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Assessment of Climate Change in Northern Zagros Forests using Stochastic Weather Generator

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1 Introduction

According to the IPCC report, for the 21th century the temperature of the earth will increase between 1.4°C to 5.8°C. Different scenarios (IPCC, 2007) will happen to change the different climate systems of the earth such as water circulation, carbon cycle, nutrition and many others environmental parameters. The major reason for these changes would be greenhouse gases specially CO_2 emission which affects the thermal equilibrium of the earth (Freiwan and Kadioglub, 2008). The Global Climate Models (GCMs) are the tools for supporting the discussions and analysis, under different emission scenarios. The GCMs are the most important mathematical models to simulate the observed climate conditions and predict the future climate changes under different greenhouse gases concentration (GHGs).

The GCMs output data used regionally by utilizing downscaling from high determination of the GCMs to a low determination. The downscaling strategies are ascertained dynamical and statistical methods (Seguí *et al.,* 2010; Ochoa *et al.,* 2015; Campozano *et al*., 2016; Liu *et al*., 2016).

The climate generators are the most appropriate and less costly techniques for evaluating and investigation of environmental change appraisal (Wilks, 1992; Bardossy, 1998). Long Ashton Research Station Weather Generator (LARS-WG) is a stochastic weather generator specially used for studies of climate change impact (Semenov and Barrow 1997). According to IPCC (2014), climate and non-climate stressors are projected to impact forests during the 21st century leading to a large-scale forest die-back, biodiversity loss and diminished ecological benefits. Fischlin *et al*. (2007) report that 20–30% of the plant and animal species would be at expanded danger of annihilation if the worldwide normal temperature increment surpassed 2–3°C over the pre-industrial level. The ecosystem of the forests as an interface of climate systems is giving a variety of vital services such as oxygen production, soil protection, drinking water treatment, increasing the level of underground water sources, balancing of weather, avoiding of landslides and controlling of flood and also decreasing the speed of drought, heating, cooling and heavy winds, and protecting of animal species (Lasch-Born *et al*., 2015). The negative effects of climate changes will obviously decrease the capability of the forests to make all these services.

In Iran, forest has reduced from 19.5 million hectares in 1943 to 11.075 million hectares in 2009 (Pourhashemi *et al*., 2004). Among all the forests in Iran, Zagros Forest located in the western and north-western part of the country and covering about 5 million hectors, have the most critical ecosystem situation because of destructive proceedings such as cutting trees, grazing, man-made firings, using different kinds of chemical muck in farming fields, penetration of living area into the forest, increasing of population and also drought, wide natural burnings, pest and illness infestation, and haze. Zagros forests, which are situated in semi-Mediterranean climate, are a standout amongst the most mainstream and touchy biological systems in Iran. The principle tree sort in Zagros forest are *Quercus* spp. (oaks). Around 40% of water resources of Iran results from this region. The Zagros vegetation zone is separated into two principle parts in light of climate conditions and oak species. These two zones are ordered to southern and northern locale. The northern district has higher moistness than the southern locale (Jazirehi and Ebrahimi, 2003; Sagheb Talebi *et al*., 2004; Haidari *et al*., 2013).

The principle motivation behind the present study is to simulate future precipitation, minimum and maximum temperatures in the northern Zagros forest which can be utilized for effect appraisals that require local-scale climate scenarios. The approach is based on the LARS-WG weather generator from HadCM3 under A2 scenario.

2 Materials and methods

2.1 Study area

The northern Zagros forest is located in northwest of Iran between 35° 25' to 35° 30' N and 35° 30' to 44° 54' E in cities of Marivan, Bane, Saghez, Sardasht and Piranshahr with a surface of 6.1 million hectares (Fig. 1). The northern Zagros forest is situated in high heights and latitude and also is near the humidity resources; therefore, this area is wetter than other parts of Zagros forest. The average annual precipitation of the base time (1986–2010) at Marivan and Sardasht stations was 967 and 810 mm respectively, while Saqqez station demonstrated minimal measure of precipitation over a 24-year period, 547.5 mm (Fig. 2). The mean temperature of the base time was 13.8°C and 10.8°C for Bane and Saqqez, individually. The maximum temperature observed in Marivan station was 41.4°C; meanwhile the minimum temperature was related to Saqqez station with -36°C (Fig. 3). The geographical information and basic statistics for precipitation and temperature of each station are presented in Table 1.

The LARS-WG model was utilized to generate synthetic weather data of precipitation, minimum and maximum temperatures taking into observed data between 1986 and 2010 for four weather stations. The output data is utilized for examination of the observed and synthetic data arrangement for investigation of climate condition and its effect on northern Zagros forest.

The northern Zagros forest is limited based on the growth of Quercus infectoria and Quercus libani species which make the forest type beside Q. persica, Q. magnosquamata and Amygdaluas spp (Jazirehi and Ebrahimi, 2003). The Quercus infectoria and Quercus libani are determined as dominant species in this region. The tree species in the study area are in 11 different types: Q.Barantii, Q.Barantii - Amygdaluas spp, Q.Barantii - Pistacus Atlantica, Q.Barantii - Q.Infectoria, Q.Barantii - Q.Libani, Q.Infectoria - Q.Barantii, Q.Infectoria - Q.Libani, Q.Libani - Q.Barantii, Q.Libani - Q.Infectoria (Fig. 4). The forest data is taken from Shahid Beheshti University and library studies of the forestry group at University of Tehran.

2.2 LARS-WG and model validation

LARS-WG is a stochastic weather generator that used to create long-term weather output data to assess impact of climate change (Racsko *et al*., 1991; Semenov and Barrow, 1997). This model generates synthetic daily climate data (precipitation, maximum and minimum temperatures). The climate generator is utilizing the observed daily weather data to decide parameters determining probability distribution for variabilities of climate and also connections between the variables. The daily weather data is used to process the synthetic data by using a pseudo-random number generator. The generating daily data determines dry and wet spell lengths based on rainfall days. The generating synthetic rainfall is modelled by semi-empirical distributions for every month for times series of dry and wet days. The minimum and maximum temperatures used a Fourier series based on normal distribution with the mean and standard deviation (Semenov & Barrow 1997).

The basic measurable parameters, for example, mean and coefficients of variation are utilized to assess LARS-WG model for five stations by observed data between 1986 and 2010. The mean and coefficient of variation are used to compare historical and generated rainfall data for monthly and annual series. The student's t test and F test are used to evaluate the simulated observed data in LARS-WG model. The Kolmogorov-Smirnov is also investigated for evaluation of this model for stations (Qunying *et al*., 2009).

