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TRACKING CLIMATIC CHANGES USING GLACIAL TRACES AND EVIDENCE AT HEZAR MOUNTAIN, IRAN

Mehrabi A.[1*],
Karimi S.[1],
Pourkhosravani M.[1],
Derakhshani R.[1,2]
[1]Shahid Bahonar University of Kerman, Iran. mehrabi@uk.ac.ir
[2]Department of Earth Sciences, Utrecht University, Utrecht, Netherlands.

Although the current situation of the Iran's land and the dominance of arid and semi-arid conditions cast a doubt on the existence of glacier reign in this land, there is evidence of geomorphological traces of glaciers in different areas of Iran indicating the function of glaciers in these regions. Therefore, regarding these traces and evidences, the past climatic conditions can be reconstructed. Based on what mentioned above, this study mainly aimed to trace the climatic changes through the glacial traces and evidences on the Hezar Mountain. Tracing the climatic changes indicates that the temperature of the study area was 6.58 °C colder than that of the current temperature during the period of glacial reign. In addition, the isopluvial map of the Hezar Mountain during the period of glacial reign indicates that the minimum rainfall at that time was 617 mm at the outlet of the basin and the maximum rainfall was 1340 mm at the highest part of the basin. On the other hand, glacier cirques, glacier valleys, and moraines were identified as the most characteristic geomorphological evidence of glaciers in the study area. Finally, laboratory indicators (granulometry), as a complement to glacier evidence, proved the existence of glacial sediments in the Tenguieh Basin. In addition, the permanent snow line was estimated at the height of 3326 meters in the Tenguieh Basin during the glacial reign and based on Porter's cirque floor height et the height of 3333 m through the Wright method.

KEYWORDS:
Glacial traces, Climatic changes, Quaternary, Kerman's Hezar Mountain

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Introduction

One of the most important features of the Quaternary period is the climatic changes leading to some changes in the morphological systems. The land was impacted by environmental changes and extreme climatic fluctuations during the late Quaternary period [1]. Long-term trends during this period include interglacial and cold conditions during the Pleistocene to glacial and warm Holocene conditions. These long-term trends were disrupted through several climatic events and smaller environmental changes [2]. Environmental climatic changes during the last cold period means the Last Glacial Maximum (LGM) during the last glaciation period from 26.5 to 19,000 years ago [3], which impacted and transformed the old landforms and environments. The maximum glacial expansion cooling during the last glacial period, the cooling at the Younger Dryas period and the Little Ice Age impacted not only the regions located at the high altitudes, but also the regions located at the low altitudes as well as tropical regions. For this reason, glacial evidences are one of the most important impacts through which the past climatic changes and future changes can be predicted [4, 5].

Many studies were conducted on glacial landforms during the period of maximum glacial expansion during the last glacial period at higher geographical latitudes. However, fewer studies were conducted at lower latitudes [6]. Iran is one of those countries where the glacial reign was doubtful because of being located at low geographical latitudes and the desert belt of the Earth [7]; however, existing the geomorphological evidence of glaciers in different regions of Iran indicates the glaciers' function in these regions [8]. Certainly, ice and glaciers in Iran are not comparable to what happened in Europe and the U.S. in terms of width and dimension, which motivated the researchers to pay less attention to this issue or less surveyed the landforms in these regions in their studies due to their mentality of ice performance in Europe or other cold regions of the world. This mental background caused the mystery of ice and glacier traces to be hidden from their view or were reluctant to speak about confidently. For this reason, many studies were not reported on Quaternary glaciers in Iran. In addition, few studies were conducted only in the recent centuries.

Bobek was among the first researchers who studied the climatic changes in Iran through the glacial evidences [9]. Bobek identified glacial centers and the permanent snow line changes during the Pleistocene period through surveying the geomorphic characteristics of different parts of Iran. He introduced the most important glacial centers in western Alborz through studying the Alborz Mountain ranges. Further, Schweitzer [10] estimated the permanent snow line of these heights during the Pleistocene period at the height of 3600 meters while studying the glacial landforms on Sabalan Mountain at northwestern Iran. Dezio [11] and Gronert et al. [12] estimated the permanent snow line in the present time at the height of 3900 meters and in the Pleistocene period at the height of 3400 meters while tracking the glacial traces on Bakhtiari Mountains. In addition, Kuhle [13] concluded that the height of the permanent snow line in the Pleistocene period was 1500 meters lower than that of the present snow line at these heights while tracking the glacial traces on the Jopar Heights in central

Iran. Furthermore, he stated that the temperature was less than 10.5 °C than that of the current temperature at Jopar Heights during the Pleistocene period. Moreover, Ramesht et al. [14] estimated the height of permanent snow line during the Pleistocene period as 2900 meters in this basin during the Pleistocene period while tracking the glacial traces on the Tigrany Mahan Basin at southeastern Iran. In another study, Jafari and Barati [15] reconstructed the climatic conditions of the Pleistocene's glacial period at Alvand Mountain in Hamedan based on the geomorphic evidences and concluded that the region's temperature during the Pleistocene period was 9.26 °C lower than that of the present temperature and the region's precipitation was 317 mm higher than that of the present time. In addition, the assessment of climatic changes through tracking glacier traces was performed through various researchers around the world [16–22]. In this regard, this study aimed to evaluate and analyze climatic changes through the glacial traces and evidences at the Hezar Mountain in Kerman province.

