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Full Length Research Paper

Investigation of the last Quaternary climate from the geomorphic evidence in Namak Lake basin, Central Iran

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Two important characteristics, alternate climatic oscillations and the appearance of human beings, distinguish the Quaternary from other geological periods. The climatic changes have shown increases and decreases of glacial scope in high latitudes, but there are different and opposing theories about the climatic situation in glacial periods of low latitudes such as Iran. In this study, the climate of the last glacial period of Namak Lake basin, located in north central Iran was investigated by using the past geomorphic evidence and statistical analyses. The present temperature and rainfall of this basin were studied and its related displacements were plotted, as were glacial cirques and lake terraces as geomorphic evidence. Regarding the snowline at different points of the basin, the temperature and rainfall of the basin in the Wurm glacial period was rebuilt by the Wright method and the changes relating to the present time were studied. Morphogenetic plans of the basin in two periods were prepared by using annual rainfall and temperature, and the Peltier method. Results show an increase of 48% (180 mm) in the annual rain and a decrease of 5.6°C in the Wurm glacial period compare with the present temperatures. The geomorphic evidence of the climatic changes including the Namak Lake terraces, travertine mines; vast areas of pediment and the effects of human civilization have yielded proven results.

Key words: Quaternary, holocene, morphogenetic, climate change, Namak Lake.

INTRODUCTION

Geomorphic evidence shows climatic changes over time. In the past, the temperature of the earth was warmer than it is today by about 8 to 15°. But there were also some periods which were colder than today, so that alpine and continental glaciers developed in the upper, middle and lower latitudes. Glaciers developed 925, 800, 680, 450, 330 and 2 million years ago, the strongest of which occurred 800 million years ago, advancing towards 5° of latitude. The last glacial period, named the glacial age, started in the Quaternary period, about 2 million years ago. The Quaternary is the last period in the long history of earth and is divided by geologists into two main periods: the Pleistocene and the Holocene. The last 12,000 years of this era are called the Holocene and the rest are called the Pleistocene.

The appearance of man and the repetition of glacial and interglacial periods are two important characteristics of this era. Therefore, we must deal with two different climates, glacial and interglacial.

Today, glaciers cover about 10% of the earth's surface, while in the glacial period, this figure amounted to 30%. Today's glaciers are divided into 2 types, continental and mountain (alpine) glaciers. Mountain glaciers are found in 3 shapes: cirques, valleys and pediment. The glaciers in Iran are of the mountain type and are mostly in the shape of cirques. In Elburze, Kerman and Shirkooh of Yazd, valley type glaciers are also seen. Glaciers from high latitudes are called cold ones and glaciers from middle and tropical attitudes are called warm glaciers.

In the study of glaciers in the Alps, 6 glacial periods, named Bibre, Donau, Gunz, Mindel, Riss and Wurm have

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been investigated. In northern Europe, 3 glacial periods, called Elster, Saal and Vistule and in northern America, 4 glaciations – Nebraska, Kansas, Illinois and Wisconsin have been specified. In terms of time, Illinois conforms to the Riss periods in the Alps and Saal in Europe, and Kansas conforms to Elster and Mindel (Jedari, 2008).

Today, the glaciers of Iran are on the mountains of Elburze and Zagros in an area of about 20 km^2. The largest glacier is on the western part of the Elburze mountain in Takht-e-soleiman, located on the northern slope. In the eastern Alburze are 2 small glaciers on the top of Damavand; in Zagros 5 glaciers of a maximum width of 500 m and height of 150 m; and in Sabalan 7 glaciers on the northern, eastern and western slopes exist (Ferrigno, 1988).

To date, many researchers have studied the Iranian glaciers. Ramesht (2005) found that moraines are left in the heights of Elburze and Kordestan to testify to glaciations before Wurm; he estimated that Iran's climate was colder and drier during the glacial periods. He noted a decreasing trend of temperatures, 4 to 5°C lower than today's. Ramesht (2005) worked on the heights of Zagros along the Iran-Iraq border and traced the permanent snowline on 1800 m heights in the Wurm period. Ramesht (2005) investigated the Sabalan glaciers. He showed that the glacier's bottom limits were 3980 and 3960 m, respectively, northwest of the top of Sultan and north of the top of Haram. Ramesht (2005) in their studies of central Iran, maintained that in central Iran wherever the glacial places of mountain zones in central Iran were supplied appropriately, glaciers could reach from the foot of the mountains and all the valleys to the plain (Ramesht, 2005). Pedrami (1982) referred to glaciers in the Dorrin Valley of Kashan and showed that its drifts are well preserved. He presented a diagram, based on his studies, of the snowlines of Iran's borders in the Wurm glacial period. Ramesht (2005) in his studies on the glaciers of central Iran, and based on geomorphic evidence and erosive remains, investigated glaciers 1600 m in height in central Iran, including Zofreh and Shirkooh. The cirques of Salafchegan and its glacial valley were investigated by Shooshtari (2003). Rafiee (2009) worked on the glaciers of Kahak Qom. In the most recent studies, the snow border in central Elburze was set to 2749 m (Zamani, 2009), in Karkas 3000 m (Yamani, 2007) and in Kahak of Qom 2672 m (Rafiee, 2009)

In this study, the changes of climate in the Quaternary period were investigated by studying the limits and extensions of the snow boundary in Namak Lake basin.

MATERIALS

The study area is located on longitude 48° 28' to 52° 28'E and latitude 32° 58' to 36° 28'N (Figure 1). This zone includes the southern slopes of the central Elburz up to the northern slopes of the southern heights of Kashan and Karkas, and from the eastern slopes of Zagros to Dasht-e-kavir. The size of area under study equals 92544 km^2, 42020 km^2 (45.4%) of which is mountain and 50524 km^2 (54.6%) consist of plains and lakes. Altitude ranges from 800 m around Namak Lake to 4375 m in the Jajrood heights (Figures 2, 3 and 4). In this domain, there are 3 large and some small playas, which absorb the surrounding water (Namak Lake, Hoze Sultan and Mighan Kavir). This basin is one of the seven main basins in the central Iranian basin. The average annual rainfall varies from lower than 200 mm in the southeastern parts to more than 800 mm in the northern heights and rainfall follows the Mediterranean pattern. The weather is influenced by height in Namak Lake basin. In terms of temperature, 44% of the area is ultra-cold, 49% cold and 7% mild. In terms of the aridity index, 14% is hyper arid, 31% arid desert, 42% Mediterranean and 13% has other climates.

METHODS

In the current research, the climate of Namak Lake climate was studied, at the present time and during the last glaciation period, that of Wurm. In order to examine the present condition of this basin, statistics relating to the temperature and rainfall of 32 stations inside and outside its surrounding were selected (Table 1). After gathering the data and rebuilding them to remove the outliers and estimating the correlation of the missing values of these variables against the height factor in SPSS, the models were extracted. The maps of rain and temperature were drawn by the digital elevation model (DEM) map and the models earlier discussed. The way of determining temperature in the last glacial period is based on the snowline. The snow border is a line above which snow does not melt. Different methods can be used to determine the snow border. Porter (2001) used five ways to rebuild the height of the equilibrium line. He believed that the results reached by these means are not comparable. These five methods consist of: 1) using the height of the cirque's bed; 2) examining the lateral marine of the upper part the of valley; 3) using the glaciations' threshold; 4) using the height ratio; and 5) using the accumulation-area ratio.

One of the other ways of determining the snow border is Wright's method. In this, a height is set as a permanent snow border, by placing cirques and determining their height such that 60% of the cirques are higher (Ramesht, 2005).

In this research, the place of cirques was determined by using topographic maps 1.50000, DEM and field observation (Table 2 and Figure 5). Then the height above the height of 60% of the cirques in the region was determined as a permanent snow border. Regarding the average annual temperature amounting to 0 for the snow border, the total average annual temperature of the basin was calculated. By using the relation between rainfall and temperature, the rainfall rate in the Wurm period was estimated. In the next stage, the results were verified by examining other factors, such as lake terraces, the effects of human civilization and travertine mines.