2.3 Generation of Climate Scenario

To generate climate scenarios for future, the observed data at four selected synoptic stations are used during 1986-2010 for LARS-WG model. In the current study, HadCM3 is used to simulate the local climate scenario under SRA2 emission scenario for three different periods, 2011-2030, 2046-2065 and 2080-2099, to predict the future climate conditions.

3 Results and Discussion

3.1 Results of Validation of LARS-WG

The daily precipitation, minimum and maximum temperatures for North of Zagros forest for the period 1986-2010 (24 years) was used to evaluate LARS-WG model. The daily climate data was analysis by comparing the historical and synthetic data using varios statistical test such as t-test, F-test and K-S. The mean monthly correlation of the precipitation, minimum and maximum temperatures were acceptable at 0.05 level of confidence. Table 2 shows the model performance for simulating the daily weather data in every station. The assessment results show that the performance of LARS-WG in simulating distributions of minimum and maximum temperatures is better than precipitation. These analyses show that the LARS-WG model can be reasonably used to predict future weather data for this area.

Figure 5 represents the comparison between synthetic and observed precipitation data in different stations. The monthly precipitation is in close agreement with the generated data by LARS-WG model, except for August and January in Marivan and Saqqez stations, respectively. The standard deviation of observed and synthetic data shows an acceptable confidence values at all stations except for the months of January, May and August in Marivan station, February, August and December in Piranshahr station, September and November in Saqqez station and November in Sardasht station.

The monthly minimum and maximum temperatures for all stations are presented in Figures 6 and 7, respectively. The observed and simulated monthly means of minimum and maximum temperatures are close to each other in all months. There was no significant difference between observed and simulated data as the probabilities of t -test were more than 5% level.

3.2 Generation of Climate Scenario

The historical data in the study area was then used to generate daily precipitation, minimum and maximum temperatures for the periods of 2011-2030 (first period), 2046-2065 (second period) and 2080-2099 (third period) based on HadCM3 A2 emission scenario. The Friedman test was used to evaluate the level of changes between observed and predicted of precipitation (Table 3), minimum temperature (Table 4) and maximum temperature (Table 5). In this test, the decision-making is based on the amount of P-value at 0.05 significance level.

Fig. 8 shows the comparison of observed and predicted precipitation in different periods. It is notable that the level of monthly precipitation will be different in every month for each station during 2011-2030 (Fig. 8a). It shows a decreasing trend in all stations except Sardasht during February. However, an increasing trend is exhibited in all stations except Marivan during November. The comparison between observed and predicted precipitation shows a slight change in the summer months. The monthly precipitation during 2045-2065 indicates a decreasing trend in April for all stations (Fig. 8b). The maximum increase of precipitation is observed during December in Marivan station (45mm); however, a decreasing trend is predicted in Marivan station during November (25mm). Fig. 8(c) indicates the comparison between observed and prediction of precipitation during 2080-2099. There is a remarkable decrease in intensity of precipitation during this period. The decrease obviously happens especially during March and April. The spatial distribution of annual precipitation in the present and future periods is illustrated in Fig. 9. There is a notable spatial difference of changes in the precipitation intensity during future periods compared to the present periods.

The results of the minimum and maximum temperatures prediction by using LARS-WG are shown in Figs. 10 and 11. The minimum temperature during 2011-2099 would increase in all stations except Sardasht station which shows the decrease of Tmin during January for the period of 2011-2030 (-0.04°C). However, the maximum temperature would increase in all stations about 0.78°C, 1.6°C, and 3.7°C by 2030, 2065 and 2099, respectively. The maximum rate of changes in maximum temperature would happen during November for the period of 2011-2030 and during summer season for the period of 2045-2099. Figs. 12 and 13 illustrate the spatial distribution of minimum and maximum temperatures for different periods, respectively. The minimum temperature would increase by 3.5°C in 2099 compared to the observed period. The increase (decrease) in minimum and maximum temperature variation influences the increasing (decreasing) of potential evapotranspiration. Thus, the investigation of these variations is the most important factor in estimating the crop water requirements in the current study area.

3.3 Impact of climate change on forest species

Before analyzing the impact of climate parameters on the forest species under future scenario, the required conditions for forest specie must be considered during 1986-2010. Previous studies show the impact of climate conditions on different Oak species, e.g Iranian Oak, Quercus Libani and Quercus Infectoria (Azizi *et al*., 2013). Their results display a statistically positive significant between mean monthly precipitation and standard chronology in February, March, April and May during 1951–2010. However, the negative significant is observed in relation between maximum and mean monthly temperatures and standard chronology during the period of the study. The investigation illustrated that the maximum height growth for Oak species happened under 50% and 74% light intensities (Ghelichkhani *et al*., 2006). The Oak species in Zagros region are adjusted to arid and semi-arid climate condition (Parvaneh and Valipour, 2012). Fig. 14 illustrates the spatial distribution of Zagros forest according to climate conditions by using IDW method. Northern Zagros shows a good climate situation with enough level of precipitation for forest growth, but there is not forest cover in this region. The overlay analysis of land-use, topography and vegetation maps describe a farming area, living field area and elevation above 2000 m that separate forest part from non-forest part in the study area.

The annual precipitation average during 2011-2030 shows an increasing of precipitation compared to the observed data in north of the study area. The generation of climate scenario depicts that minimum and maximum temperatures will increase by 0.5˚C and 0.9˚C, respectively. Temperature and humidity are playing important roles in the distribution of different forest species in the study area. Quercus libani species is a sensitive type and it is necessary to be in a cold climate in comparison with other types. This is the reason that we can find more of this type in the highest heights of the forest area of the northern Zagros. The investigation of forest species showed that Quercus Infectoria species is more thermal compared to Quercus libani, while Iranian Oak is more resistant in comparison with two other species and will grow in all the areas. According to the climate prediction, it can be estimated that Quercus libani species will be reduced and limited in future. In contrast, Quercus infectoria will increase. Finally, the changes of climate variability will not influence Iranian Oak.

4 Conclusions

Weather generators have been broadly utilized for generating long-term period data of climate for evaluation of climate variability in various districts of the nation (Iran). LARS-WG model was used to evaluate climate change condition in northern Zagros forest based on historical data of precipitation and temperature for a long time (1986–2010). This model was assessed for its validity in Piranshahr, Sardasht, Saqqez and Marivan stations in Kurdestan province. The analysis of output data from the model showed that the prediction of monthly mean precipitation and its standard deviation was in concurrence with the historical data as proved by the *t* and *F* tests at 5% probability. The similar results were observed for minimum and maximum temperatures in the study area. The level changes of observed and predicted data were evaluated by the Friedman test. Based on the model predictions, the precipitation is expected to decrease in most stations in future, while the minimum and maximum temperatures are predicted to increase.

