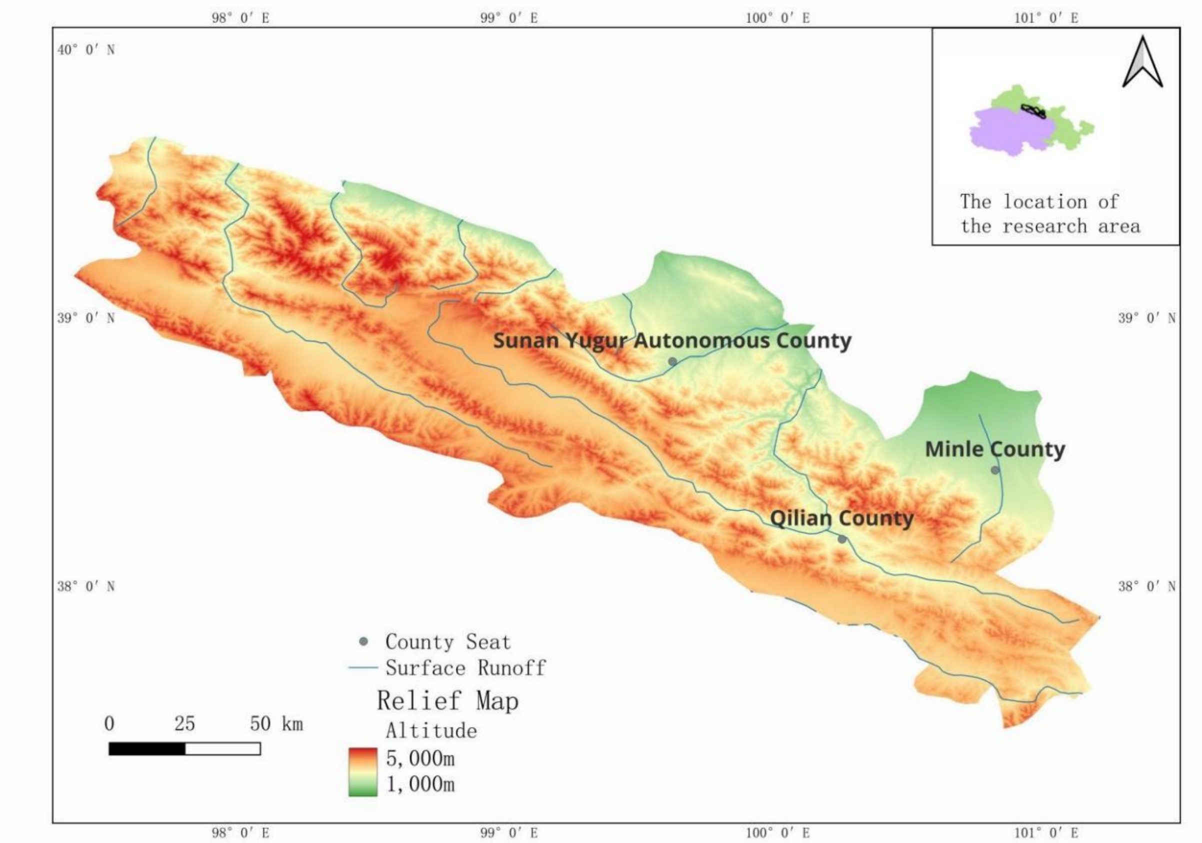
The Qilian Mountains are located in the northeastern part of the Qinghai-Tibet Plateau in China. They form a narrow, elongated mountain range extending in a northwest-southeast direction, with valleys and gorges interspersed throughout. The range spans approximately 1,000 kilometers in length, with an average width of 200–300 kilometers, covering a total area of 176,700 square kilometers. It straddles the provinces of Gansu and Qinghai. Its western segment connects with the Altun Mountains (Dangjin Pass), while its eastern segment links to the Qinling Mountains and Liupan Mountains via the Wushaoling Pass. It is roughly located between 94°52′ and 103°09′ east longitude, and 36°26′ and 40°01′ north latitude (Zhao et al., 2025). The highest peak is the Unity Peak of the Shule South Mountains, reaching an elevation of 5,808 meters.

