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Simulation of Climate Change Impacts on South-Western Asia Heavy Precipitation (Case Study: Kurdistan Province, Iran)

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Abstract

This study aims at simulating the impacts of climate change on Kurdistan rainfall using 3-dimensional models of the general circulation of the atmosphere. Using data from six synoptic stations and employing Lars model, this study was carried out. The results of the calculation of bias and absolute errors on the modeled parameters for all stations represent that the model's power in coverage of the variance of the parameters under study was considerably acceptable. The best rainfall simulation is observed at Sanandaj station with absolute error of 1.83 and the weakest was 8.22 at Marivan station. The average heavy rainfall in Kurdistan province is increasing for the upcoming climate period ranging from 0.1 day in central parts and north-east Kurdistan to 0.7 day in other parts. The highest rate of increase among the means of heavy rainfall can be observed at the west corner and Marivan station.

Keywords: Climate Change, Heavy Rainfall, Kurdistan Province, Lars Model

1. Introduction

Rain is the most common atmospheric phenomenon resulting from complex interactions of climate system. Although many parts of Iran have arid and semi-arid conditions and lack in major water resources to supply heavy cloud rainfall, some other parts (both arid and wet areas) have heavy and showery rainfall. Considering the relative position of Iran, its huge area and the extent of unevenness, rainfall phenomenon has highly heavy temporal and spatial fluctuations (Masoudiyan, 1998, p.85). Sometimes the total amount of annual rainfall of some regions is less than that of a few-day rainfall of their own cluster. It seems that one cannot thoroughly justify or clarify the cause of Iran's sharp spatial and temporal fluctuations with one or more factors or cases. Climate change is gradually spreading to the whole world and affecting all parts of human life. In order to examine much more closely the dimensions of the problem, an institution called the International Panel on Climate Change (IPCC) was established by the World Meteorological Organization and United Nations Environmental Program with the goal of assessing the recognition and study of scientific, technical, socio-economic aspects and adventures and due to man-made climate change. In order to carry out climate change studies on various resources in the future, climate variables shall, at first, be simulated according to greenhouse gases. There are different ways to do so, the most valid of which is to use the data of General Circulation Model (GCM). Climate is a changeable phenomenon and its changeability has been an issue of interest for climatologists. Climate change affects all environmental phenomena and is of great importance now. Climate changes have recently attracted a good deal of attention due to economic, social outcomes and its due financial losses. In this section, world literature of climate change

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and more specifically Iran's have been reviewed so as to be a leeway for the present study and provide the possibility of comparing the results of other studies with this study's. In between 1900-1994, rainfall increased in high latitudes of north hemisphere, especially in the cold season[10]. But, it has decreased in tropical and subtropical regions ranging from Africa to Indonesia since the 1960s onwards. In general, global rainfall mean increased until 1960 and decreased afterwards until 1980. It shall be noted that these ups and downs have not been equal across the world. Although temperature has increased in many parts of the world, climate change does not necessarily indicate a change in both temperature and rainfall. For instance, a thorough study in Canada suggests that although temperature has increased in most stations, there is no strong evidence showing a rainfall change except for its increase in a few points such as Moncton[4]. The global mean for annual average of annual rainfall has got an increasing line trend about 24mm during a decade. Spatial patterns of rainfall trend and increasing rate correspond with the images obtained from implementation of general circulation models of atmosphere resulting from carbon dioxide rise[5].