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Figure Captions:

Fig. 1. Location map of the study area

Fig. 2. Spatial distribution of average annual precipitation during 1986-2010 in northern Zagros forest

Fig. 3. Spatial distribution of average annual temperature during 1986-2010 in northern Zagros forest

Fig. 4. Topology of Zagros forest

Fig. 5. Comparison of observed and generated mean and coefficient of variation of monthly precipitation at study area.

Fig. 6. Comparison of observed and generated mean and coefficient of variation of monthly minimum temperature at study area.

Fig. 7. Comparison of observed and generated mean and coefficient of variation of monthly maximum temperature at study area.

Fig. 8. Comparison the changes of observed and predicted precipitation in different periods.

Fig. 9. Spatial distribution of annual precipitation in the observed and future periods.

Fig. 10. Comparison the changes of observed and predicted minimum temperature in different periods.

Fig. 11. Comparison the changes of observed and predicted maximum temperature in different periods.

Fig. 12. Spatial distribution of annual minimum temperature in the observed and future periods.

Fig. 13. Spatial distribution of annual maximum temperature in the observed and future periods.

Fig. 14. Spatial distribution of Zagros forest under climate changes by using IDW method.

Table Captions:

Table.1. The selected meteorological stations with information on location, elevation and relevant statistics

Table.2. K-S test for daily precipitation, minimum and maximum temperatures distributions.

Table.3. Comparison between observed and predicted precipitation during three different periods.

Table.4. Comparison between observed and predicted minimum temperature during three different periods.

Table.5. Comparison between observed and predicted maximum temperature during three different periods.