On the basis of the interannual variation characteristics of precipitation and the spatial heterogeneity of the number and types of glaciers in the Qilian Mountains, from east to west, the Qilian Mountains can be divided into eastern, middle and western sections. The middle section of the Qilian Mountains is close to the center. Its representative peaks include those of the Corridor South Mountain, Tuole Mountain, Tuole South Mountain and Datong Mountain. The two inland rivers, the Heihe River and the Beida River, are the three main peaks of the Qilian Mountains. City and Qilian County in Qinghai Province are important water sources for agricultural irrigation and industrial production. In the study area, only upstream glaciers were considered on the basis of the paradigms of previous scholars (Chen et al., 2013; Xia, 2013), which administratively includes Sunan Yugu Autonomous County and Minle County of Zhangye city, Gansu Province and Qilian County of Haibei Tibetan Autonomous Prefecture, Qinghai Province, located between 35°13′ and 41°8′ east longitude and 94°36′ and 103°45′ north latitude, with a total area of approximately 31,500 km ? After the EPSG:32647-WGS84 projected coordinate system is used, the spatial extent of the study area can be obtained by overlaying the abovementioned elements such as surface runoff, the county seat, the digital elevation DEM and the mask extent. As shown in Figure 1.

2.2 Current Status of the Middle Section of the Qilian Mountains

The easternmost end of the Qilian Mountains is Wushaoling, which is the boundary between monsoon and nonmonsoon regions and between the arid and semiarid regions of Northwest China. The Qilian Mountains are located northwest of this line and are in an arid area; therefore, it has a typical temperate continental climate in low-elevation areas and a plateau mountainous climate in high-elevation areas. In terms of specific characteristics, owing to the large vertical drop in the mountainous area (the lowest point of the study area is 1598 m, the highest point is 5335 m, and the average altitude is 3510 m) and the long and narrow east–west corridors, the vertical zonal differentiation pattern and zonal differentiation pattern of dry humidity coexist. There are representative meteorological stations in the middle section of the Qilian Mountains, such as Minle, Sunan, Yeniugou, Qilian, Gangcha, Chaka, and Tianjun. Researchers have concluded that the annual range of temperature in this region tends to decrease with increasing altitude. The peak precipitation occurred at an altitude of 2900 m, the precipitation in the southeast was significantly greater than that in the northwest, and the contribution to precipitation in summer generally exceeded 60% (Yang et al., 2024).

Figure 1: Geographical location of the study area



As of 2012, the glaciers in the central section of the Qilian Mountains have been in a state of retreat for a long time since the observation records began in 1960, and the retreat speed of the low-elevation ice margin is faster than that in the high-elevation areas (Xia, 2013). The shrinkage of the glacier is manifested mainly as an increase in the elevation of the glacier end, a reduction in the glacier area and the number of glaciers, in addition to a loss of mass and a decrease in the thickness of the material balance.

The area of glaciers changes with the alternation of the four seasons in a year, and the development of glaciers at different latitudes and different orientations also differs. In particular, glaciers in the three directions of true north, northwest and northeast account for nearly 80% of the total number of glaciers in the middle section of the Qilian Mountains (Chen et al., 2013). When different researchers measured the long-term ascent rate of the glacier terminal, the results obtained were 4 ± 0.5 m/a. The estimation model based on the stable rate also revealed that more than one-third of the Qilian Mountains glaciers may disappear in the next 30 years. If this trend continues, the Qilian Mountains glaciers may disappear completely by the end of this century (Li et al., 2017).