The morphogenetic regions of Namak Lake in Wurm and at the present time were prepared by the method of Louis Peltier (Fowler and Petersen, 2003). In this method, 9 regions were determined by using temperature and rain (Figure 6). The classifications for the morphogenetic regions are:

1) Selva – Wet and hot annually
2) Maritime – Wet and warm annually
3) Moderate – Less precipitation but still warm
4) Savanna – Lower amounts of precipitation but temperatures range from low to high annually
5) Semi-arid – Low precipitation amounts and warm to hot
6) Arid – Very little precipitation and hot
7) Boreal – Warm but cycles between freeze-thaw cycle and enough precipitation to nurture hardy vegetation
8) Periglacial – Freeze-thaw cycle is dominant and occurs often
9) Glacial – Freeze-thaw cycle less effective since temperatures

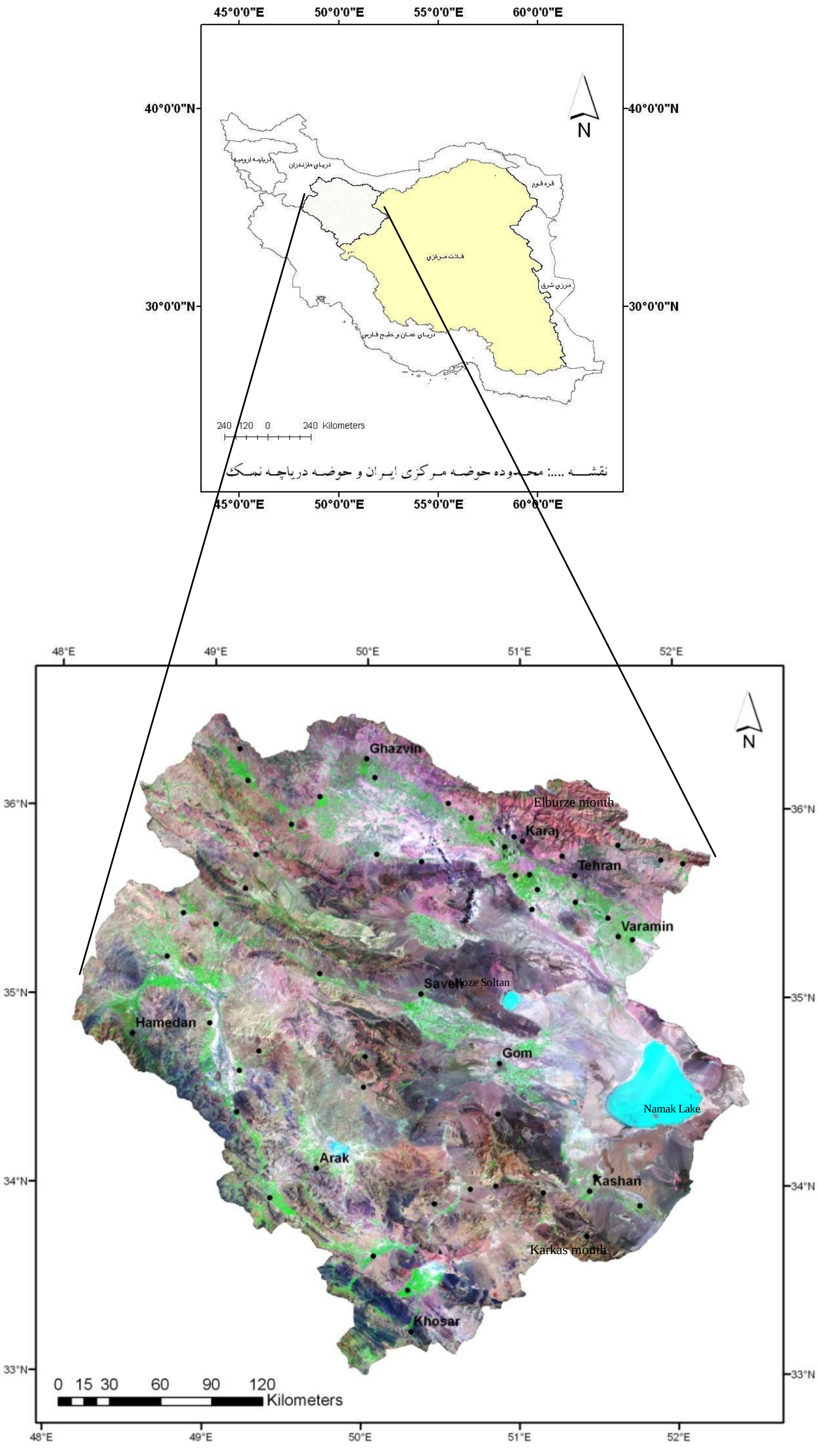

Figure 1. Basin of Namak Lake.

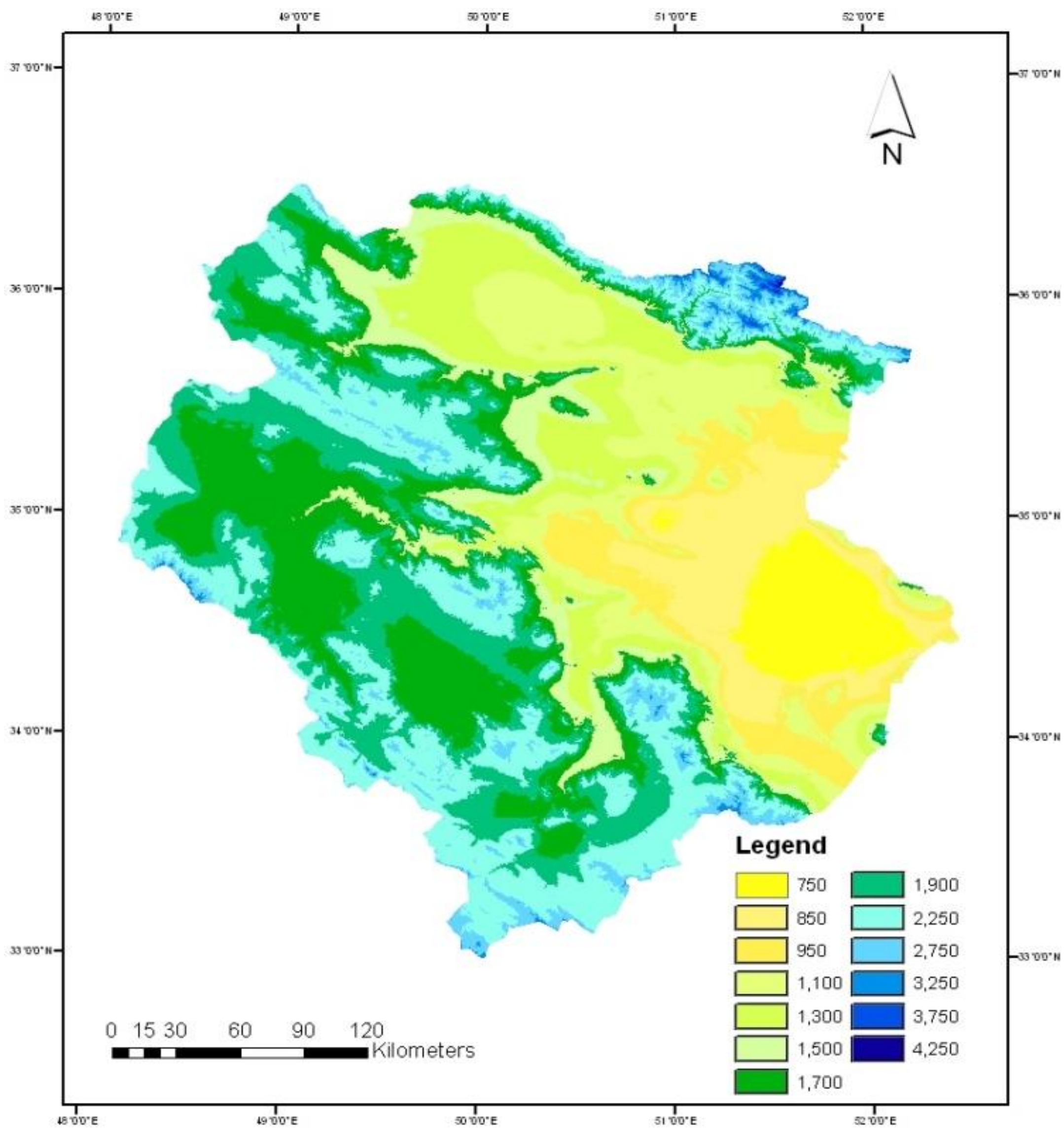

Figure 2. Hypsometry map of Namak Lake basin.