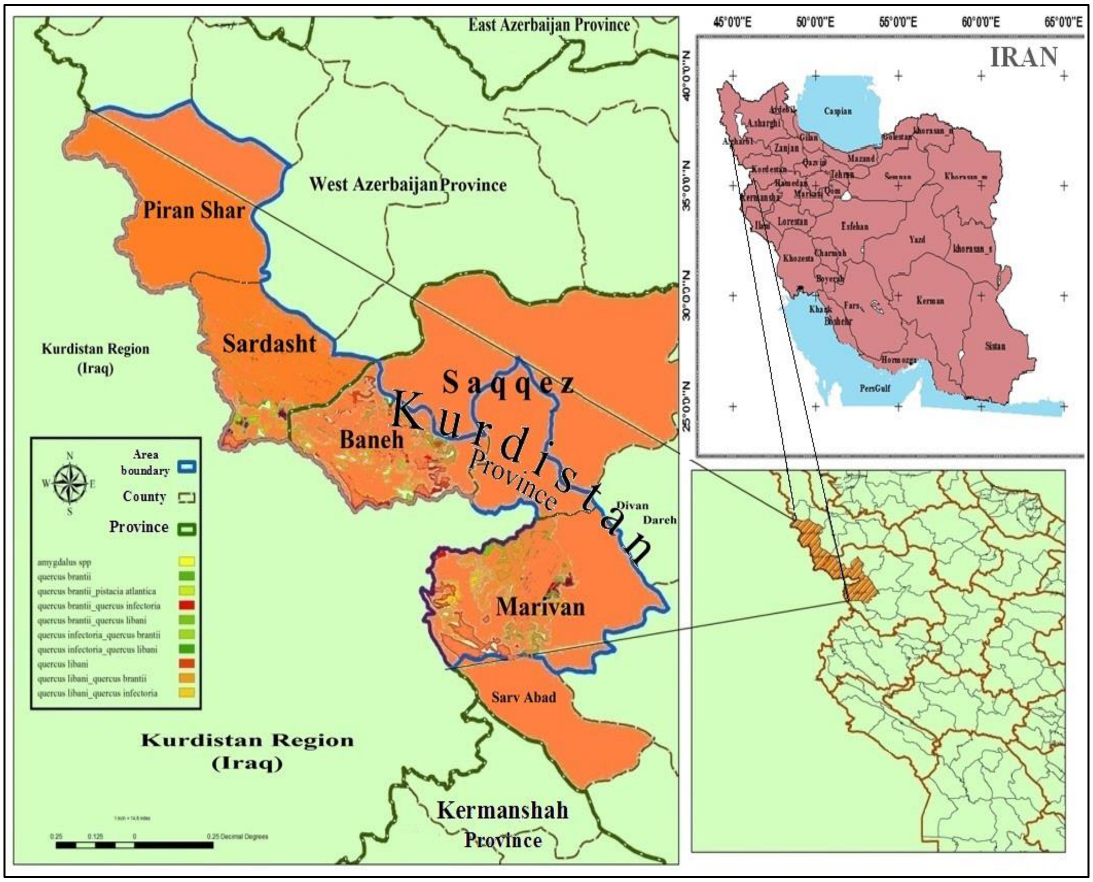

Figure 1. Location map of the study area

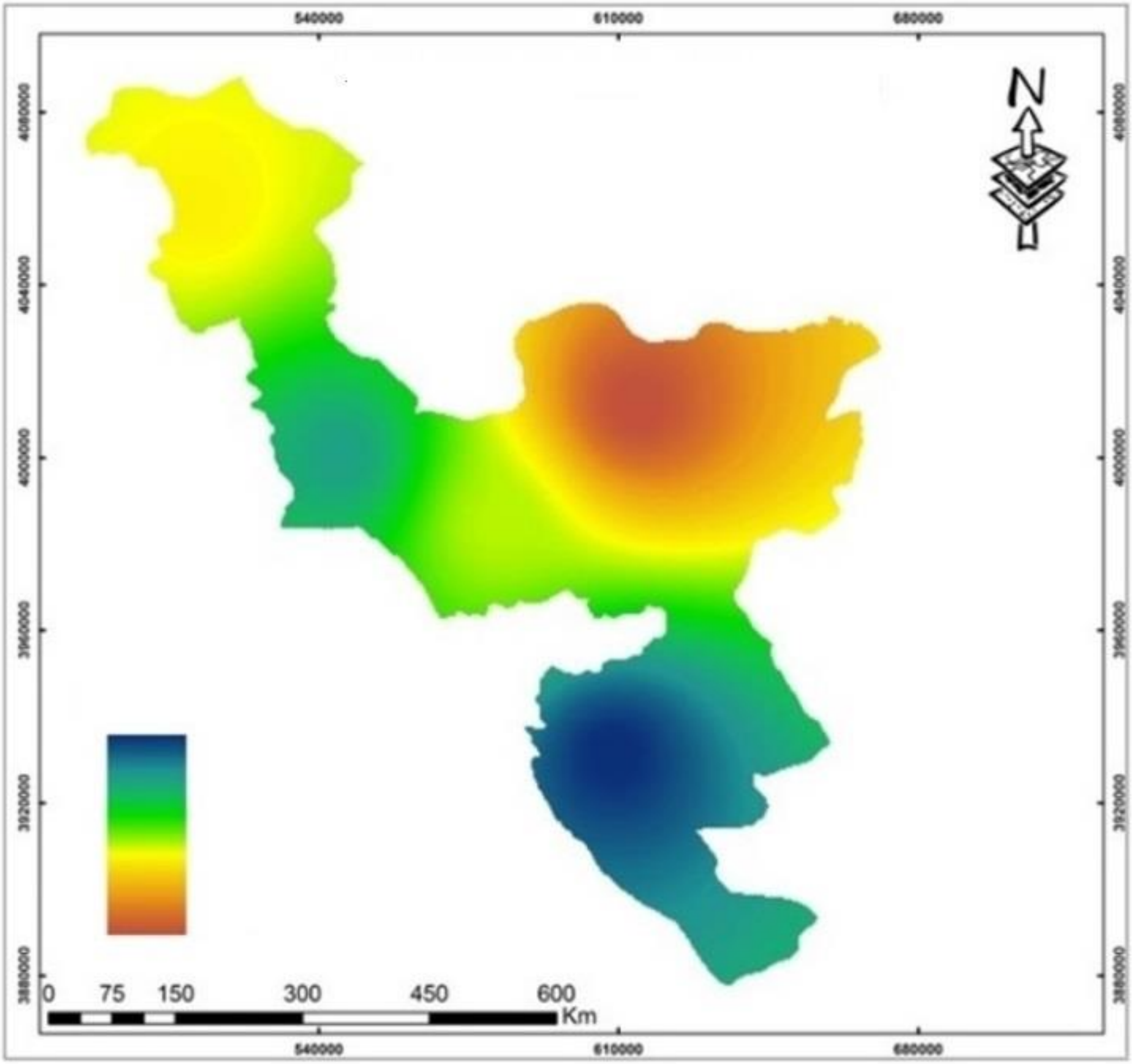

Figure 2. Spatial distribution of average annual precipitation during 1986-2010 in northern Zagros forest

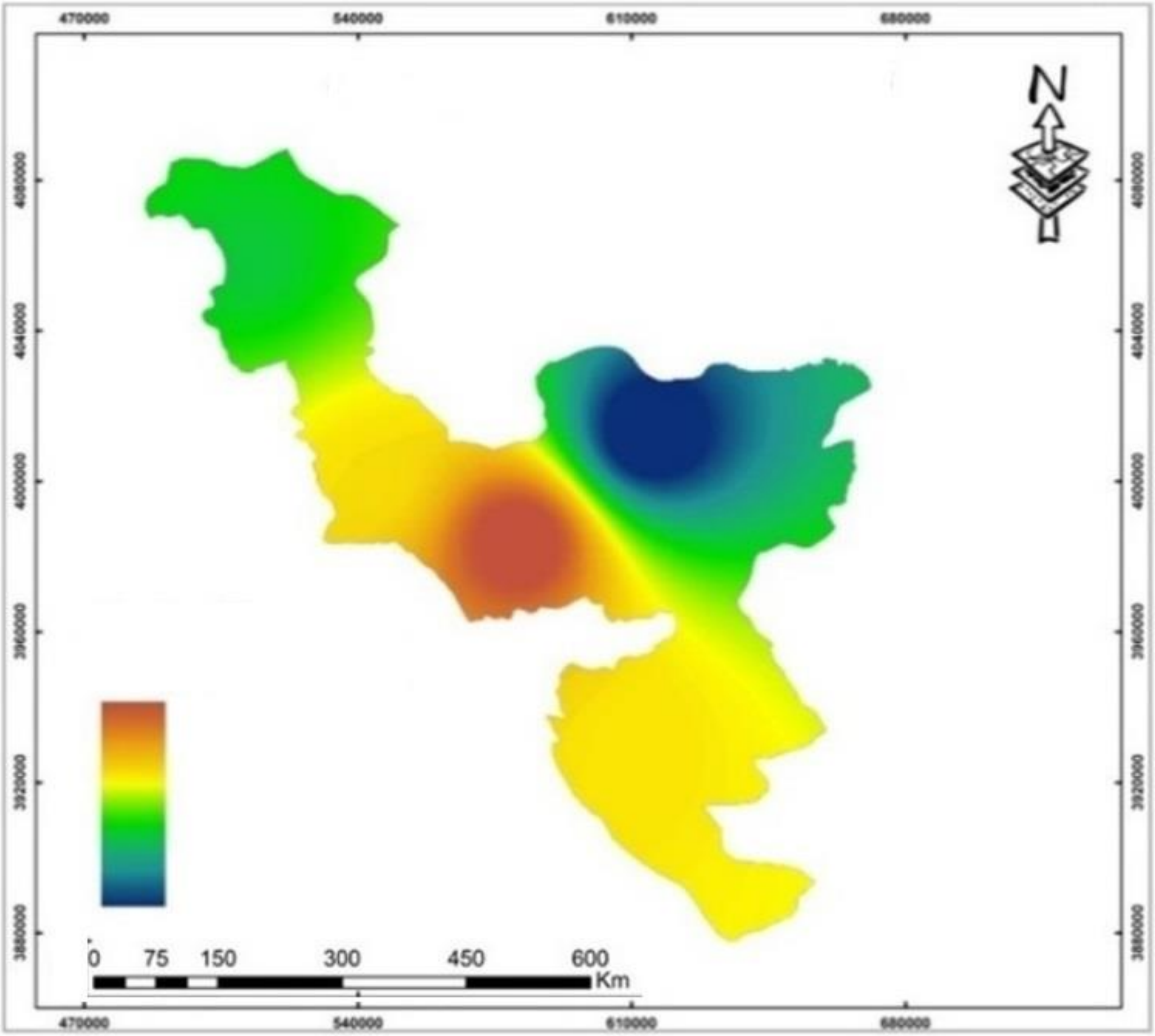

Figure 3. Spatial distribution of average annual temperature during 1986-2010 in northern Zagros forest