Hezar Peak, with the height of 4501 meters above the sea level, is the highest peak in Kerman Province and central Iran, located at 29° 30′ north latitude and 57° 16′ East longitude (Fig. 1). From the geological viewpoint, this mountain by NW-SE trending situated in the intersection of Lalehzar and Sabzevaran fault system in the southeastern part of Central Iran volcanic belt that is the most prominent magmatic feature in the Kerman porphyry copper belt which is formed during subduction of the Neo-Tethys oceanic plate. This mountain ranges have some big mines such as Sarcheshmeh copper mine, that is considered as the second largest copper deposit worldwide [23–30]. The tectonic situation of this area beside mechanism and geometry of the faults have played an effective role in controlling the copper mineralization in this magmatic region and could be considered as a process that has not been ineffective in the formation of Hezar Mountain [31; 32].

Materials and method

The present study was conducted based on the Wright and Porter's methods for reconstructing the climatic conditions in the past. For this purpose, the glacial cirques were first identified through the topographic maps of 1,500,000 and then their validity was confirmed by field control. In the next step, the correlation between altitude and precipitation parameters, as well as altitude and temperature, was calculated with the adjacent stations and its relation was determined in the Excel Software.

Then, the isopluvial and isotherm maps of the present time of the area were prepared in ARC GIS Software through this relationship and the Digital Elevation Model (DEM) of the study area. Then, the permanent snow line was calculated through the Wright and Porter's method and then the adiabatic temperature reduction was measured to draw the isopluvial and isotherm maps of the study area in cryogenic phase.

In the next step, the isothermal map of the past was drawn through the height of permanent snow line and adiabatic temperature reduction in ARC GIS Software. Then, the point correlation between temperature and precipitation at the present time was calculated through overlapping the isopluvial and isotherm maps of the present time and the final Quaternary precipitation map was drawn through the obtained relationship and temperature data of the past time. In the next step, the samples of sediments from the study area were taken and the QDF, Hazen and Trucks indices were calculated through performing granulometry operations on these sediments.

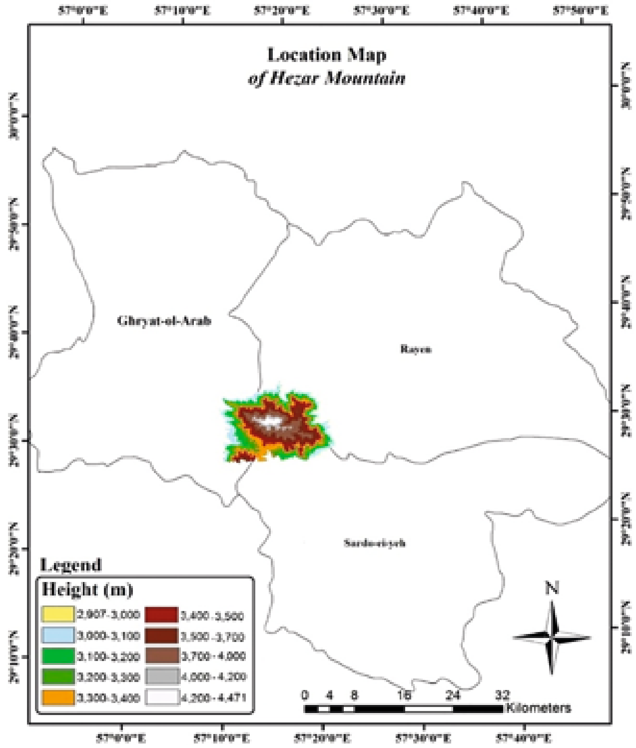

Fig. 1. Location of the study area

Results

Topographic features of the study area

Hezar Mountain is the highest peak of central Iran at an altitude of 4501 meters above the sea level. The highest slope of the Hezar Mountain is 45° (Fig. 2). In addition, the dominant slope direction at Hezar Mountain is towards the south and southeast (Fig. 3).

Climatic features of the study area

Assessing the climatic changes of the study area based on morphic indices

Although the curved lines apparently illustrate only the point altitude digits from the sea level, the truth is something else. Based on the morphological indices, not only the shape of many geomorphic phenomena, but also the substance and even the processes leading to the formation of such shapes can be re-identified in topographic maps through relying on three contour lines, drainage patterns, and peak distribution method factors. The forms of the study area can be identified and analyzed in the form analysis and process of an area through relying on the tools such as the topographic and geological maps, satellite images, and field