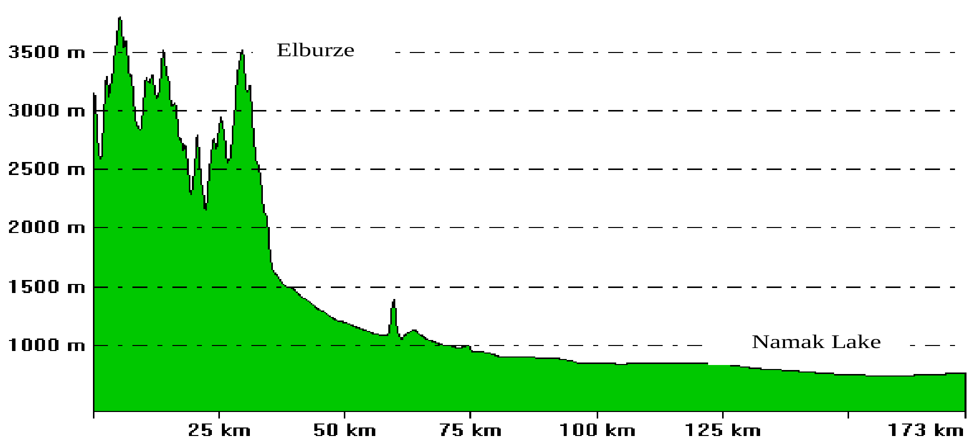

Figure 3. Elevation profile of Elburze – Namak Lake.

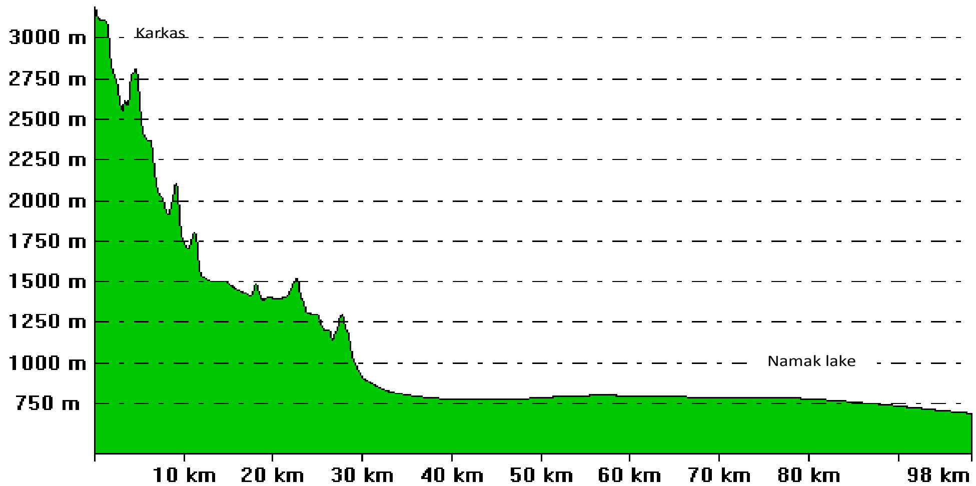

Figure 4. Elevation profile of Karkas – Namak Lake.

Table 1. Synoptic stations of Namak Lake basin.

Row	Station	Latitude	Longitude	Height (m)	Rain (ml)	Temperature (°C)
1	Arak	49.77	34.1	1708	345.27	13.65
2	Ardestan	52.38	33.38	1252	104.82	17.4
3	Avaj	49.22	35.57	2034	345.52	10.24
4	Brujerd	48.8	33.9	1632	474.4	13.64
5	Damane Feraidan	50.48	33.02	2300	323.06	10.01
6	Dargazin	49.07	35.35	1870	329.53	10.74
7	Dodahak	50.63	34.06	1400	142.96	15
8	Dushan Tape	51.33	35.7	1209	254.77	17.52
9	Duzaj	49.82	35.4	2100	226.48	10.37
10	Gakan Ashtian	49.97	34.55	1741	282.51	12.96
11	Garmsar	52.27	35.2	825	123.54	17.58
12	Ghazvin	50	36.25	1278	318.85	13.88
13	Golpayegan	50.28	33.47	1870	249.01	12.95
14	Gom	50.85	34.7	877	157.66	18.03
15	Hamedan	48.53	34.85	1749	305.48	10.77
16	Hamedan (Noje)	48.72	35.2	1679	331.62	10.8
17	Esfahan	51.66	32.62	1550	118.1	15.9
18	Karaj (synoptic)	50.9	35.92	1312	272.8	13.5
19	Karaj (Daneshkade)	51.03	35.8	1321	240	14
20	Kashan	51.45	33.98	982	138.9	18.9
21	Khonsar	50.32	33.23	2300	352.9	11.7
22	Khandab	49.2	34.4	1742	331.2	15.8
23	Khoramdare	49.18	36.18	1575	309.6	10.9
24	Malayer	48.82	34.28	1725	309.3	13.31
25	Natanz	51.9	33.53	1684	143.8	14.7
26	Save	50.33	35.05	1108	202.2	18.2
27	Shams Abad	49.73	33.82	2400	341.3	11.5
28	Tafresh	50.03	34.68	1930	294	12.6
29	Takestan	49.65	36.05	1325	239.7	13.5
30	Tehran	51.32	35.68	1190	229.9	17.1
31	Veramin	51.65	35.31	1000	162.7	16.6
32	Zanjan	48.48	36.68	1663	304.2	11.1

Table 2. Range of height of cirques in Namak Lake basin.

Row	Height (m)	Cirque number	Percent	Row	Height (m)	Cirque number	Percent
1	2500 - 2600	91	12.7	10	3400 - 3500	16	2.2
2	2600 - 2700	109	15.2	11	3500 - 3600	33	4.6
3	2700 - 2800	90	12.6	12	3600 - 3700	24	3.4
4	2800 - 2900	84	11.7	13	3700 - 3800	7	1.0
5	2900 - 3000	88	12.3	14	3800 - 3900	11	1.5
6	3000 - 3100	46	6.4	15	3900 - 4000	9	1.3
7	3100 - 3200	53	7.4	16	4000 - 4100	5	0.7
8	3200 - 3300	33	4.6	17	4100 - 4200	2	0.3
9	3300 - 3400	14	2.0	18	4200 - 4300	1	0.1
Total		716	100				

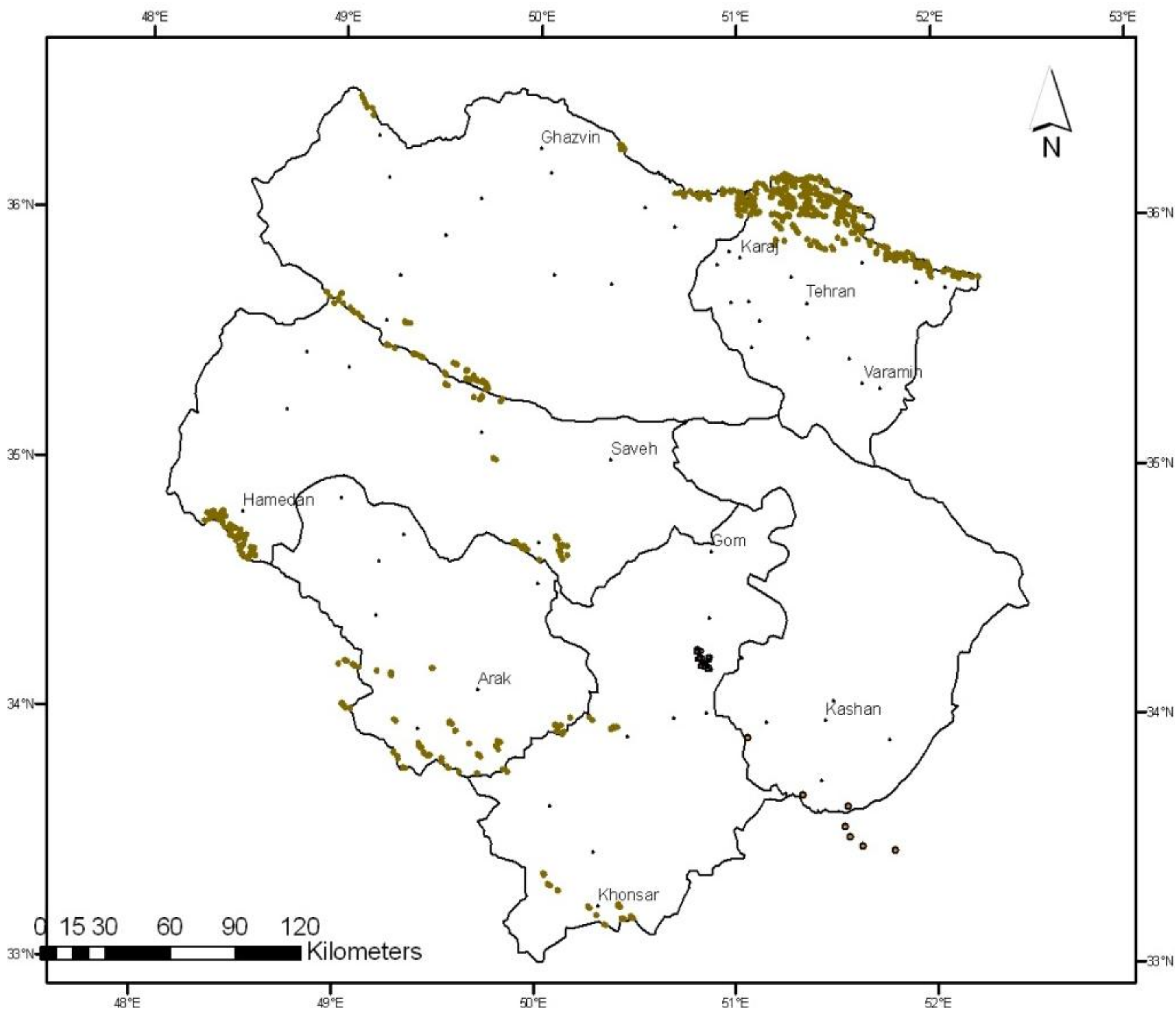

Figure 5. Cirques of Namak Lake basin.