Such studies have been carried out for various geographical regions. For instance, we can refer to West and North of Switzerland where winter rainfall has increased by 30% in between 1900-1901 or the U.S.A where it has increased up to 10% since 1910 comparing to prior years (Carl, 1998:231). These patterns have also been different in Latin and Central America. For example, one can point to the falling trend of rainfall and runoff in some parts as southern Chile and mountainous areas of Argentina. And in some parts of Mexico and Central America, there has been an increasing or decreasing trend depending on the situation and slope of its basin. Also, there has been a decreasing trend in the north and northwest of Nicaragua over 1995-1996 and a feeble trend for Colombia during 1955-1995[11]. There have generally been different trends of rainfall in Europe and there have been changes across its regions in both annual and seasonal scale[22]. For instance, spring rainfall has increased from Southwest to Northwest of European continent whereas there is a reverse state in Central Europe. According to a Polish study, in addition to the confirmation of considerable difference of rainfall patterns, there has been a rise in annual rainfall in urban and industrial regions in between 1931-1980. However, there has been a falling trend of rainfall throughout the country in the 1980s. There has been a significant positive trend in the rainfall rate up to 18% in the North and South Western Bangladesh and a significant negative rate to its South-East. Rainfall has increased since 1950 in India, Pakistan, Nepal, Srilanka and Myanmar (Burma) and in many cases has caused flooding. In general, based upon different studies, rainfall is not only lower than annual average but also more changeable within wet, arid and semi-arid areas of Asia. In some points across these regions, there is about 90% rainfall over less than 2 months. In fact, in some stations located in arid and semi-arid regions of northern Asia, rainfall has decreased during so many years ago and there has been a decreasing trend of rainfall in Russia in between 1951-1995 and this trend has been exacerbated during the warm period. In Kazakhstan, a falling trend has been observed for the annual rainfall in 1894-1997, whereas the seasonal rainfalls have seen a slight increase in spring, summer and fall. So, it is obvious that winter rainfall has had a decreasing trend in Kazakhstan. In Pakistan 7 out of 10 studied stations have had an increasing trend of rainfall in the monsoon season. Southeast monsoon highly affects temporal-spatial changes of rainfall in modest Asia. In China, the rainfall has constantly decreased since 1966 and has worsened since 1980. In Thailand, there are reports of falling rainfall as well. Since Asia is a vast continent and parts of which are hit by monsoon, it is supposed to have various patterns. Temperature rise often causes rainfall decrease in Asia whereas in the Northern hemisphere high temperature has meant rainfall increase. Therefore, Asian's rainfall pattern is different from that of Northern hemisphere[11]. Choe et al. have analyzed changes of extreme events, the average rainfall and temperature in the Asian pacific region during 1955-2007. Rainfall trend has been examined using data from 57 stations in Canada meadows during 1921-1995 and the results have indicated a significant increase (0.62mm)[1]. Analyzing the changes of long-term rainfall trend in Japan has shown that 100 to 200 mm rainfall has started to increase and rainfall less than 1 to 10 mm has seen a decreasing trend. Also, Japan's rainfall focus has increased in the current century[7]. Daily rainfall changes in China's Northern semi-arid regions have been analyzed using data from 30 stations in between 1956-2000. The results suggest that comparing to the 1950s, the number of rainy days has decreased by 8 days in the 1990s and the frequency of low rainfall days has decreased for high rainfall days[8]. Srilanka's annual rainfall has also been analyzed for the past 100 years using Kendall, Spearman tests and linear regression. The results have been an indicator of rainfall increasing trend (Jayavardan et al, 2005:7). The analysis of annual and seasonal trend in Norway has also shown rainfall increase[9]. Monthly and annual rainfall has been examined for central and southern Nijeria during a period of 72 years and the results suggest that rainfall has not been accidental in the region and taken a descending trend[2]. Rainfall changes in some regions of Russia, Europe and North America have been assessed using a 100 year series of annual average rainfall. The results show an increasing trend of rainfall by 6% in 30 to 70 degrees of North latitude (Sterling, 1999:297). Rainfall trend has been examined using data from 107 Portugal stations and with the help of non-parametric methods including Men-Kendall test. The results suggest a space pattern of systematic change of annual rainfall in Southern Portugal which is not systematically so much valid. The analysis results of second trend of rainfall show the rise of autumn rainfall, the fall of winter rainfall and the rise of early spring rainfall comparing to its late rainfall[13].

2. Methodology

In this study, for simulating the effects of climate change on Kurdistan heavy rainfall, input data was first collected and corrected. The model input includes four parameters of Min temperature, Max temperature, rain fall and sunshine hours as the daily representative of sunshine in stations during a period of over 20 years of daily statistics. Having accessed the data from the meteorological agency, each parameter was arranged on monthly basis to be entered into the model. Analyzing different climate variables in an area such as region, district, province, country, etc. is not possible without station or point analysis. Thus, in order to evaluate the climate change in Kurdistan, 6 stations with at least 20 years of statistical data by 2010 were chosen among the province's synoptic stations. Figure 1 illustrates the location of the stations under study.

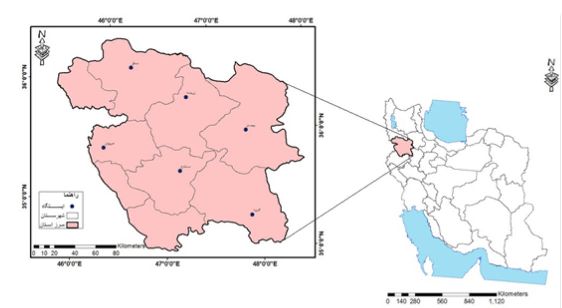

Figure 1. Location of Stations under Study in Kurdistan.

Table 1. Features of GCM models

Model	Separation Precision in Atmosphere	Separation Precision in Oceans	Simulated Scenarios
ECHO-G	T30, L19	T42	A1

(IPCC 4th Assessment Report, 2007)

In order to examine the climate change in the coming periods, climate change scenarios need to be developed. To do so, ECHO-G model output was employed. Table 1 shows some features of this model.