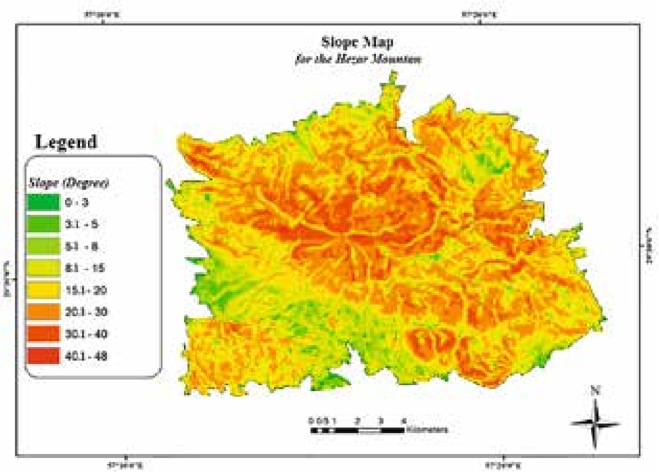

Fig. 2. *Slope map of the study area*

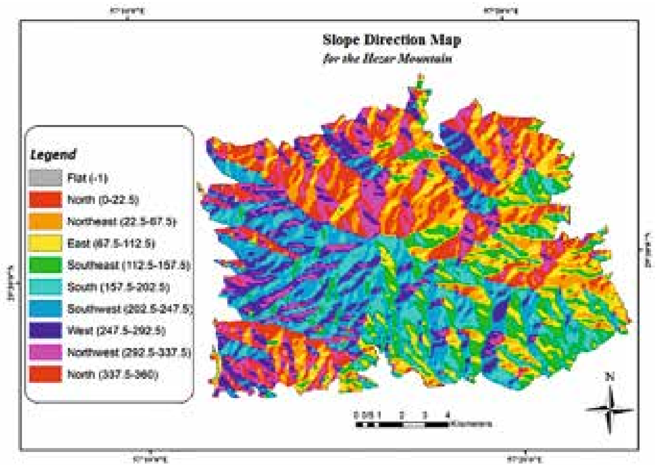

Fig. 3. *Map of slope direction of the study area*

surveys. There is a relationship between form and process which refers to the form each process creates or the process each form depends on. Geomorphologists believe that the processes are water (stagnant and running water, glacial, etc.), wind, gravity, and human.

Each of these creates its own form. Identifying the forms for researchers indicates that it is possible to determine the type of the process creating form as long as the form does not change. If the forms and processes are consistent, i.e. the forms currently belong to a process which is dominant in the region, the analysis of such processes is not difficult although it requires particular skill. When the forms are inconsistent with the current process, it is necessary to reconstruct past processes with respect to the forms. For example, a glacier cirque or a U-shaped valley is the forms which is created in the solid state during the process of water performance. If there is no such process in the current situation in the region, it indicates its impact in the past. Based on this fact, in the areas where the glacial process does not dominate, but similar glacial forms can be observed, form analysis can be undertaken with respect to other processes. The existing typical cirque traces in the northeast and southwestern slopes are directly detectable in field observations as well as through satellite images and topographic maps in the Hezar Mountain Massif.

Initial surveys were conducted to identify index forms in the Hezar Mountain massif through 1: 50000 topographic maps based on the morphological principles. It is worth noting that the glacial cirques identified in the topographic maps are not the cirques themselves which are currently active, but the inherited evidence from earlier periods which are snow-covered for a long period of years in the present condition, which the snow centralization on the cirque walls is quite clear (Fig. 4).

The cirques numbered on the Hezar Mountain are over 81 large and small cirques distributed between 2600 to 4000 meters' height. As shown in Table 1, cirques densities at altitudes of 3600 to 3700 meters are higher than those of other elevated floors, so that about 22% are centralized at this altitude.

Table 1

Distribution method of glacial cirques in the study area

Elevated floors	Number of cirques	Cirques percentage	Cumulative percentage
2600–2700	5	17.6	17.6
2700–2800	3	70.3	87.9
2800–2900	2	47.2	34.1
2900–3000	5	17.6	52.2
3000–3100	8	88.9	39.3
3100–3300	5	17.6	57.3
3300–3400	10	35.1	91.5
3400–3500	8	88.9	79.6
3500–3600	6	41.7	19.6
3600–3800	18	22.2	42.9
3800–4000	11	58.1	100

Estimation of permanent snow line in the past through Wright method

Wright's method is used for determining the permanent snow line. In Wright's method, the cirques' height difference is calculated. It is then determined through multiplying it by 60% of cirques and subtracting the result of the maximum permanent snow line height (33). Based on the cirques counted by Wright's method, 60% of the cirques were identified, indicating that the elevation line which 60% of cirques are above this elevation line. Then, the permanent snow line in the study area was specified at 3326 meters' height through obtaining the height difference among the cirques and using the 60% line (Table 2).