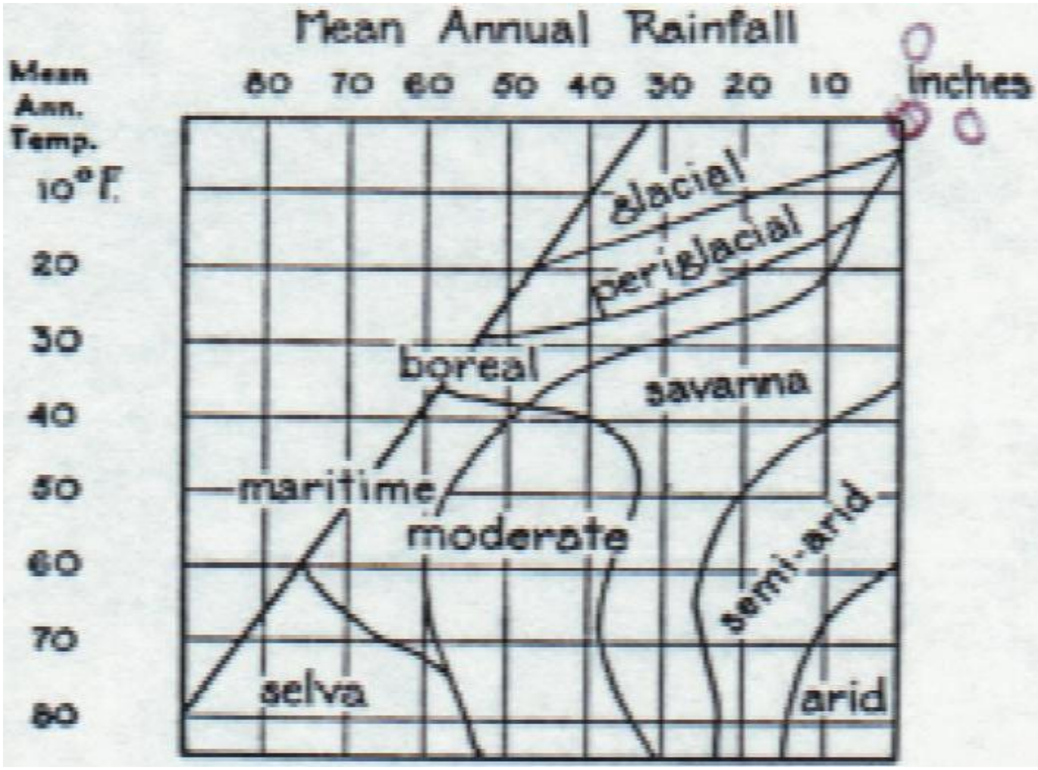

Figure 6. Peltier's graph of morphogenetic regions.

stay very low all year round.

First, the diagram above entered the Arc map environment, and its coordinates were defined on the basis of rainfall and temperature, so that every point coordinate in the diagram was set by temperature and rainfall. Then the temperature and rainfall figures at the present time and in Wurm were combined. The table relating to this map includes the temperature and rainfall rate. Two point layers whose cells were determined by temperature and rainfall at the present time and in Wurm were prepared and corresponded to the Peltier diagram. Morphogenetic regions were correspondingly recognized in the diagram.

RESULTS

In Table 1, selected synoptic stations, geographical coordinates, average temperature and annual rainfall are shown. As shown, the rainfall rate follows a decreasing trend from west to east but the temperature has an increasing trend in the same direction (Figures 7 and 8). In this research, a line at 2800 m was calculated as the snow line of this basin, which means that 60% of the cirques are located at a height above 2800 m. The temperature gradient in relation to the height is:

$$T=22.43-0.006H \quad (1)$$

where T is the average temperature of the point H (m) above sea level). By Equation 1 and the DEM map, a temperature map can be prepared (Figure 9). To calculate the temperature in the Wurm period, Equation 2 was used (Figure 10).

$$T_w = (H_s - H) * 0.6/100 \quad (2)$$

where T_w is the Wurm temperature, H_s is the snow in Wurm and H is the height.

The relation between rain and height is:

$$P=40.88+0.135H \quad (3)$$

The rain map of the basin can now be drawn by Equation 3 (Figure 11).

The linear regression between rainfall and the temperature is:

$$P= -25.24T+605.2 \quad (4)$$

where P is the annual rainfall (mm) and T is the average temperature. The rain map in Wurm is prepared from the temperature map in Wurm and Equation 4 (Figure 12).

Climate parameters now and in Wurm are shown in Table 3. The average temperature during Wurm is decreased by 5.6°C and the annual rainfall in the same period increased by 180.8 mm. The result of the morphogenetic study was maps in Wurm (Figure 12) and

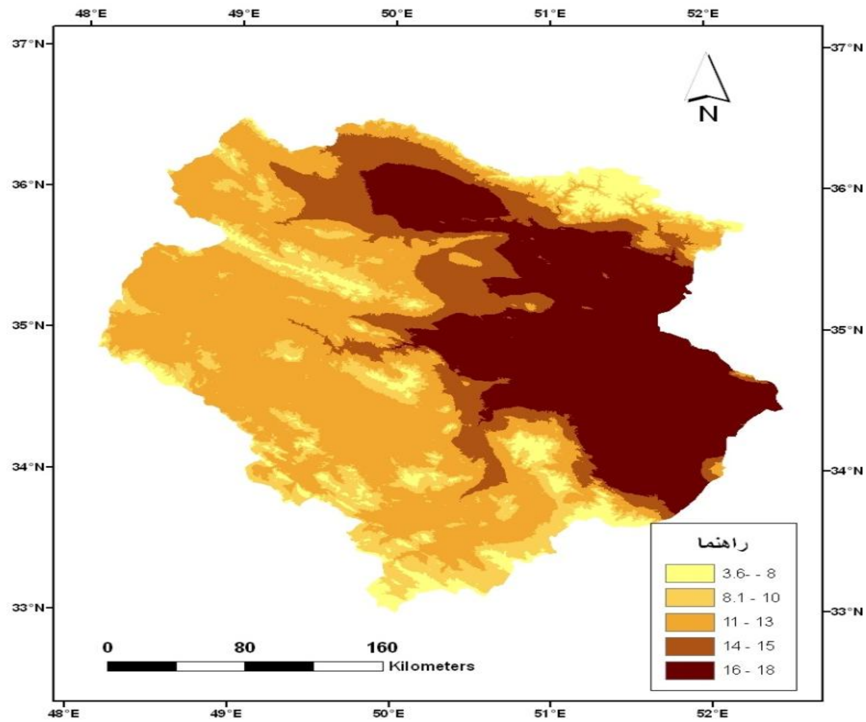

Figure 7. Temperature map of Namak Lake basin.