3. Data And Methods

3.1 Data Source

The data analyzed in this paper were selected from the 2014 and 2024 Landsat satellite series remote sensing images and were analyzed through a series of steps. The basic requirement for images was that the cloud cover was <20%, and the images were shot between May and September to reduce measurement errors caused by the partial absence of images and seasonal snow cover. All the remote sensing images from 2014 were selected from the geospatial data cloud website (http://www.gscloud.cn/search). For the downloaded Landsat 7 TM C2 L2 satellite products, 2024 remote sensing images were selected from the Landsat 8-9 OLI/TIRS C2 L2 satellite products. The time interval between the two selections of original images was 10 years, which fully reflected the glacier conditions and their change rates in 2014 and 2024. The main differences between these two satellite image products are reflected in the number of bands and measurement year, their consistency in terms of observation accuracy, and the data collected using the same method; therefore, these two satellite image products can be used as a comparison object for the same area during different periods.

Since the scanning range of a single downloaded remote sensing image is 185 km*185 km and the scope of the study area is relatively large (which is calculated on the basis of the length and width of the smallest rectangle formed by the boundary of the study area; its length and width are approximately 341.37 km*287.82 km), a single remote sensing image is not sufficient to cover the entire space, and the processed images in each period are obtained by mosaizing four satellite images.

The accuracies of the two remote sensing image products used in this paper, Landsat 7 TM C2 L2 and Landsat 8-9 OLI/TIRS C2 L2, were 30*30 m; that is, the area of a single pixel was 900 m^2. On the basis of the above figure, the actual areas of various features in the Qilian Mountains, including glaciers, can be calculated with the following formula:

$$S=n*900/1000000\ (km^2)$$

where S is the area of the surface object and n is the number of pixels.

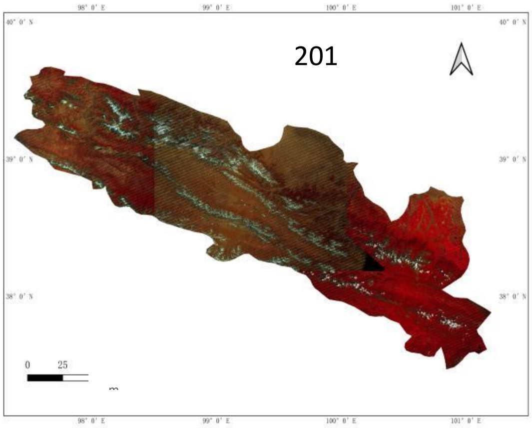
3.2 Research Methods

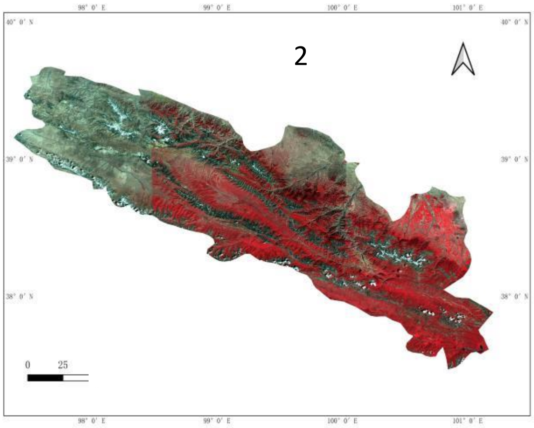
In this paper, the K-means method in the unsupervised classification of remote sensing images is used to classify remote sensing images. This is a convenient algorithm for cluster analysis that can quickly calculate the distance between each object and the classification center (expressed as the chromatic aberration in remote sensing images) to complete the classification. Afterward, we used image combination classes to delete the color bands without data and manually adjusted and merged the images to achieve the results needed in the study.

For image processing, ENVI software was used. We imported four satellite images downloaded in advance. At this time, the original data could not be directly classified. Since the downloaded file is saved according to the single band, the band merging operation is first needed. The sign of success in this step is the ability to synthesize a standard false-color image.