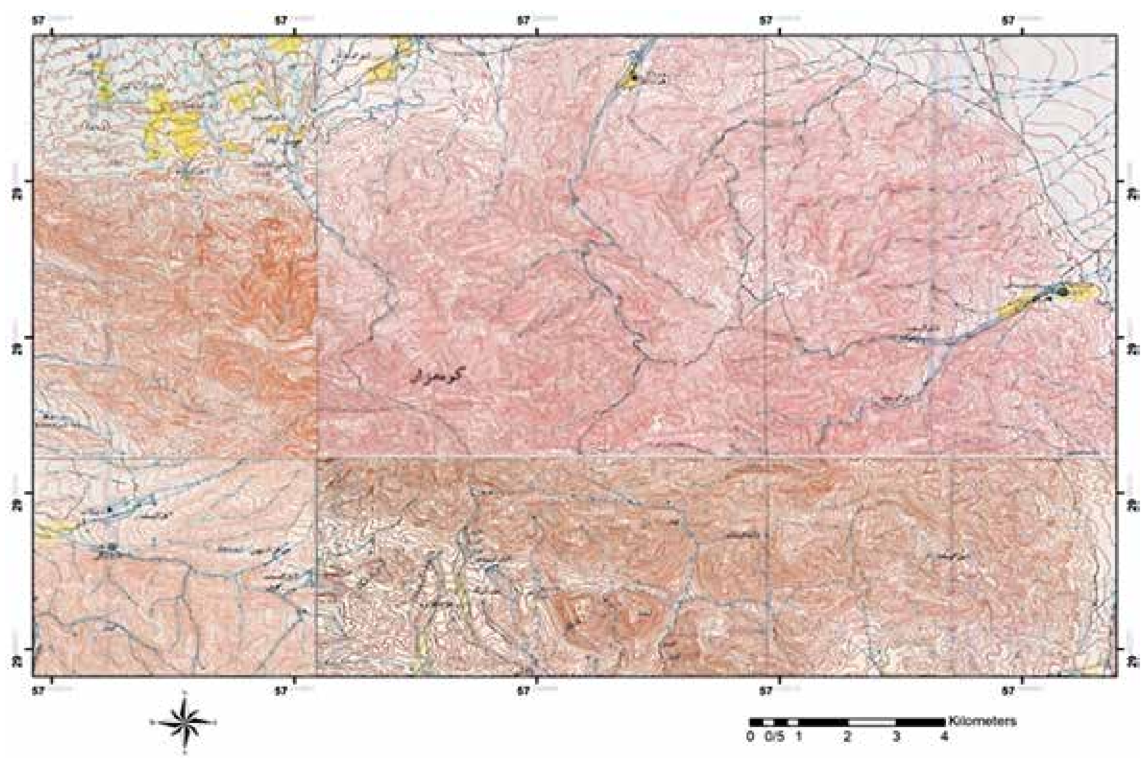

Fig. 4. *Reflection of glacial cirques on topographic map of Hezar Mountain*

Table 2

Estimation of the height of permanent snow line in the present and the past in Kerman's Hezar Mountain

Time	Total	Northeast foot	Southwest foot
Current snow line (m)	4349	4155	4543
Quaternary snow line (m)	3326	3132	3520
The difference between permanent snow line in the past and present (m)	1023	-	-
Ice – water balance line	-	2082	2497

Estimation of permanent snow line in the past by Porter method (cirques floor elevation method)

The cirque floor elevation method is one of the five methods which Porter presented in the study of low latitude glacial mountains to reconstruct the Equilibrium Elevation Altitude (ELA) (34). Among the Porter's five methods, the cirque floor study method is more appropriate for the study area with respect to the clear evidence of glacial cirques because, according to Porter, when a glacier only fills the cirque, then its permanent ELA is not much higher than the average Cirque Floor height (CF) (Fig. 5). Equation (1) is used to calculate the view or mode of using this method for finding the past snow line and ice-water equilibrium line in the study basin after preparing Table 2. Here, the arithmetic means and mode (each) are listed below in order to compare the average height of the glacier cirques and the elevations where the cirques are of the highest frequency. The point view or mode has the highest frequency along the data axis.

$$Mo = L + \frac{d1}{d1 + d2} \times h \, , \qquad (1)$$

L = Lower view category limit, d1= the frequency difference between the category before the view category and the view category frequency, d2= the frequency difference between the category after the view category and the view category frequency, h= Category distances

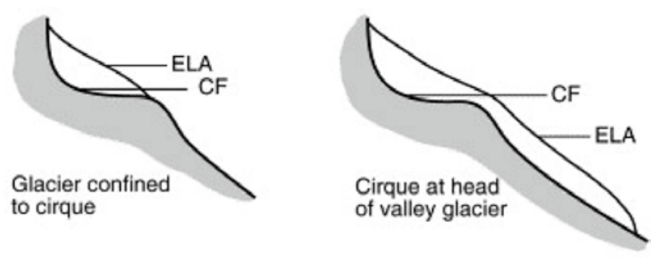

Fig. 5. *Cirques floor elevation method; After Porter [34]*

The height of the permanent snow line of the last glacial period is equal to the amount of view amount at the height of the glacial cirques' floor. As observed, the amount of mode or view in the study area is 3333 meters. In other words, the permanent snow line during the glacial reign was at the Hezar Mountain located at the height of 3333 meters, which is just 8 meters different from the Wright's method.

Table 3

Frequency distribution of glacial cirque floor elevation at Hezar Mountain

Altitude	Cirques frequency	North	Northwest	West	Southwest	South	Southwest	South	Southeast	East	Northeast	North	Percent
2600–2700	5	1	2	-	-	-	-	-	-	2	-	-	6.2
2700–2800	3	-	3	-	-	-	-	-	-	-	-	-	3.7
2800–2900	2	-	-	1	-	-	-	-	-	1	-	-	2.5
2900–3000	5	2	-	2	1	-	-	-	-	-	-	-	6.2
3000–3100	8	5	-	-	-	-	1	-	-	2	-	-	9.9
3100–3300	5	3	-	1	-	1	-	-	-	-	-	1	6.2
3300–3400	10	-	-	-	-	-	-	-	1	3	-	5	12.4
3400–3500	8	-	2	-	-	-	1	-	2	3	-	-	9.9
3500–3600	6	-	1	-	-	-	-	2	-	2	-	1	7.4
3600–3800	18	4	-	2	-	5	-	-	-	2	5	-	22.2
3800–4000	11	-	-	1	1	2	-	-	-	2	5	-	13.6
Total	81	15	8	7	2	8	2	2	3	17	10	7	100
View (meter)	-	3050	2750	2950	-	3700	-	3550	3450	3400	3800	3350	3333

Tracking the icebergs traces based on climatic evidences

The current date is usually considered as a reference point for comparisons. However, the views of decades, or in some cases even the recent centuries, were greatly altered through human activities. Therefore, it is required to compare long time series for observations to determine the recent climatic change. The quantitative values of these parameters are required to investigate the changes of climatic elements including temperature and precipitation. The climatic stations of the region were selected to reconstruct past climatic conditions (Table 4).