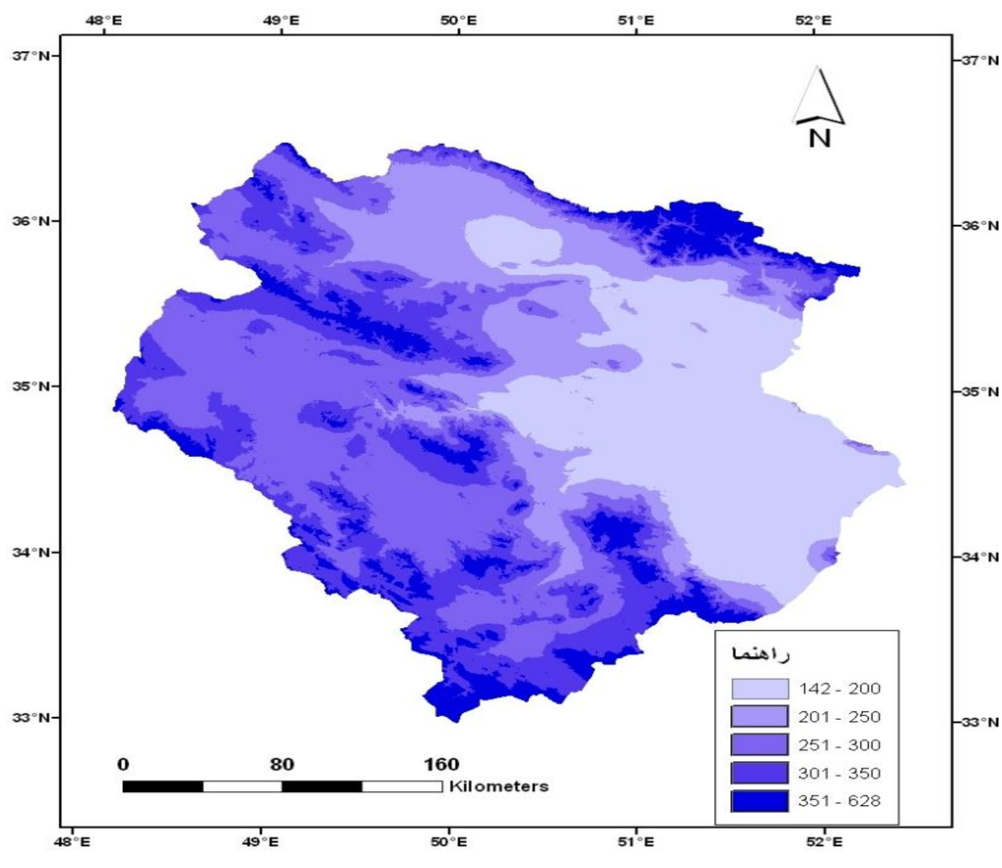

Figure 8. Rain map of Namak Lake basin.

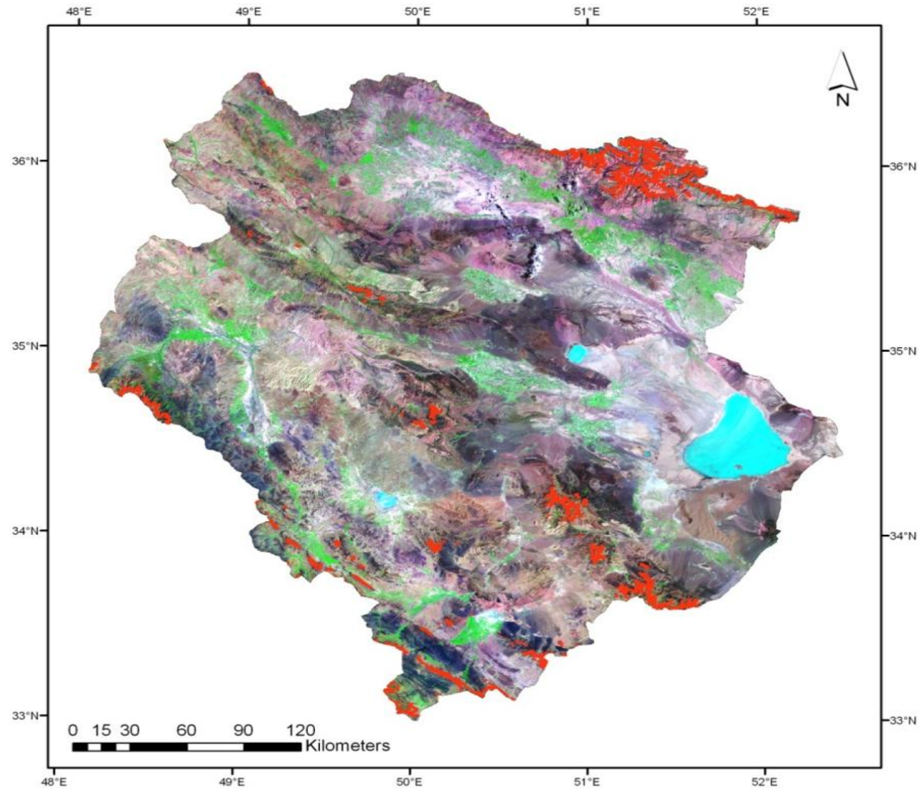

Figure 9. Snow line of Namak Lake in Wurm.

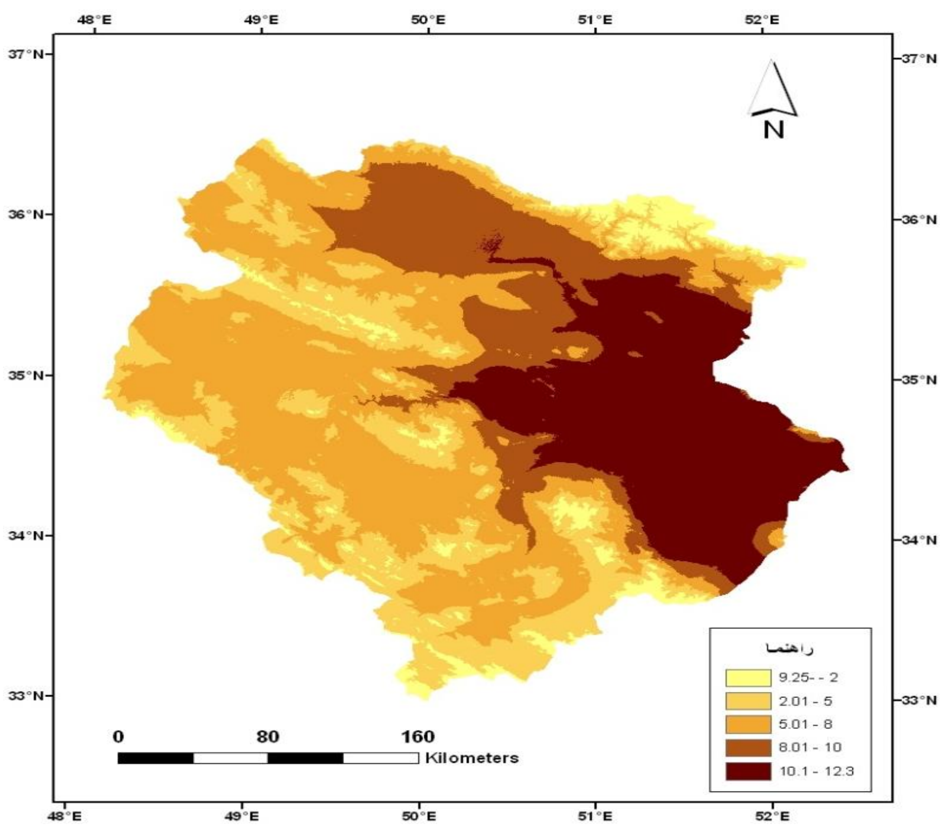

Figure 10. Temperature map of Namak Lake basin in Wurm.