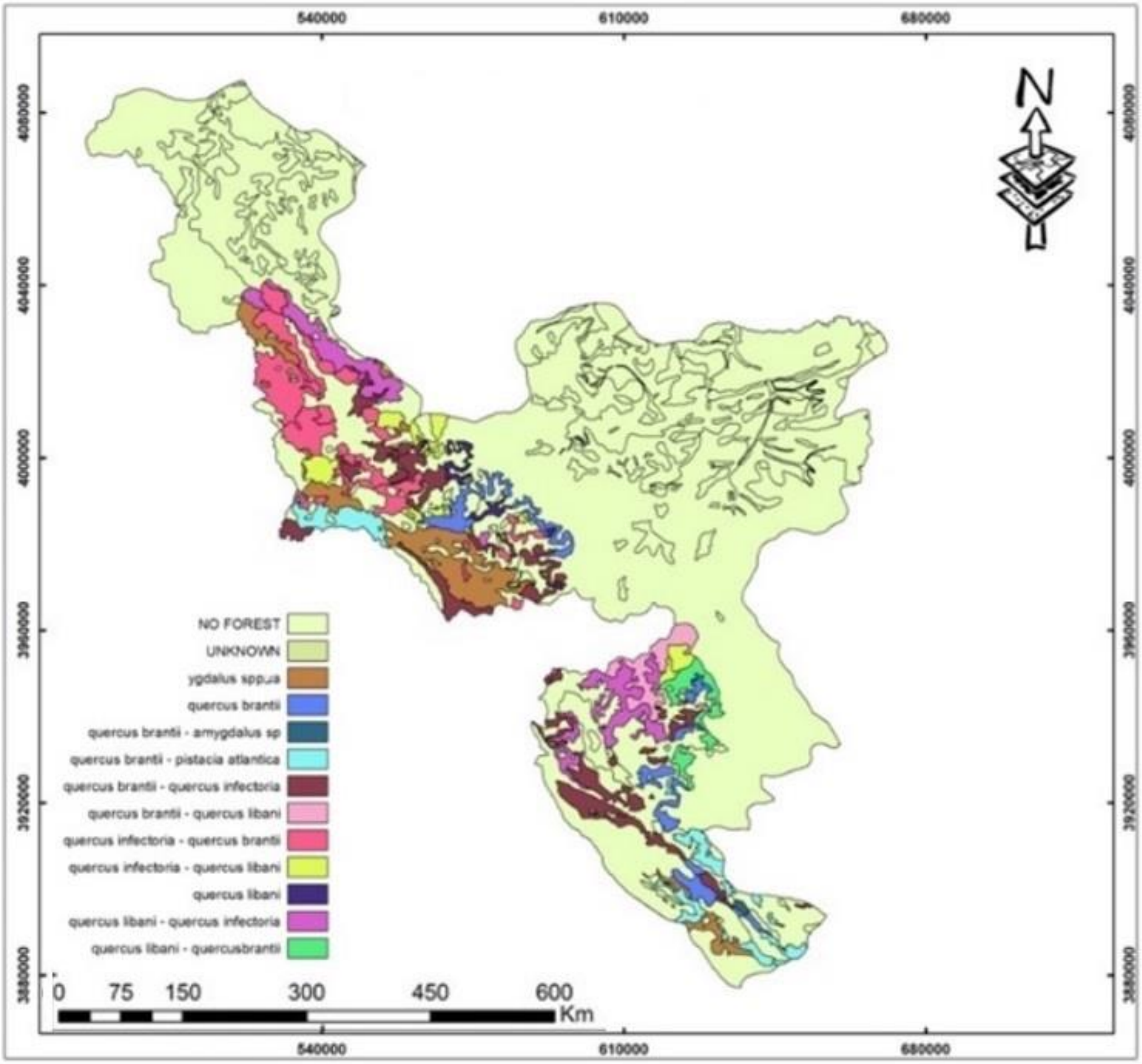

Fig. 4. Topology of Zagros forest

Figure 5. Comparison of observed and generated mean and coefficient of variation of monthly precipitation at study area.

Figure 6. Comparison of observed and generated mean and coefficient of variation of monthly minimum temperature at study area.

Figure 7. Comparison of observed and generated mean and coefficient of variation of monthly maximum temperature at study area.

Figure 8. Comparison the changes of observed and predicted precipitation in different periods.

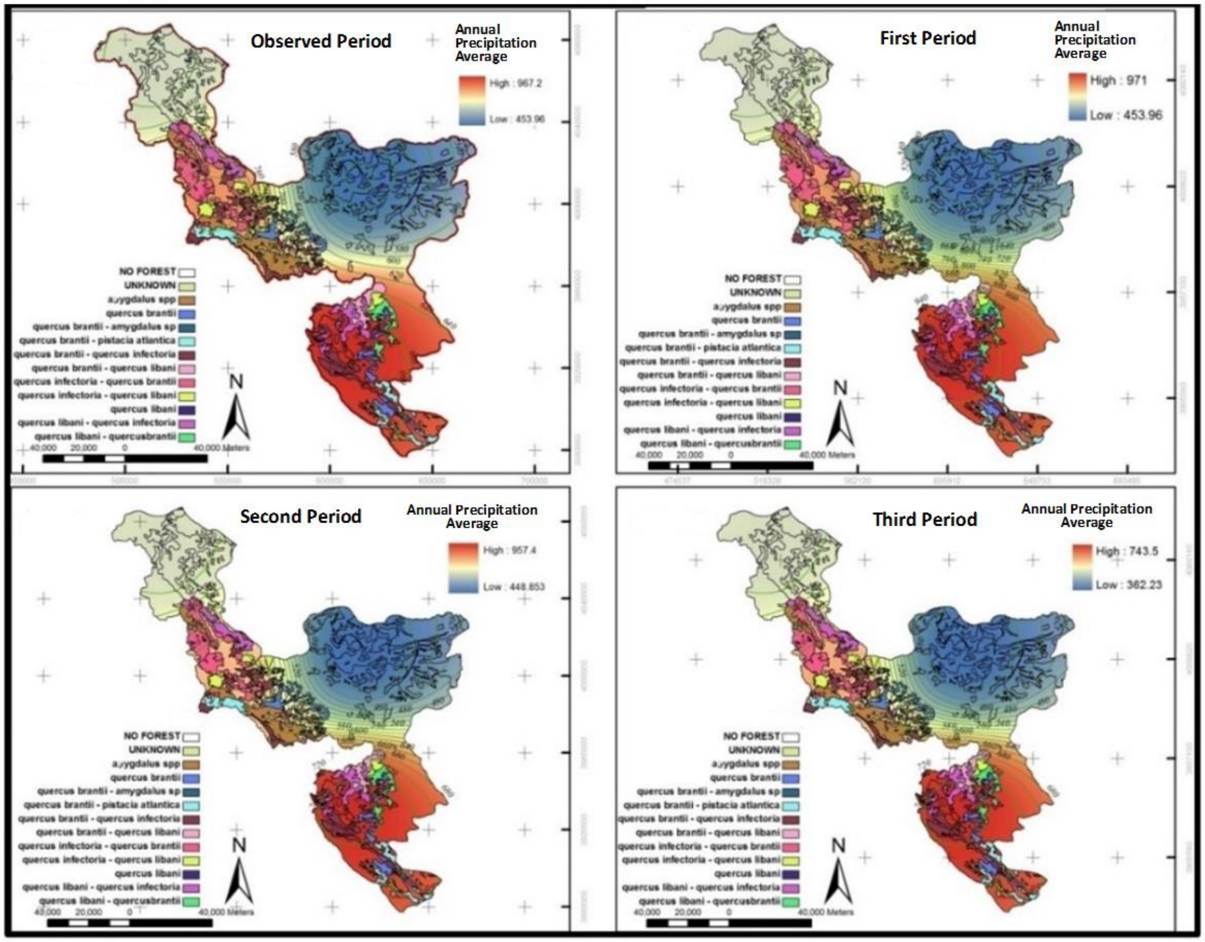

Figure 9. Spatial distribution of annual precipitation in the observed and future periods.