Evaluating the rate of changes of climatic elements as temperature requires knowing the current temperature and how it changes with respect to the law of temperature rhythm reduction. To determine the rate of temperature rhythm reduction, a fitting between the altitude and the temperature of the stations was performed (Equation 2). Based on this equation, there is a decrease in the temperature of 0.67 °C per every 100 m of elevation in the study area; then the isotherm map of the present time was drawn through this equation and the Digital Elevation Model (DEM) of the study area (Fig. 6).

$$T = -0.0067H + 29.139 \qquad R^2 = 0.96$$

Reconstructing the temperature conditions of the region during the period of glacial reign

First, the permanent snow line of the past was determined to reconstruct the temperature conditions of the study area during the glacial reign and draw the map of the corresponding isotherms lines. Determining this line can help estimate the past average temperature through the principle of temperature rhythm reduction. For this purpose, if the estimated snow line height is included in the correlation equation of height and temperature, the resulting temperature indicates the current temperature of this altitude, which determines the difference between the rates of the current temperature and the previous

Table 4

Characteristics of the climatic stations in the region

Station name	Longitude	Latitude	Height (m)	Current temperature (°C)
Baft	53 35	29 14	2280	14.37
Bam	58 21	29 06	1067	22.04
Jiroft	57 48	28 35	601	26.76
Rafsanjan	55 54	30 25	1581	17.83
Sirjan	55 41	29 28	1739	16.95
Shahrbabak	55 08	30 06	1834	15.64
Kerman	56 58	30 15	1754	16.25
Lalehzar	56 50	30 06	2775	12.18

zero (Table 2). The estimated average temperature was subtracted from the current temperature of the stations and the past temperature of the stations was calculated. Then, the past isotherm map of the study area was prepared through the height of permanent snow line of the study area as well as its adiabatic decline (Fig. 7).

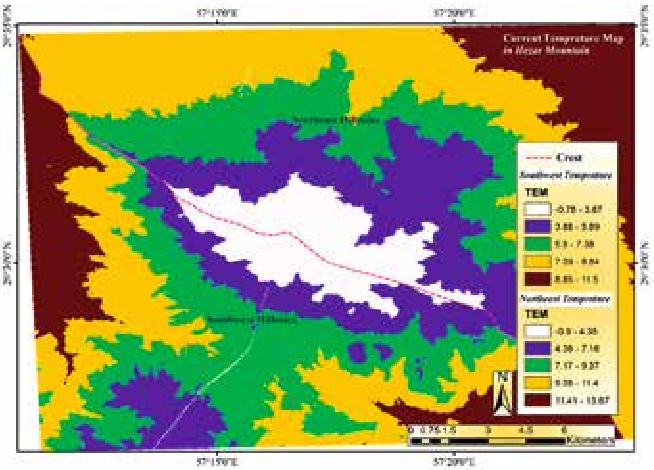

Fig. 6. Isotherm map of the present time in the study area

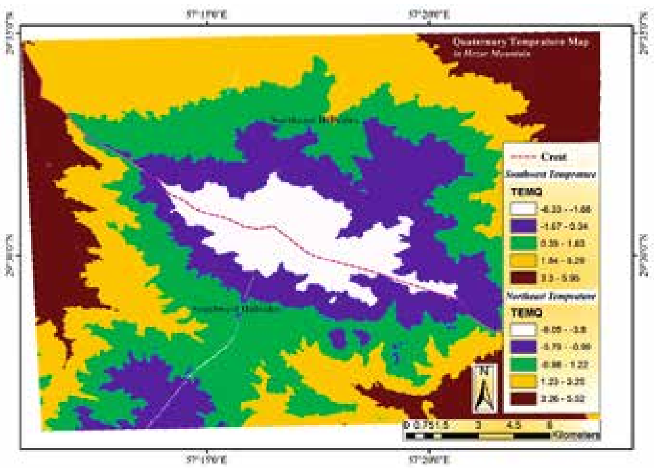

Fig. 7. Isothermal map of the past time in the study area

It is possible to evaluate the humidity conditions during the period of glacial reign in the study area through drawing the isopluvial map of the present time. To achieve this purpose, the precipitation stations were selected and the fitting between precipitation and altitude was performed after sorting the data and deleting outliers (Equation 3). Then, the isotherm map of the present time was prepared through this equation and Digital Elevation Model (DEM) of the study area (8).

$$P = 0.2584H - 321.51 \qquad R^2 = 0.94$$

As illustrated in Figure 8, the highest amount of rainfall at the present time is 836.9 mm in the northeast slopes of the Hezar Mountain. In addition, the lowest rainfall was 275/14 mm for these feet.

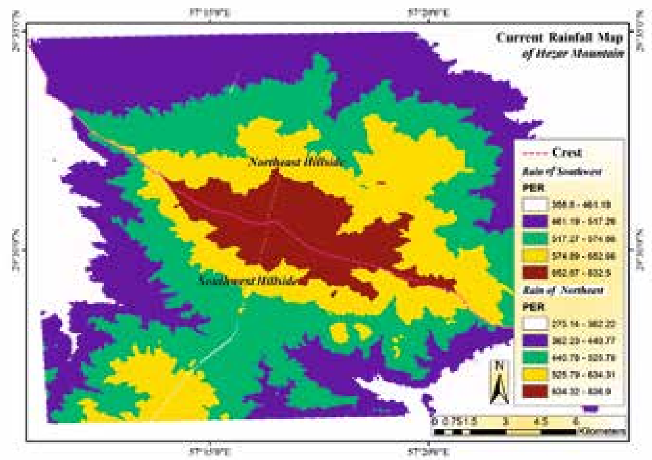

Fig. 8. Isotherm map of the present time in the study area

Reconstructing the precipitation during the glacial reign

The past precipitation amount was estimated to reconstruct the rainfall conditions during the period of glacial reign through the Equation (3) and the past temperature. Then, the fitting between past rainfall and elevation was performed (Equation 4).

$$Pt = -49.572x + 956.82 \qquad R^2 = 0.68$$

The isopluvial map during the glacial reign was drawn in the Arc GIS Software through applying Equation (4) (Fig. 9).