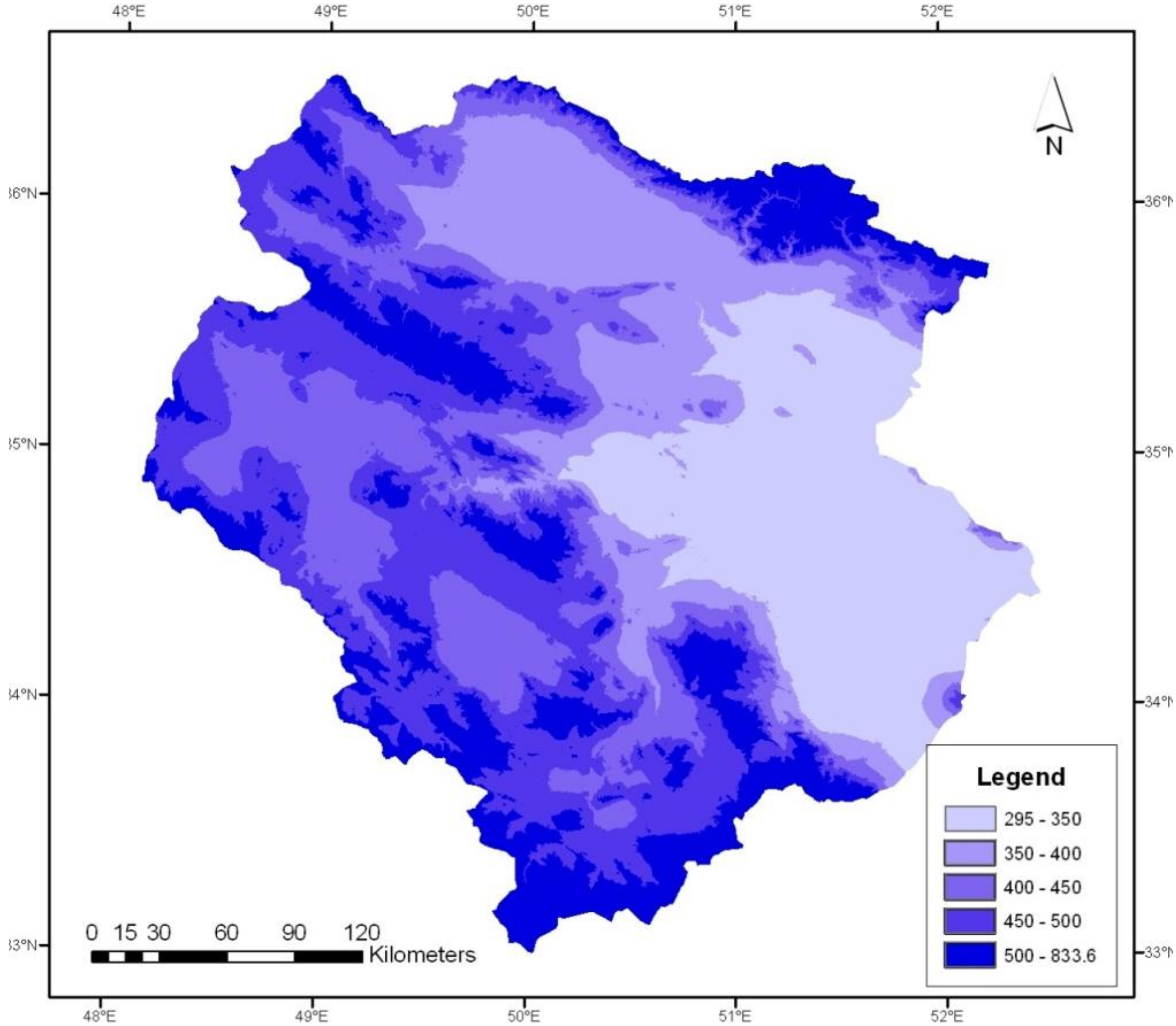

Figure 11. Rain map of Namak Lake basin in Wurm.

in the present (Figure 13). Table 4 shows the morphogenetic area in Namak Lake basin.

DISCUSSION

An increase 48.4% in the rainfall rate and a 5.6° decrease in the average temperature of this zone in the last glacial period, Wurm, have resulted in many climatic and geomorphic changes.

Nowadays in summer, there is a high pressure axis besides tropical change into a high latitude up to 40°N, while in winter, this axis changes to low latitudes as far as Bahrain. In summer, because high pressure is exerted on the Caspian Sea, low pressure from the west is blocked, so producing less rain. In the glacial periods, conditions similar to the current winter conditions dominated. A polar high-pressure cell maximum extended to cover a wide area of the northern hemisphere. Similarly, the high pressure axis regressed and western low pressure areas divided the western latitudes. By dominating relatively wet climates in the center and south of Iran, the cold temperatures of the heights in these regions caused mountain glaciers (Zomorrodian, 2008). There are many signs of this wet and cold period in Namak Lake zone including glacial cirques in the heights of the Elburze mountains, Karkas, in the southern heights of Kashan, Kahak of Qom, Salafchegan, Alvand of the Hamedan and Zagros mountains on the western side of the zone. Alluvial terraces in the rivers indicate changes in the base surface of a lake. Among them are the Jajrood terraces. These terraces show a thickness of 40 to 219 m in Lar,

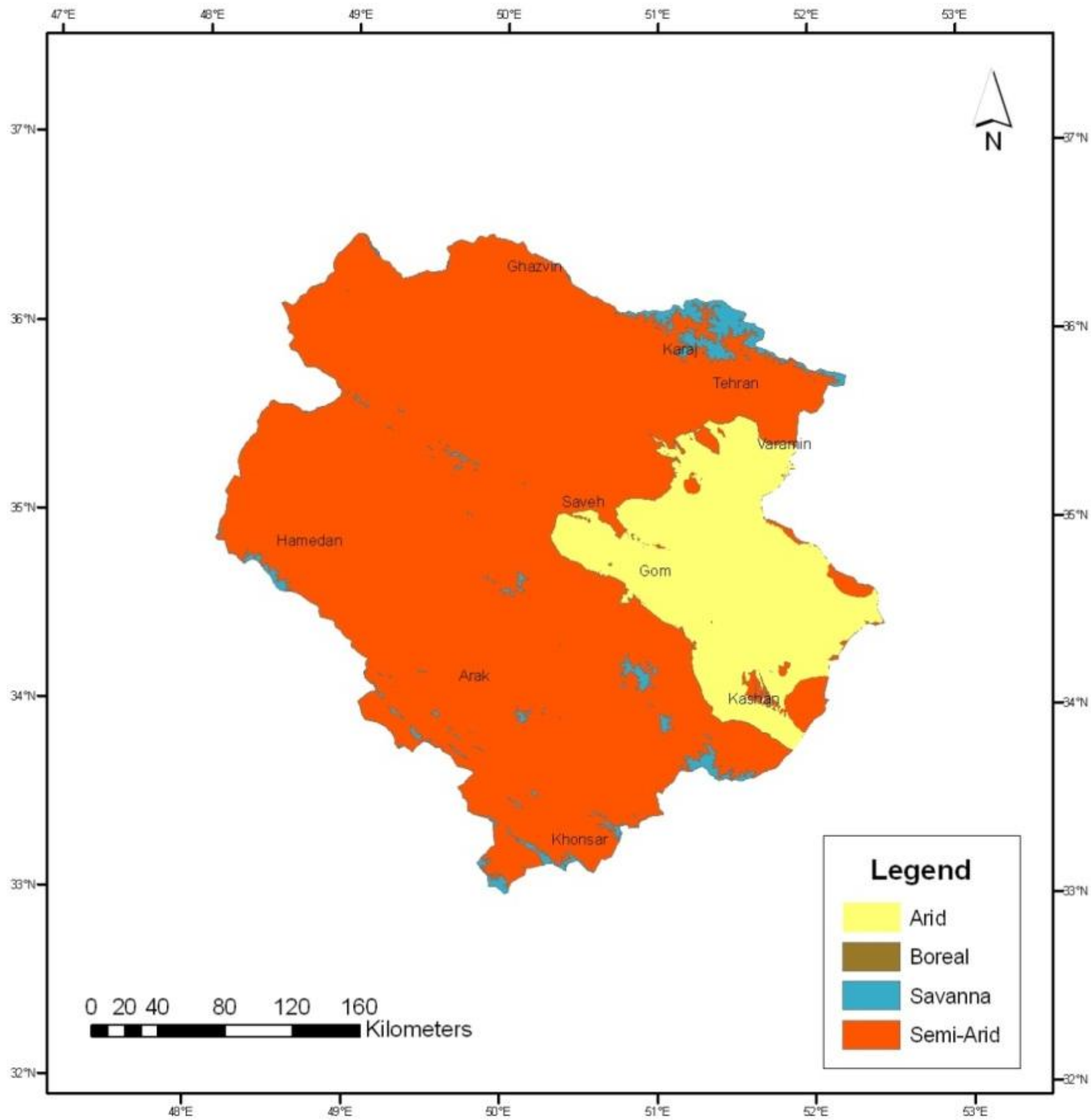

Figure 12. Morphogenetic map of Namak Lake basin.

Table 3. Climate parameters now and in Wurm in Namak Lake basin.

Climate parameter	Temperature (°C)			Rain (ml)		
	Minimum	Average	Maximum	Minimum	Average	Maximum
Now	-3.4	7.6	17.8	145.2	373.8	622.5
Wurm	-9	2	12.2	298.2	554.6	833.6

Jajrood Bridge, eastern Parchin and Lashkarak.