To avoid the inclusion of land that is not in the middle section of the Qilian Mountains in the classification results, the standard false color image obtained in the previous step needs to be cropped. The cropping operation in this study was performed in ENVI. When cropping, the boundary of the central Qilian Mountains was first imported into the ROI, and then the subset data from the ROI function was used to complete the cropping process using the mask. The results in Figure 2 were obtained.

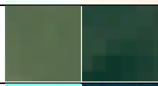
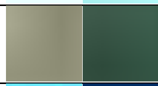
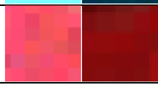
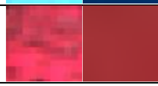
Figure 2: Remote-sensing preprocessed image of the middle section of the Qilian Mountains





The features to be extracted were determined in ENVI. In accordance with the research purpose of this paper, the eigenvalues of glaciers, vegetation (cultivated land, woodland and grassland were covered since they were not the main points), bare land and water body were extracted, and the interpretation symbols in Table 1 were established:

Table 1: Various land interpretation signs selected after standard false-color synthesis

Type of land use	2014	2024
Glacier		
Bare land		
Water body		
Vegetation (forest, grass, and tillage)		

After the classification is complete, some postprocessing operations are usually required to improve the accuracy and reliability of the classification results. The postprocessing methods used in this study are mainly major and minimum analysis (majority/minority analysis) and combined classes (combined classes). The former reduces the points with color differences that are too large compared with those of the surrounding pixels and removes small isolated plaques to enable classification. The result is smoother. The latter reclassifies and integrates the existing classification results, which can simplify the classification system and reduce computational redundancy.

The glacier cover could be distinguished from other nonglacial areas by removing the black background using GIS software, and the land use status of the middle section of the Qilian Mountains was obtained. In the analysis form, detailed numerical values and accuracy test reports of the area were obtained, as well as the land change forms (e.g., bare land, grassland, etc.) after glacier retreat. In addition, the results can be imported into GIS software in dat format for further visualization of this change process.

After obtaining the current status of glaciers in the central Qilian Mountains for 2014 and 2024, we used the data to generate long-term (next 100 years) forecast trend curves. One of them is a geometric straight line; that is, after the simulation, the amount of glacier reduction at every ten-year interval was averaged. Under the same situation, one line with a constant slope is used; the other is a constant rate curve; that is, the glacier decrease rate is the same as the 2014–2024 rate every ten years after the simulation, so the more the current time line decreases in the long term, the more the curve gradually becomes gentle as the glacier area base decreases.

4. Results Analysis

4.1 Data Results

After the above-described processing steps of the original remote sensing images, two current maps reflecting the land use of the central section of the Qilian Mountains in 2014 and 2024 were obtained, which are the direct sources for further data processing (Figure 3 and Figure 4).

In the Figures 3 & 4, the number and proportion of cells of each type of land were examined using statistical analysis. After the postclassification images are obtained, the change detection statistic function in the basic toolbar is selected, the image before change and after change are selected, and the corresponding regions of interest are paired to obtain the change detection statistic. Data table. Taking the present study as an example, the data included the pixels, proportions and true areas of each type of land in the middle section of the Qilian Mountains during the two periods. Since the background is unclassified by default in the change detection data, it should be noted that the background areas of the two images must be the same and do not participate in the change calculation. The current land use status of the middle section of the Qilian Mountains in 2014 and 2024 is shown in Figure 5, and the area-converted results are shown in Table 2.