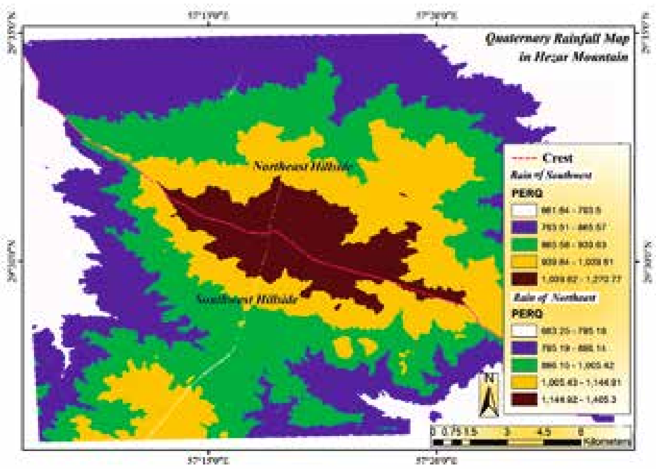

Fig. 9. The isopluvial map of the study area during the glacial reign

As shown in Figure 9, the maximum amount of precipitation in the study area is estimated as 1405.3 mm and the minimum amount as 661.64 mm during the glacial reign. Generally, the studies indicate that the amount of precipitations during the glacial reign was more than that of the present time in the study area.

Identifying the geomorphic traces of glaciers through field operations

Geomorphic evidence is considered as one of the best evidences for climatic change in different eras because any process available in the nature can shape specific geomorphic forms. If any evidence of glacial forms in the region was observed, it means that the glaciers would have been reigned in that region in the past, although there is no trace at the present time. The study area is one of the areas which is not exceptional in this regard. In other words, some geomorphic evidence was found in which current processes are unable to shape. Rather, these forms are just the ones which glaciers produce as follow:

1. Cirque

A glacial cirque is regarded as the first and easiest form which are produced by mountain glaciers. This phenomenon is confined to the high, steep walls as a semicircular pit and is formed as an amphitheater above the glacial valleys. The ice flows are formed after sorting the snow in the cirques which then flows downstream as a river. The surveys indicate that there are numerous cirque traces in these Hezar Mountains, located between the heights of 2600–4000 meters (Fig. 10).

2. Moraines and erratic boulders

When the glacial period ends, the glaciers leave all the sediment they carry with themselves on the ground and create a rough coverage called the moraine (Fig. 11). Lack of grain layering distinguishes the moraine from other sediments, which is considered as a common feature of these sediments. Unlike aquatic deposits, this sediment has no sign of layering, in which the smallest clay grains are intermixed with boulders in an extremely irregular structure.

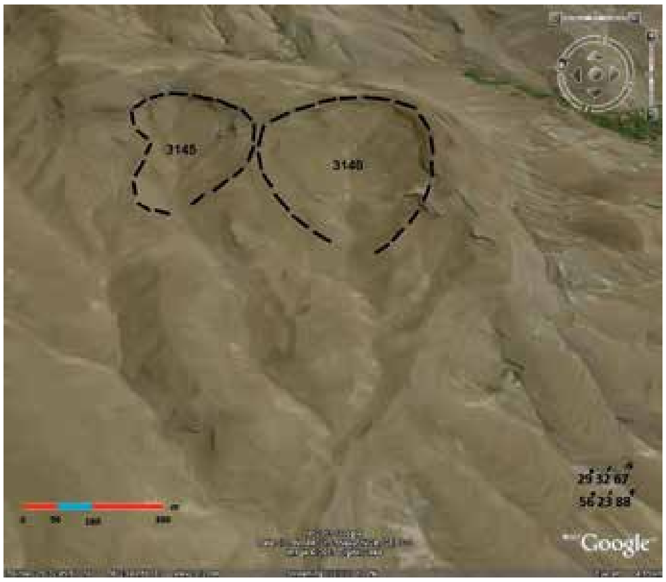

Fig. 10. *An example of a glacial cirque at the Hezar Mountain*

Fig.11. *Moraines and erratic boulders in the study area (near Babzangi village)*

3. Glacial valleys

Glacial valleys are considered as the main forms of mountain glaciers. These valleys have a sloping wall and their cross-section is U-shaped. In fact, as the glaciers deepen their valleys, they extend the valleys, and as a result, they create a wide transverse profile which is typically U-shaped. These valleys are the most distinctive mountain glacial landforms, which several variables such as ice mass thickness and other characteristics, bedrock structure and lithology, topographic characteristics and orientation of valleys and duration of glacier deployment are effective in their formation and development. These glacial forms are seen as an inheritance of Quaternary glaciers in the Hezar Basin, which not only have a U-shaped cross-section but also their floor has a small and large moraine (Fig. 12).