Carbonated stones in the lakes, rivers and cold and hot springs or in caves are indicators of the rapid climatic rebuilding of this zone. Based on studies on the mountain regions of Kashan, it appears that to the south large mines of travertine stones existed in Zardkooh Sefidab,

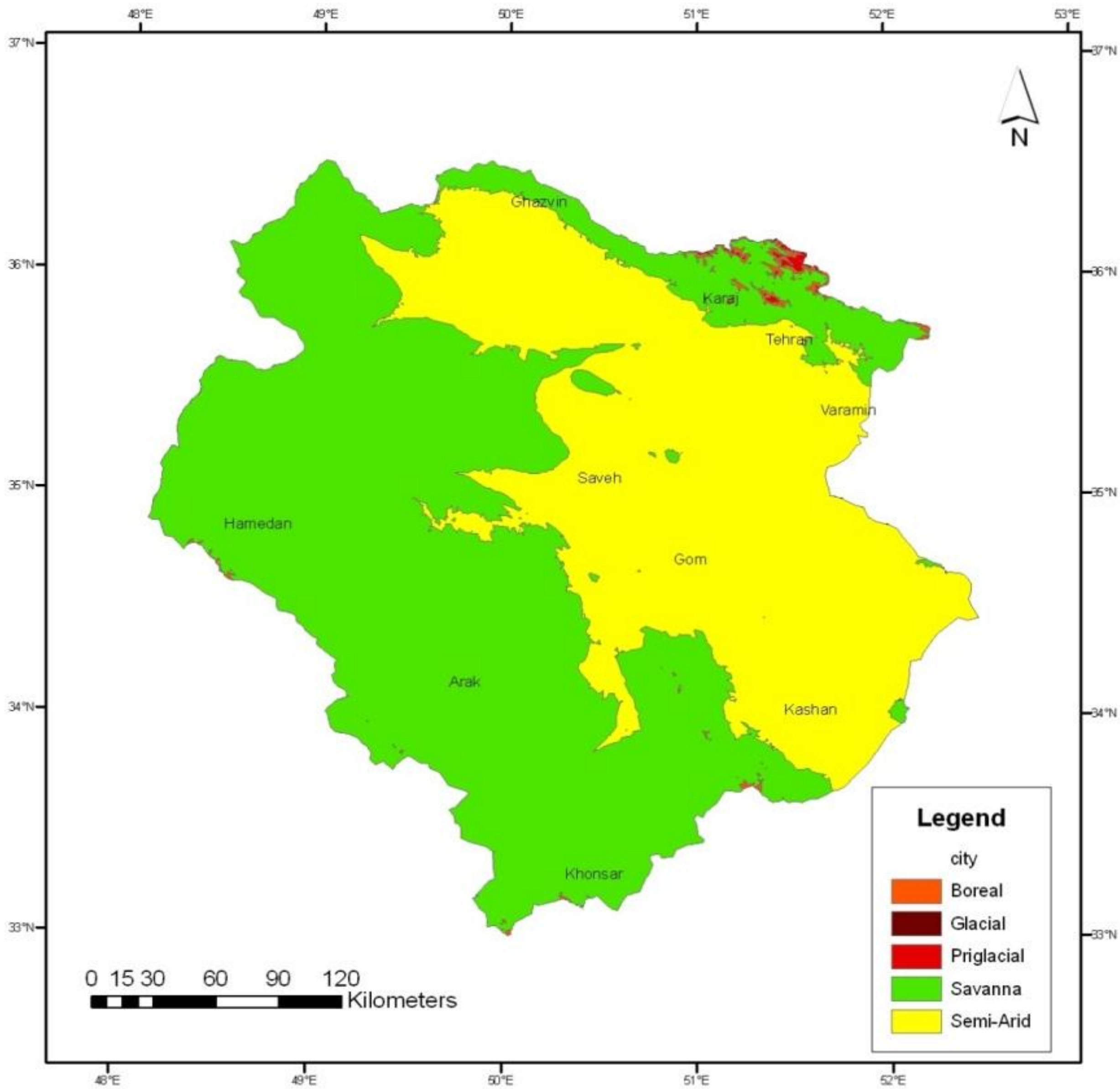

Figure 13. Morphogenetic map of Namak Lake basin in Wurm.

Table 4. Change in area of the morphogenetic regions in Namak Lake basin.

Morphogenetic		Glacial	Periglacial	Boreal	Savanna	Simi arid	Arid
Wurm	Hectare	17.1	14224.7	40129.9	5400249.8	3819818.5	0
	Percent	0.0002	0.15	0.43	58.23	41.19	0
Now	Hectare	0	0	224.4	220959.5	7421344.1	1631912
	Percent	0	0	0.002	2.38	80.02	17.60

Kaftarkhooh and Fin (Figure 14). These travertines belong to springs which are linked with waters saturated with calcium bicarbonate; some of the springs now have water saturated with calcium bicarbonate. Traces of major major civilizations (Figure 15) such as Sialk in Kashan indicate suitable conditions for agriculture and animal husbandry. Studying sediments around the hills of Sialk indicates that these sediments originate from rivers which

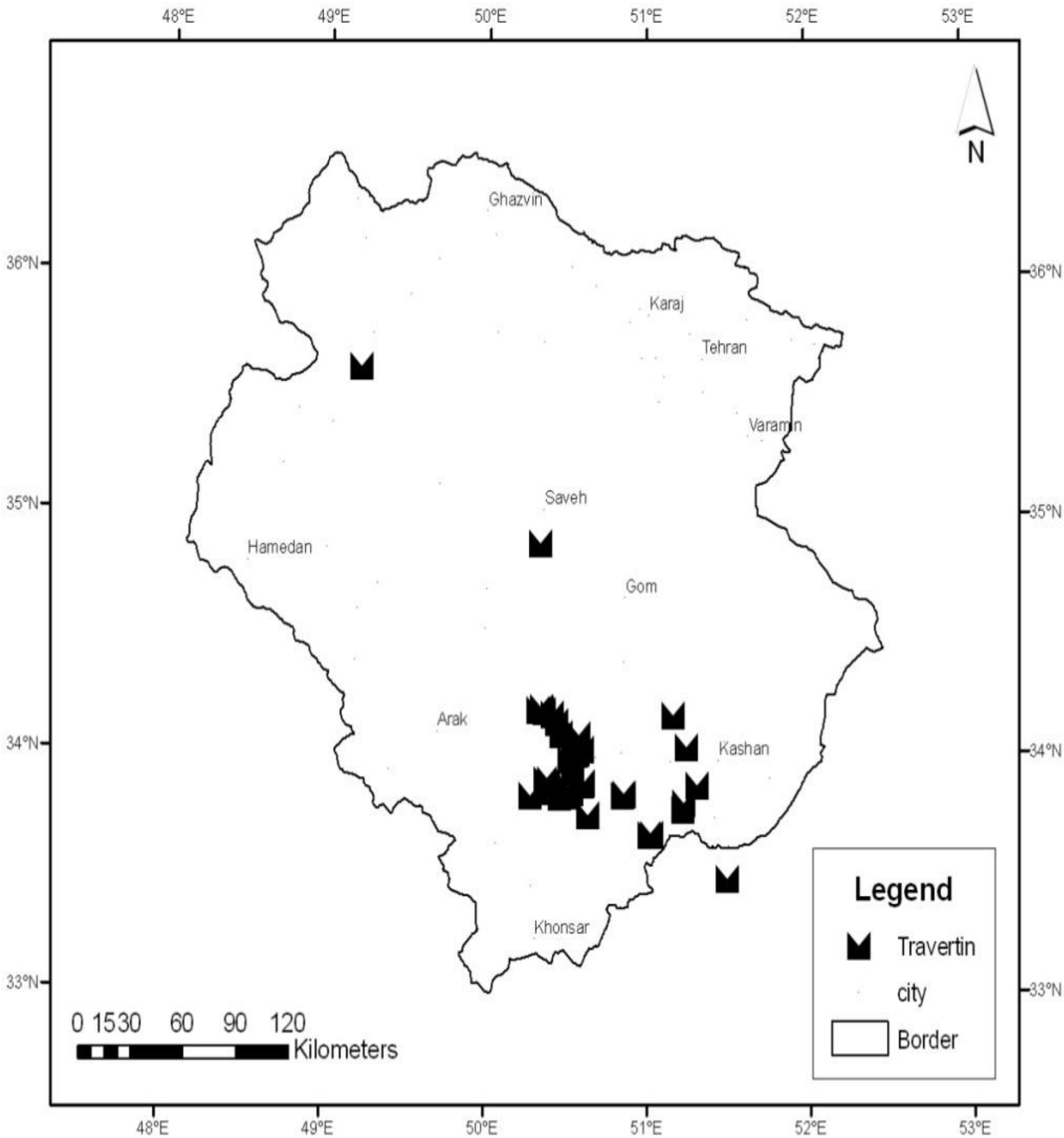

Figure 14. Map of Travertine mines.

existed 5000 to 7000 years ago. Studying the last vegetations of Sialk shows the existence of river vegetation and step zones such as Tabrizi and spruce. Moreover, sedimentary remains indicate the existence of a lake beside the city of Saveh (Krinsley, 1970). Some lake terraces in the margin of Namak Lake and Houze Soltan indicate that there was one lake which included Houze Sultan, Namak Lake and the dried-up Saveh Sea. On the lake terraces, this research finds 3 base surfaces, 790, 800 and 900 m, around Namak and Houze Sultan Lakes (Figure 16).