Figure 3: Current land use in the middle section of the Qilian Mountains in 2014

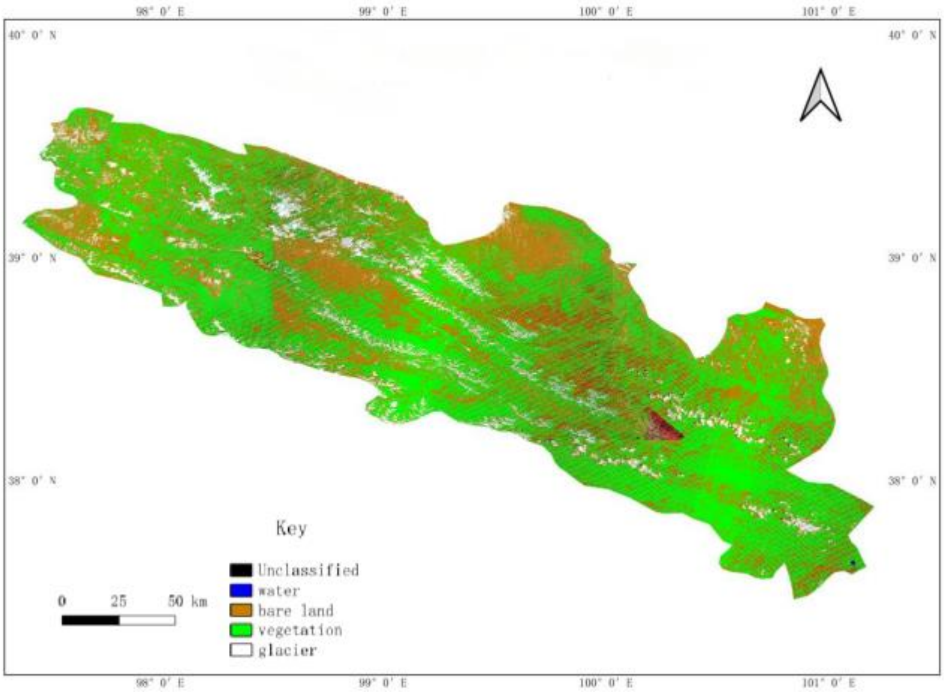


Figure 4: Current land use in the middle section of the Qilian Mountains in 2024

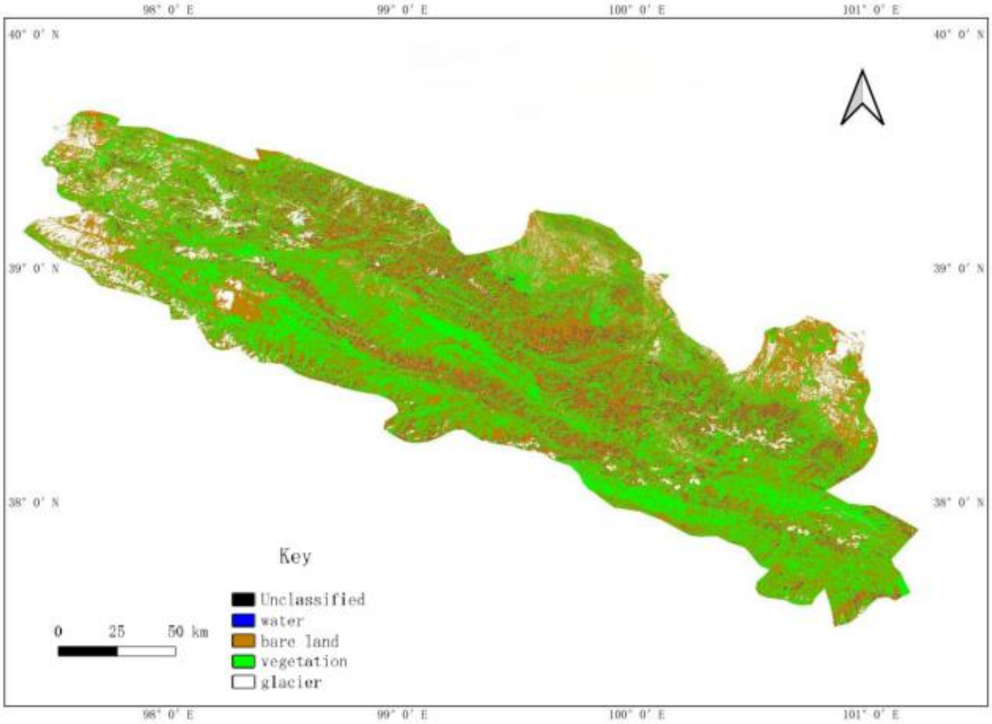


Figure 5: Number of pixels of surface features in the middle section of the Qilian Mountains in 2014 and 2024