Table 5

The granulometric characteristics of samples taken from the Bobzangi Valley

Particles' diameter	Weight per (g)	Weight per (percent)	Cumulative percentage	Inverse cumulative percentage
≥2000	81.2	41.7	41.7	100
1800	10.5	5.4	47.1	58.3
841	12.7	6.5	53.6	52.9
600	6.9	3.5	57.1	46.4
425	8.1	4.2	61.3	42.9
350	6.5	3.4	64.7	28.7
250	11.4	5.9	70.6	53.3
150	22	11.4	82	29.4
125	5.1	2.6	84.6	18
90	6.1	3.1	87.7	15.4
63	24	12.3	100	12.3

Fig. 12. *Glacier valley of Babzangi in the Hezar Basin*

Sedimentological analysis

1. Granulometry

Resorting to the laboratory methods, especially in the study of sediments is a conventional method in proving the glacial traces (14). The present study was conducted to test the validity of the analytical and formative findings and obtain convincing evidence and confirm the existence of glacial traces on the specimens in the study area. The variations in the particle diameter and density of each of them can be determined through measuring the particle diameter (granulometry), and the type of sediment can be found using particle size and cumulative percentage of sediments. In other words, each type of sediment has its own unique granulometric curve, which the glacial sediments have curves which are more elongated longitudinally.

In this regard, 30 samples of sediments were first collected in the study area and then the grains were separated in different sizes. Then, 300 g of the sampled sediment were selected from the sediments, and then washed with water. This process continued until the output water made clear, and then the samples were placed in an ironing machine and dried at 105 ° C heat. The dried sediments were re-weighted and then 11 sieves with the 63, 90, 125, 150, 250, 350, 425, 600, 841, 1800, 2000 micron were selected. Now, the samples were shed at the largest tom (2000 microns) to determine the amount of material in different diameters and finally sifted through a vibrator machine. Each sieve can hold sediments whose diameter is larger than that of the sieve's pores and send the others to the below sieves. After sorting the seeds , the amount of particles left in each sieve was accurately weighted with an accurate balance and written down along with the sieve number (Table 5) and its diagram was drawn (Fig. 13).

Based on the comparison of Figures 13, the studied sediments are part of the glacial sediments, which is another reason for the performance of late Quaternary glaciers at the Hezar Mountain.

2. QDF Index

This index indicates the degree of sorting the sediment particles. By sorting, it means the range of grain size changes in a sediment. In other words, sorting indicates the uniformity of a sediment in terms of size. The QDF index is one of the indices indicating the amount of sediment sorting. In this index, the value obtained is

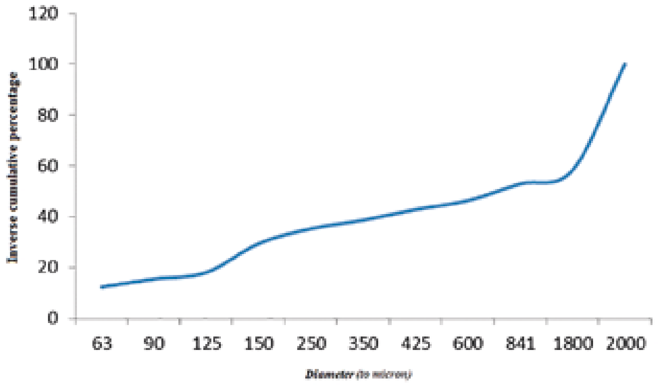

Fig. 13. *Granulometric diagram of the taken sample*

inversely related to particle sorting. Thus, the smaller index leads to better particle sorting.

$$QD=\frac{q_3+q_1}{2} \tag{5}$$

QD = Amount of sorting, q_3 = 75% diameter of sediment, q_1 = 25% diameter of sediment, the sorting rate for the taken sample is equal to:

$$QD=\frac{1800+125}{2}=1012.5 \tag{6}$$

The obtained value indicates that the sorting rate of the sample is very bad, and this type of sorting (very bad sorting) is specific to glacial and avalanche sediments.

3. Hazen Index (effective diameter)

This index, most commonly used by hydrologists, determines the amount of sediment porosity. When $I \leq 2$, then the regular and larger sediment is called irregular sediment, then I is called irregularity coefficient.

$$I=\frac{d_{60}}{d_{10}}=\frac{850}{63}=13/4 \tag{7}$$

The obtained number indicates that the sediment is irregular.

4. Trucks Index

$$So=\frac{q_3 * q_1}{M^2} \tag{8}$$

So = Truck index, q_3 = 75 % diameter of sediment, q_1 = 25% diameter of sediment, M = 50 % diameter of sediment

$$So=\frac{1800*125}{425^2}\quad 1.2 \tag{9}$$

Conclusion

Iran is one of the regions impacted by climatic fluctuations, but its size and scope were not as deep and wide as Europe and North America. Therefore, it seems far-fetched to confirm this claim that the Hezar Mountain Basin as one of the regions in central Iran is in the final Quaternary under the reign of glaciers. However, this doubt is resolved through paying attention to the remained works and evidence. Climatic evidence such as temperature and precipitation information indicate that the temperature of the region was 6.58 °C colder during the period of glacial reign. The current isotherm map of Hezar Mountain indicate that the minimum annual average temperature of the basin is -0.9 to 4.19 °C and the maximum annual average temperature is 10.77–13.69 °C. In addition, the isopluvial map of Hezar Mountain indicate that the minimum annual rainfall is 274 mm and the maximum annual precipitation of the basin is 836 mm. Furthermore, the isopluvial map of the basin at the Quaternary indicates that the minimum rainfall at that time is 617 mm at the outlet of the basin and the maximum amount of rainfall is 1340 mm at the highest part of the basin. Comparison of the isopluvial maps of the Hezar Mountain in the past and present time indicates that the amount of environmental humidity is significantly different from that of the present precipitation during the period when the temperature is 6.58 °C.