Figure 10. Comparison the changes of observed and predicted minimum temperature in different periods.

Figure 11. Comparison the changes of observed and predicted maximum temperature in different periods.

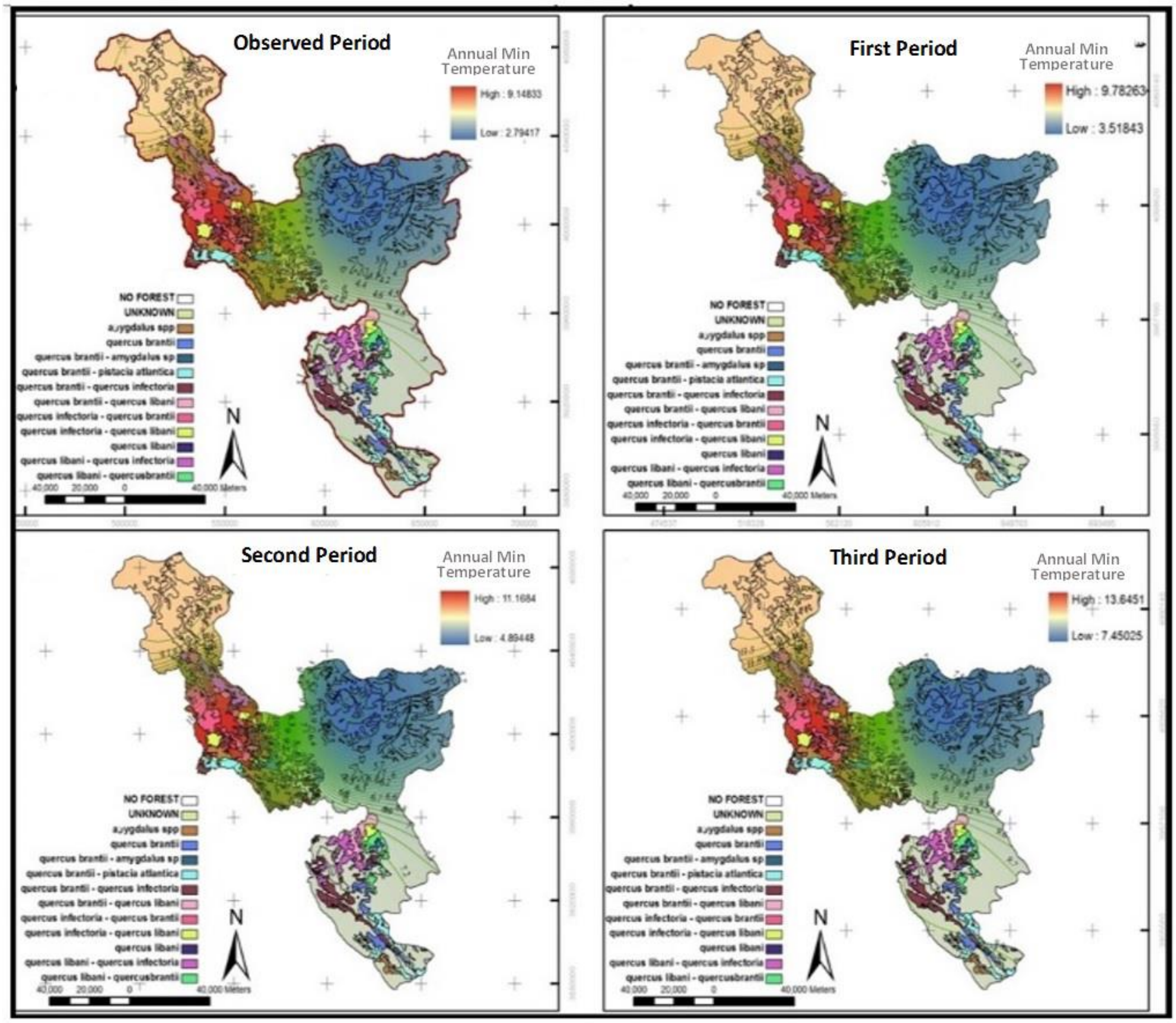

Figure 12. Spatial distribution of annual minimum temperature in the observed and future periods.