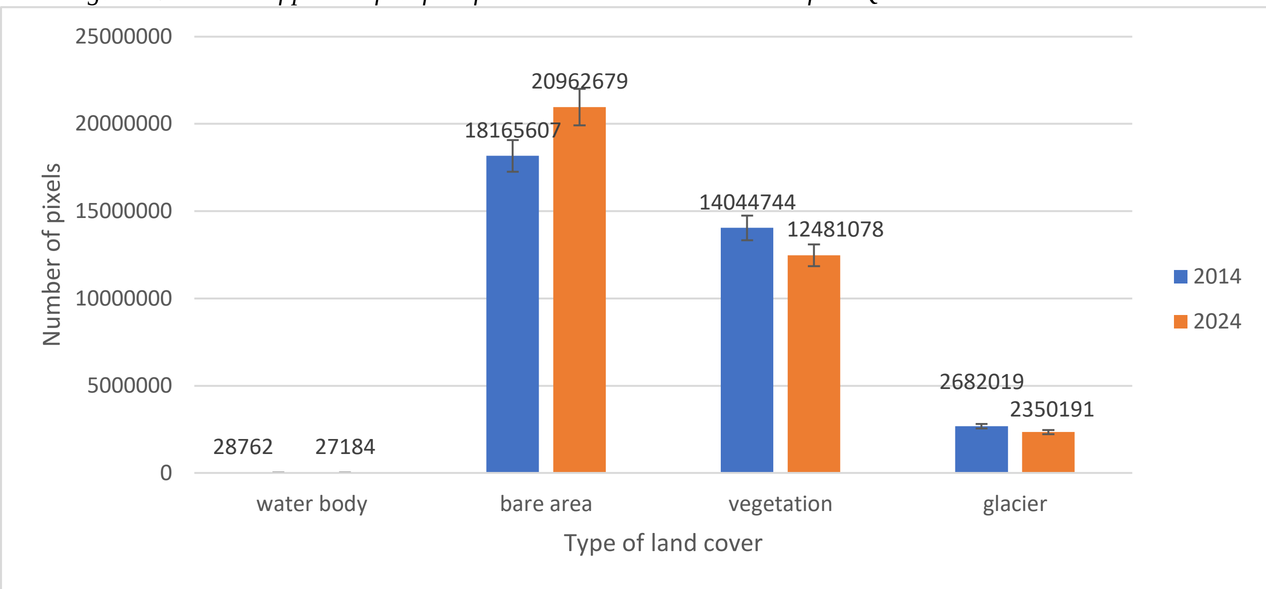


Table 2: Area statistics of each type of feature in the middle section of the Qilian Mountains (unit: square kilometer)

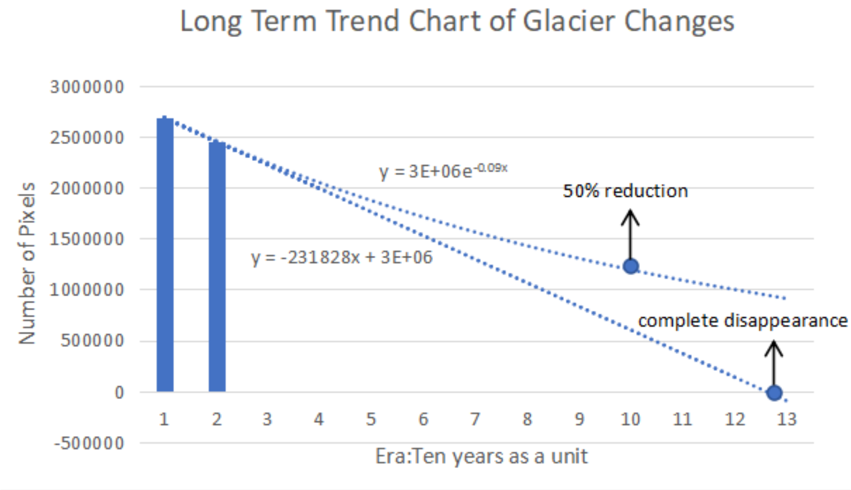
Year	2014	2024
Water area	25.89	24.47
Bare land area	16349.05	18866.41
Vegetation area	12640.27	11232.97
Glacier area	2413.82	2115.17