On the other hand, the shape of the curves on topographic maps and satellite images of the Hezar Mountain's basin illustrates the traces of 81 glacial cirques and the areas dominated by ice widths in the past time. Among the 81 identified cirques, 52 ones are located towards the north, east, and northeast. In addition, the areas dominated by the widths in the past were surveyed based on the satellite images, the curves' form of the scale and field operations. These areas, characterized by wave-shaped hills resulting from ice sheet movements after leaving the mountains in the Plains of the Hezar Basin, gave special geomorphology to these plains. The most prominent of these plains are wave-shaped plains shaped in the southwest of the basin. In addition, geomorphological evidence such as large fragments of erratic boulders, moraines, glacial valleys, and cirques are considered as one of the most characteristic geomorphological evidence of late Quaternary glaciers in this basin. The glacial valleys of this basin not only have a U-shaped cross-section but also have small and large moraines. Laboratory parameters are considered as another indicator which proved the existence of the traces of glaciers in the Hezar Basin. In this regard, the samples were taken from specific areas of the study basin and transferred to the laboratory. The results of sedimentation performed on several samples indicate that the sediments under study are glacial sediments, which is another reason for the performance of late quaternary glaciers at the Hezar Mountain.

In addition, the permanent snow line in the late Quaternary was at 3326 m (Wright's method) or 3333 m (Porter's method). In fact, sufficient rainfall along with low temperature in the basin created the conditions that glaciers can form the topography as the main process, in which the current process of the basin is unable to form. Totally, based on the traces and evidences, Hezar Mountain basin was influenced by centralized and laminar ice movements during the last phase of the Quaternary.

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СВЕДЕНИЯ ОБ АВТОРАХ / *Information about authors:*

Ali MEHRABI – Doctor of Geology, Assistant Professor, Department of Geography and Urban Planning.
Shahid Bahonar University of Kerman, Iran.
Ph.: +98 9131934256.
e-mail: Mehrabi@uk.ac.ir

Али МЕХРАБИ *– доктор геологических наук, доцент. Кафедра географии и градостроительства.*
Керманский Университет Шахида Бахонара, Керман, Иран.
Тел.: +98 9131934256.
e-mail: Mehrabi@uk.ac.ir

Mohsen POURKHOSRAVANI – Doctor of Geomorphology, Associate Professor, Department of Geography.
Shahid Bahonar University of Kerman, Iran.
Ph.: +98 9133470729.
e-mail: pourkhosravani@uk.ac.ir

Мохсен ПОУРХОСРАВАНИ *– доктор геоморфологии, доцент, кафедра географии.*
Керманский Университет Шахида Бахонара, Керман, Иран.
Тел .: +98 9133470729.
e-mail: pourkhosravani@uk.ac.ir

Sadegh KARIMI – Doctor of Climatology, Assistant Professor, Department of Geography.
Shahid Bahonar University of Kerman, Iran.
Ph.: +98 9218153202.
e-mail: karimi.s.climatologist@uk.ac.ir

Садег КАРИМИ *– доктор климатологии, доцент, кафедра географии.*
Керманский Университет Шахида Бахонара, Керман, Иран.
Тел.: +98 9218153202.
e-mail: karimi.s.climatologist@uk.ac.ir

Reza DERAKHSHANI – Doctor of Geology, Associate Professor, Department of Geology.
Shahid Bahonar University of Kerman, Kerman, Iran; Department of Earth Sciences, Utrecht University, Utrecht, The Netherlands.
Ph.: +31 30 2535039.
e-mail: r.derakhshani@uu.nl

Реза ДЕРАХШАНИ *– доктор геологических наук, доцент кафедры геологии Керманского университета Шахида Бахонара, Керман, Иран; факультет наук о Земле, Утрехтский университет, Утрехт, Нидерланды.*
Тел.: +31 30 2535039. e-mail:r.derakhshani@uu.nl

МОНИТОРИНГ КЛИМАТИЧЕСКИХ ИЗМЕНЕНИЙ ПО ЛЕДНИКОВЫМ СЛЕДАМ НА ГОРЕ ХЕЗАР, ИРАН

Мехраби А. [1*],
Карими С.[1],
Поурхосравани М.[1],
Дерахшани Р. [1,2]
[1] *Керманский Университет Шахида Бахонара, Керман, Иран, mehrabi@uk.a.cir*
[2] *Факультет Науки о Земле, Утрехтский Университет, Утрехт, Нидерланды.*

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Исследование авторов направленно на отслеживание климатических изменений по ледниковым следам на горе Хезар. Температура в данной области была на 6.58 °C холоднее в период ледникового господства. Минимальное количество осадков в то время было 617 мм в нижней части и максимальное – 1340 мм – в самой верхней части. С другой стороны, ледниковые языки, ледниковые долины и морены определялись как наиболее характерные геоморфологические проявления ледников в данной зоне. Наконец, лабораторные показатели доказали существование ледниковых отложений в бассейне Тенгуех.

Кроме того, постоянная линия снежного покрова в конце четвертичного периода составляла 3326 м (метод Райта) или 3333 м (метод Портера).

Ключевые слова: ледниковые следы, климатические изменения, осадки.

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