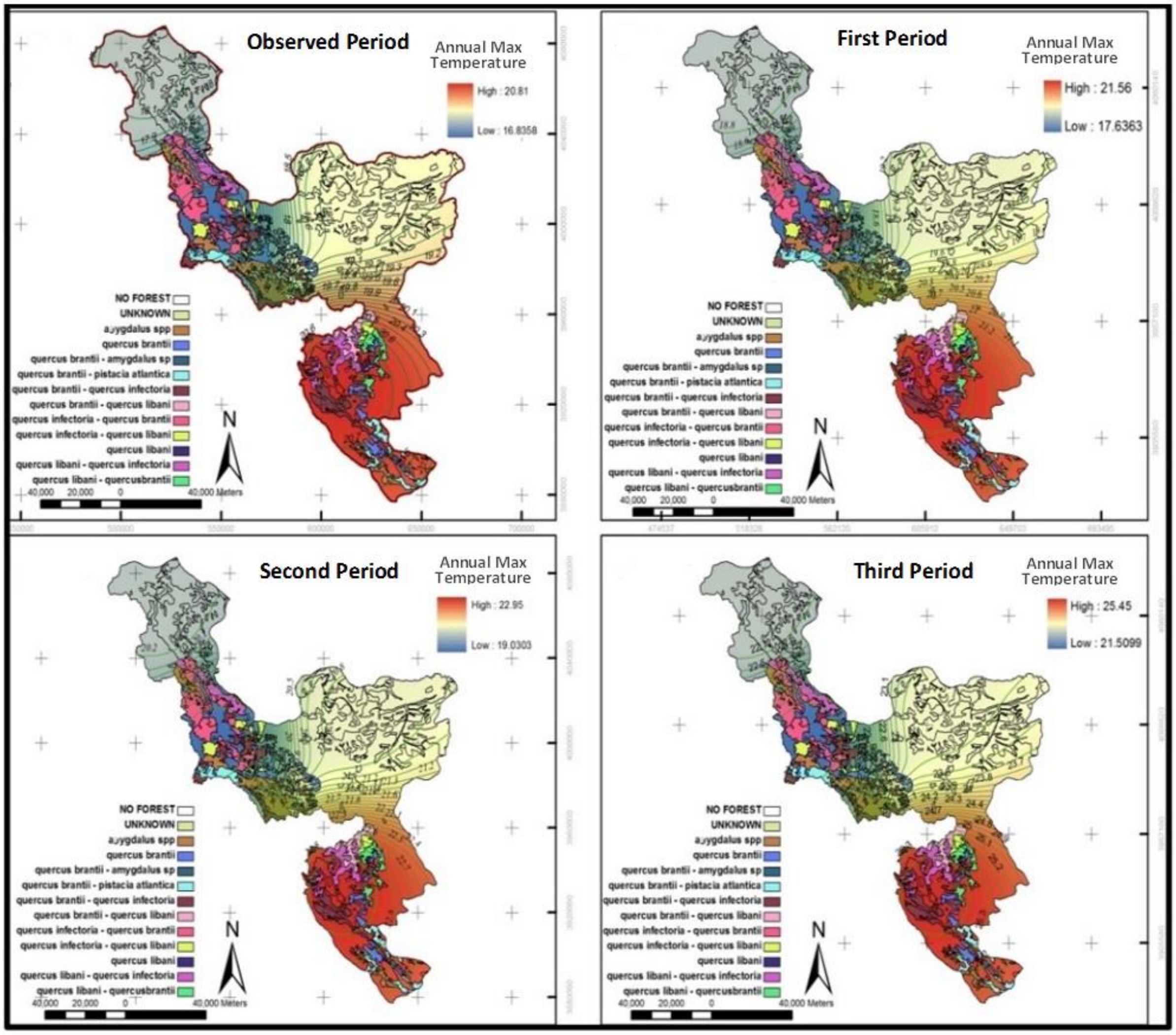

Figure 13. Spatial distribution of annual maximum temperature in the observed and future periods.

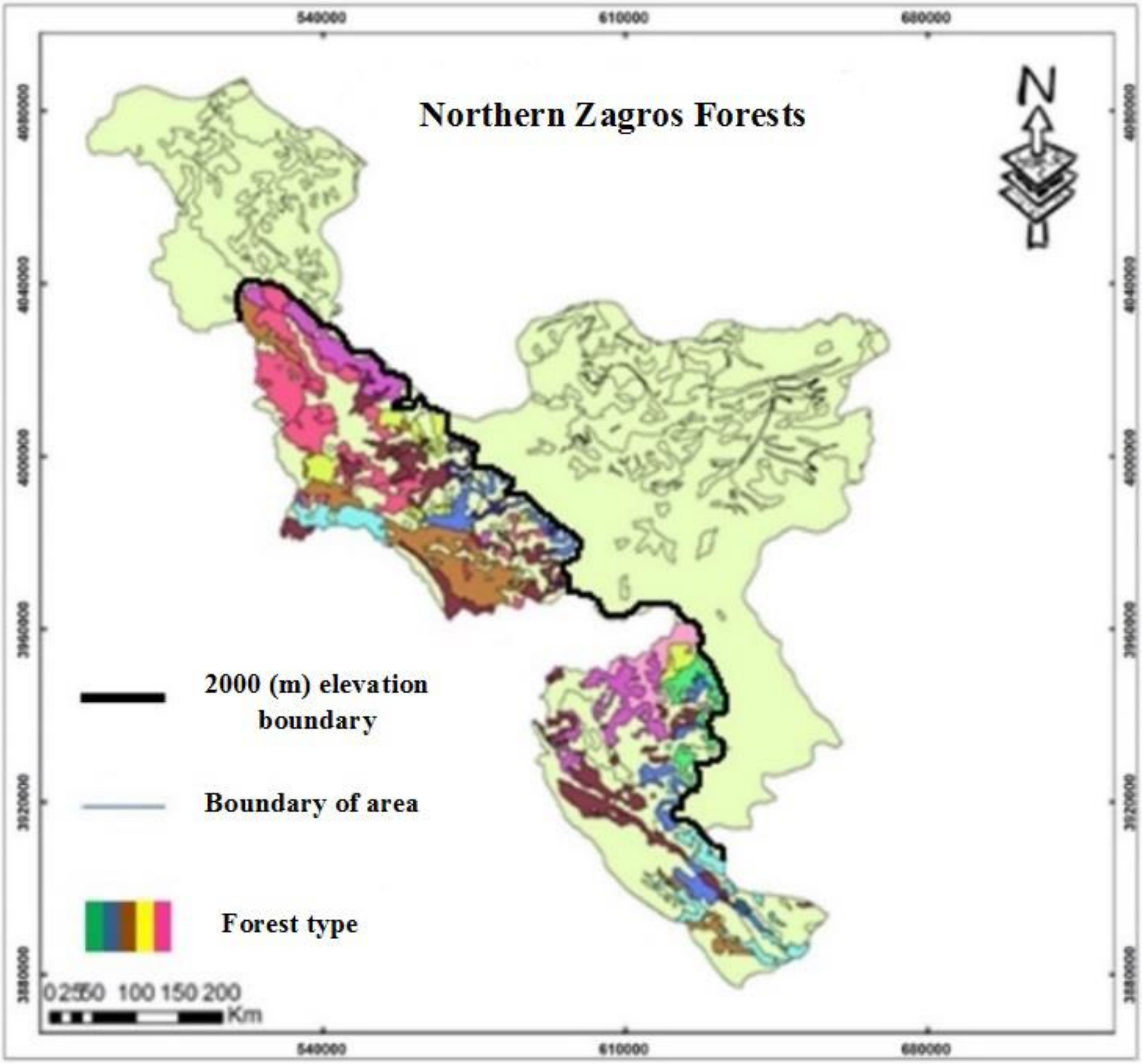

Figure 14. Spatial distribution of Zagros forest under climate changes by using IDW method.

Table.1. The selected meteorological stations with information on location, elevation and relevant statistics

Stations	Latitude (°N)	Longitude (°E)	Elevation (m)	Average annual precipitation (mm)	Average minimum temperature (°C)	Average maximum temperature (°C)
Marivan	35.31	46.12	1286	939.32	4.9	20.65
Saqqez	36.15	46.16	1525	426.3	3.8	18.9
Sardasht	36.09	46.29	1557	662.5	7.2	16.5
Piranshahr	36.42	45.09	1443	845.8	9.6	17.9

Table.2. K-S test for daily precipitation, minimum and maximum temperatures distributions.