As shown in the table, between 2014 and 2024, the glacier area in the central section of the Qilian Mountains significantly decreased; during the 10-year period, the glacier area decreased by approximately 298.65 km^2; and the average annual reduction reached 29.87 $km^2 \cdot a^{-1}$. Considering that the total number of glaciers in the Qilian Mountains was small in summer, the absolute value of the change in area was not significant. From the perspective of the change rate, this process is amplified. During the period of 2014–

2024, glacier disappearance in the study area reached 12.37±0.5%, and the disappearance rate was 1.24±0.05%*a $^{-1}$.

Judging from the data in Fig. 6 (where x is the age and y is the number of pixels), the condition of the glaciers in the central Qilian Mountains is not optimistic. If the area decrease that has been maintained for the past decade continues to shrink in the future, the central Qilian Mountains will completely lose its permanent glaciers within 100 years (2020s). If the glaciers continue to shrink at the 2014–2024 rate, that is, if the glaciers are declining exponentially at the same rate, the glaciers will still be reduced to less than 50% of the 2014 level by the end of this century.

Figure 6: Forecast of the long-term trend of the glaciers in the middle section of the Qilian Mountains



4.2 Analysis of Influencing Factors

Changes in glacier area are directly related to climate change. Local temperatures have continued to increase in recent years, with the heating rate reaching 0.34 ℃/10a in the past 60 years, with the temperature increase being more significant in summer, resulting in a long-term negative balance of glacier mass (Yang et al., 2024). In addition, the peak precipitation in the Qilian Mountains occurred at an altitude of 2900 meters, which is limited in its ability to supply alpine areas with concentrated glaciers. In addition, the precipitation is highly concentrated in summer, so the supply in autumn and winter is insufficient. The dual obstacles of season and altitude inhibit the material supply of the glacier (Zhao et al., 2015). A study on agricultural carbon emissions also revealed that from 2000 to 2020, agricultural carbon emissions in the Hexi Corridor slowly increased (Li et al., 2023). The distribution of towns in the Hexi Corridor is relatively dense, and the increase in carbon dioxide content in this area is likely to enhance the greenhouse effect in the upstream Qilian Mountains, resulting in a series of far-reaching ecological impacts. Such a rapid rate of deceleration reminds the relevant local departments that it is urgent to pay attention to this issue. The control of the middle section of the Qilian Mountains depends not only on the three counties where it is located but also on regional collaboration for comprehensive control.

5. Conclusion

In this study, the middle section of the Qilian Mountains was used as the study area, and Landsat remote sensing images (2014 and 2024) were used to classify, interpret, and quantitatively analyze the changes in glacier area over the past decade. The results revealed that the glacier area in the central Qilian Mountains decreased by 298.65 km ^{2} over the past ten years, with an average annual shrinkage rate of 1.24 ±0.05%/a and an overall shrinkage rate of 12.37 ±0.5%. This continuous glacier shrinking trend is closely related to the increase in regional temperature, changes in the spatiotemporal distribution of precipitation, and global warming, revealing the high sensitivity of the Qilian Mountains glacier to environmental change. If the current rate of retreat continues, the glaciers in the central section of the Qilian Mountains will experience significant decline by the end of this century. In extreme cases, they may even approach complete melting, which will have a profound impact on the regional water resource system, ecological patterns, and socio-economic activities.