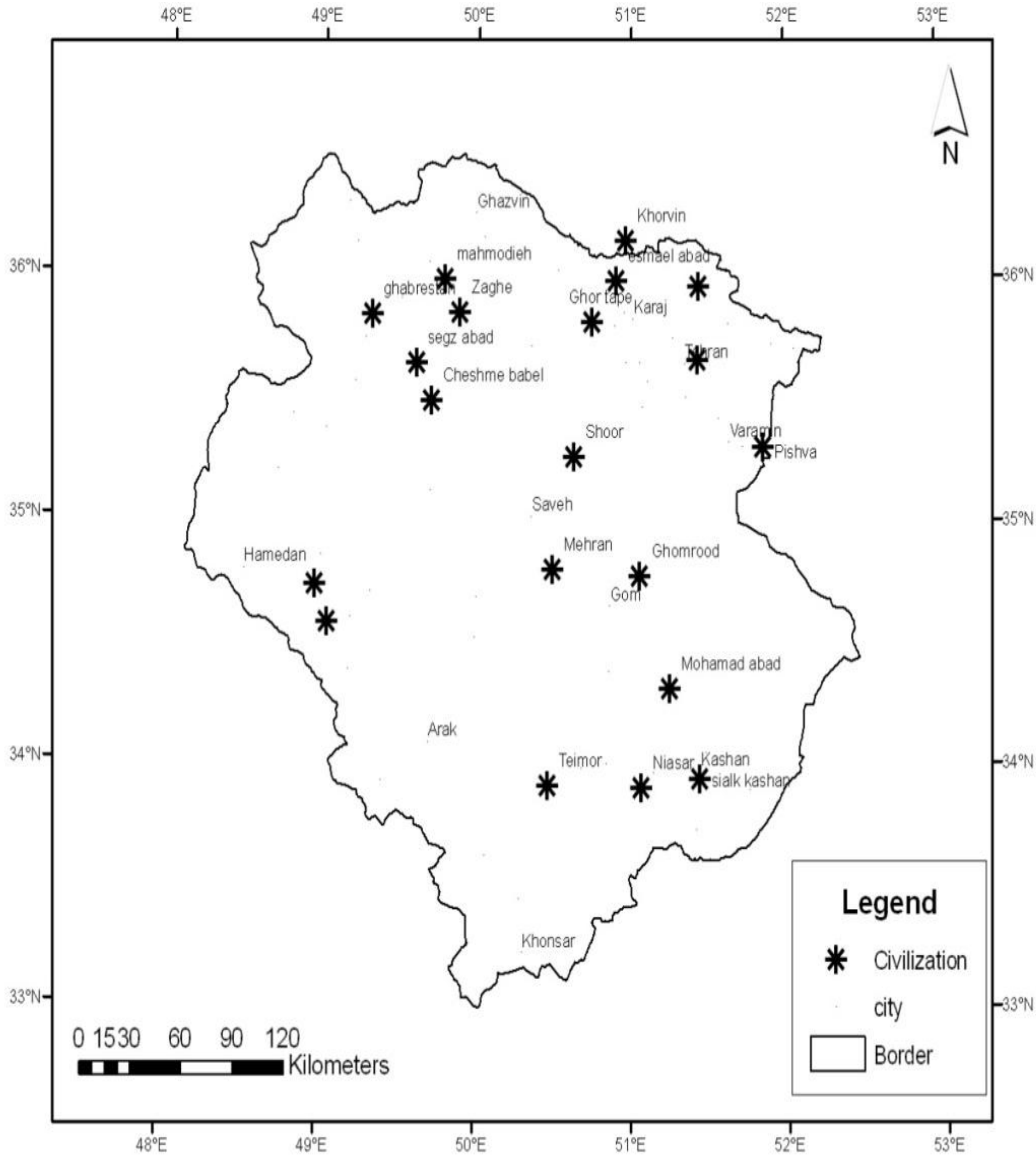

Figure 15. Civilizations in Namak Lake basin.

All of the evidences shown allowed us to conclude that the past climate of Namak Lake basin used to be colder and wetter than it is now. Dating of the sediment can help to show climate change in this basin at particular times.

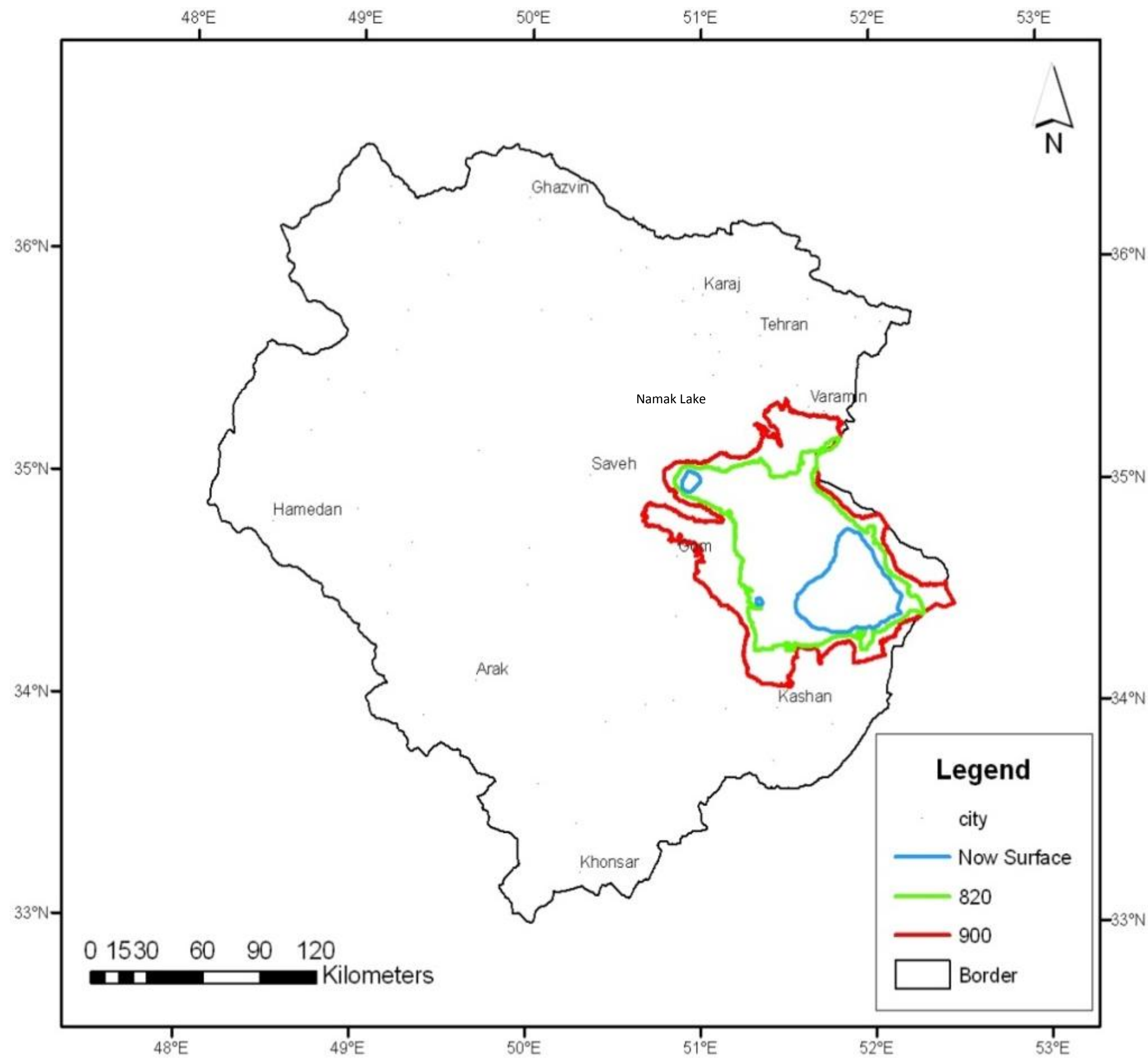

Figure 16. Base surface around Namak Lake.

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