	Marivan			Piranshahr			Saqqez			Sardasht		
	Rain	T_{max}	T_{min}	Rain	T_{max}	T_{min}	Rain	T_{max}	T_{min}	Rain	T_{max}	T_{min}
J	1	0.99	0.99	0.98	0.99	0.91	1	0.99	0.99	0.99	1	0.99
F	1	0.99	1	0.98	0.99	0.99	1	0.99	0.99	0.91	1	0.91
M	1	0.99	1	0.99	0.99	1	1	1	0.99	0.99	1	0.99
A	1	1	1	0.99	1	1	1	1	1	1	0.99	1
M	1	1	1	1	1	1	1	1	1	1	0.99	1
J	0.93	0.99	1	0.35	1	1	0.12	0.99	0.99	1	1	1
J	0.82	0.99	0.99	0.19	0.99	1	0.99	0.99	0.91	1	0.99	1
A	0	0.91	0.99	0.59	0.99	1	0.98	0.99	0.99	0.99	0.99	0.99
S	0.59	1	1	0.99	0.99	1	0.36	1	1	1	1	1
O	1	1	1	0.99	1	0.99	1	1	0.99	1	1	1
N	1	1	1	1	0.99	1	1	1	1	1	1	1
D	1	1	1	1	0.99	1	1	0.99	0.99	0.99	0.99	0.99

Table.3. Comparison between observed and predicted precipitation during three different periods.

	Marivan			Piranshahr			Saqqez			Sardasht		
	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099
J	-10.97	3.18	-31.87	7.22	8.52	-8.40	-6.59	-4.57	-3.49	3.23	-5.62	-22.20
F	-16.77	-12.88	-53.11	-6.72	12.61	-13.18	-9.38	-9.22	-6.63	14.6	-9.85	-30.53
M	0.73	-18.28	-58.75	-1.97	-4.98	-29.62	8.45	3.58	-16.01	-14.18	-4.11	-32.05
A	2.51	-12.89	-51.93	-5.03	-24.65	-47.43	4.29	-1.10	-19.20	21.23	-23.37	-57.20
M	5.6	-0.27	-18.93	-1.82	-8.54	-17.93	3.4	-0.91	-17.79	-6.07	2.31	-18.51
J	-0.29	1.82	-0.26	5.47	2.68	-1.42	-0.8	-0.41	-3.55	1.48	1.52	-1.36
J	0.05	-0.26	-0.58	0.17	-0.43	-0.65	-0.62	-1.17	-2.98	-0.01	-0.32	-0.92
A	-0.06	-0.38	-0.18	0.01	-0.57	-0.70	-0.4	-0.18	-0.75	1.62	0.14	-0.06
S	2.16	1.49	2.20	1.24	3.33	2.57	0.02	0.34	0.75	1.52	0.93	0.46
O	3.37	6.89	0.63	8.7	11.24	1.88	-6.37	-3.42	-10.68	-0.9	10.85	2.01
N	-7.01	-23.87	-17.86	9.10	17.26	-0.88	11.24	13.24	-1.44	17.21	5.70	-5.27
D	25.18	45.73	6.50	-6.4	-3.96	-10.54	-6.86	-5.38	-13.53	-9.42	-5.95	-18.42

Table.4. Comparison between observed and predicted minimum temperature during three different periods.

Marivan	Piranshahr	Saqqez	Sardasht

	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099
J	1.1	2.14	3.22	0.61	1.42	3.44	0.37	1.28	2.52	0.04	1.03	3.26
F	0.86	1.64	3.46	0.55	1.66	3.15	0.93	1.74	2.96	0.32	1.36	3.57
M	1.11	2.04	3.37	0.69	1.93	3.8	0.8	1.85	3.56	0.54	1.26	4.3
A	0.7	2.25	4.75	0.8	1.89	4.49	0.68	1.95	4.43	0.31	1.91	4.75
M	0.85	2.48	5.8	0.93	2.41	5.76	1.08	2.7	5.87	1.03	2.46	4.75
J	0.89	2.87	6.07	1.09	3.06	6.26	0.93	2.98	6.11	0.81	2.83	5.58
J	0.93	3.09	6.06	1.19	3.49	6.26	0.99	3.23	6.46	1.39	3.53	6.11
A	0.9	2.95	5.69	0.81	2.5	6.6	0.37	3.04	5.8	0.83	2.84	5.75
S	0.79	2.41	4.89	0.76	2.5	5.06	0.7	2.35	4.91	0.81	2.3	4.93
O	0.59	1.74	4.19	0.39	1.74	4.51	0.46	1.65	4.51	0.69	1.66	4.39
N	0.43	1.16	4.42	0.62	1.37	3.87	0.86	1.66	3.95	0.61	1.76	4.22
D	0.54	1.18	2.83	0.43	1.4	3.31	0.52	1.31	3.64	0.3	1.19	3.13

Table.5. Comparison between observed and predicted maximum temperature during three different periods.

	Marivan			Piranshahr			Saqqez			Sardasht		
	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099	2011-2030	2046-2065	2080-2099
J	0.73	1.62	3.22	0.63	1.61	3.44	0.14	1.02	2.52	0.68	1.63	3.26
F	0.83	1.58	3.46	0.32	1.21	3.15	0.2	1.01	2.96	1.07	1.7	3.57
M	0.98	1.87	4.37	0.39	1.43	3.8	0.25	1.27	3.56	1.05	2.07	4.3
A	0.46	2.05	4.75	0.54	1.69	4.49	0.23	1.58	4.43	0.2	2	4.75
M	0.74	2.31	5.8	0.87	2.53	5.76	0.77	2.39	5.85	0.93	2.28	5.58
J	0.71	2.61	6.07	0.66	2.89	6.26	0.71	2.73	6.11	0.8	2.71	6.12
J	0.82	3.05	6.06	1.13	3.58	6.6	1.16	3.46	6.46	1.01	3.07	6.11
A	0.9	2.99	5.69	0.66	2.83	5.54	0.87	2.99	5.81	0.82	2.97	5.75
S	0.74	2.48	4.89	0.92	2.53	5.06	0.57	2.24	4.91	0.84	2.43	4.93
O	0.65	1.88	4.19	0.92	2.22	4.51	0.73	1.9	4.51	1.19	2.13	4.39
N	1.27	2.39	4.42	0.36	1.63	3.87	0.96	1.87	3.95	0.83	2.06	4.22
D	0.1	0.87	2.83	0.52	1.45	3.31	0.69	1.53	3.53	0.18	1.29	3.13