In this study, ENVI and GIS tools were used to visualize and quantitatively analyze glacier area changes in the central Qilian Mountains, and clear dynamic evolution trends were obtained. However, some limitations still exist: The K-means unsupervised classification algorithm was mainly used rather than the more accurate supervised classification algorithm. Therefore, there is some error when dealing with complex environments. For example, distinguishing shady slopes with dense vegetation from similar colors of some water is difficult. If the algorithm can be further improved, greater identification accuracy will lead to more accurate analysis results. In this study, only the indicator of glacier area was analyzed, and meteorological elements such as temperature and precipitation were not introduced for association analysis. Understanding the driving mechanism of glacier change depends mainly on the research results of previous scholars.

Changes in the glaciers in the central section of the Qilian Mountains have entered the accelerated ablation stage, and in combination with previous long-term observations, this process will irreversibly continue in the future. The issues it raises not only represent changes in the natural geographical landscape, but also relate to the future direction of sustainable development in the Heihe and Beidaihe river basins in the Hexi Corridor. Only with the synergy of scientific monitoring, systematic assessment, and policy intervention can this important and fragile ecosystem be more effectively protected, and the win–win goal of glacier protection and resource utilization can be achieved. We hope that future research can continue to track the latest dynamics and development trends of the Qilian Mountains glaciers and that the retreat rate of glaciers in this area will slow to maintain their ecological functions.

References

Chen, H., Li, Z., Wang, P., & et al. (2013). Recent changes in glaciers in the middle section of the Qilian Mountains. *Arid Zone Research, 30*(4), 588-593.

Hock, R., & Huss, M. (2021). Glaciers and climate change. In T. M. Letcher (Ed.), *Climate change* (3rd ed., pp. 157-176). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-12-821575-3.00009-8

Li, H., Yang, T., Tian, H., & et al. (2017). Research on the retreat of qilian mountain glaciers and future trends from 1987 to 2015. *Anhui Agricultural Sciences, 45*(30), 59-63.

Li, M., Zhou, D., Zhu, X., & et al. (2023). Spatio-temporal characteristics and influencing factors of agricultural carbon emissions in the Hexi Corridor from 2000 to 2020. *Journal of Agricultural Resources and Environment, 40*(4), 940-952.

Radić, V., & Hock, R. (2014). Glaciers in the earth's hydrological cycle: Assessments of glacier mass and runoff changes on global and regional scales. *Surveys in Geophysics, 35*(3), 813-837. https://doi.org/10.1007/s10712-013-9262-y

Ren, D., & Chang, J. (2022). Analysis of hydrological environment and water resource trends in the western section of the Qilian Mountains. *Gansu Water Conservancy and Hydropower Technology, 58*(10), 1-4.

Xia, M. (2013). *Research on glacial changes in the middle section of the heihe river basin in the Qilian Mountains over the past 50 years* [Unpublished master's thesis, Northwest Normal University]. Lanzhou.

Yang, F., Zhang, W., Zhang, F., & et al. (2024). Climate characteristics and changes in the Qilian Mountains from 1961 to 2022. *Arid Zone Research, 41*(10), 1627-1638.

Yang, J., & Li, Y. (2007). *Principles of geomorphology*. Peking University Press.

Zhao, J., Huang, Y., Shi, Y., & et al. (2015). Relationship between the snow line and climate change in the middle section of the Qilian Mountains from 2000 to 2012. *Journal of Mountain Science, 33*(6), 683-689.

Zhao, J., Li, J., & Wang, S. (2025). Spatio-temporal characteristics of soil moisture in the Qilian Mountains and analysis of the main driving factors. *Arid Zone Geography,* (3), 1-14.

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Conflicts of Interest

The authors declare no conflict of interest.

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