In doing so, the output of climate models under study including Min and Max temperature, rainfall and monthly sunny hours in the base period (1971-2008) and also in the subsequent period (2011-2039) were extracted under the emission scenario of A1 from the collective scenarios of SRES based on the fourth report IPCC (AR4, 2007) from the site (CCCSN2). Then these two periods' values are compared and the climate change scenario is calculated according to equations 1 and 2 for temperature, sunny hours and rainfall respectively. In A scenario, the world would be different from its current situation, in which the world' high population growth, high increase of greenhouse gases concentration CO_2, and less fluctuation of economic progress rate have been considered (IPCC, 1999).

$$\Delta E = E_{GCM}^{fut} - E_{GCM}^{base} \tag{1}$$

$$\Delta F = F_{GCM}^{fut} / F_{GCM}^{base} \tag{2}$$

In the above equations, E_{GCM}^{base} and F_{GCM}^{base} are indicators of monthly average of the quantities under study in the base period and in turn E_{GCM}^{fut} and F_{GCM}^{fut} are indicators of monthly average of the quantities under study in the subsequent period obtained from GCM models output. Two methods of comparison and statistics were used for the model validation. In statistical method, the model's strengths and weaknesses in simulation were assessed calculating the Bias and Absolute error. The model's total power was obtained through the calculation of Bias and Absolute errors of the observed and modeled data. Bias and absolute values are calculated using the following equations:

$$Bias = 1/\mathrm{n}\sum_{i-1}^{n}(s-o) \tag{3}$$

$$\mathrm{MAE} = 1/\mathrm{n}\sum_{i-1}^{n}(S-O) \tag{4}$$

Where S and O are the indicators of modeled and observed parameters including parameters of Max and Min temperature, rainfall, shining and n the number of months. Also, in comparative method the evaluation of the model was carried out through comparing the mean and standard deviation of the test period and modeled parameter. After validation of data model for 2011-2039 based on the basic scenario, daily-based data is finally produced for 2011-2039 climate period. Having generated data for the subsequent period, climate change effects on Kurdistan heavy rainfall are simulated. Since Markov chain is essential in rainfall simulations, it is first described briefly:

Suppose that a set of random variables x are arranged in such a way that j is a day timer: j = 1,2,3,…,366 and xj signifies a specific atmospheric phenomenon. P1(j) = p(xj = 1) is the climate probability of atmospheric occurrence in j^{th} day. pII(j) P pII(j) = P ($x_{j+1} = 1 \mid x_j = 1$)is the conditional probability of occurrence of the phenomenon under study in a given day of j+1, that is, the phenomenon has occurred in j+1 day. P0(j) + p1(j) = 1 and p00(j) + p01(j) = 1, where p01(j) and p11(j) are called transition probability. (Xj)j is called Markov provided that the occurrence of a given phenomenon in J+1 follows the following equation for all j^{th} days:

$$p = \left(x_{j+1} = 1 \middle| x_i = x_i, i\langle = j\right) = p\left(x_{j+1} = 1 \middle| x_j = x_i\right) \quad (5)$$

When there is no transition probability to dependent j, then time is homogenous according to Markov chain. M^{th} rank of Markov chain (where m = 1,2,….) is defined as following:

$$p = \left(x_{j+1} = 1 \middle| x_i = x_i, i\langle = j\right) = p\left(x_{j+1} = 1 \middle| x_j = x_i, j - m\langle i\langle = j\right) \quad (6)$$

For most of the WG rainfall, separate methods are used to ascertain rainfall occurrence and its intensity. The first rank and Markov chain for rainfall occurrence is defined with two conditional transition probabilities.

P01 = Pr (j^{th} rainfall/if there is no rainfall in j−1)

P11 = Pr (j^{th} rainfall/if there is rainfall in j−1)

Daily rainfall amounts are highly rightward. The simplest and most justified distribution model is a view that requires one μ parameter and its probability density function is defined as following:

$$F(x) = \frac{1}{\mu}\exp\left[\frac{-x}{\mu}\right] \quad (7)$$

The distribution (γ) of two parameters defined by β comparative parameter is defined as following:

$$f(x) = \frac{(x/\beta)^{a-1}\exp\left[-x/\beta\right]}{\beta\,\Gamma(a)} \quad (8)$$

Most WGs assume the amounts of rainfall in consecutive wet days are independent.

Other atmospheric variables such as Max and Min temperature and sunshine generally relate to shining (a representative of other trends like cloud cover). In the classic model of WGEN the variables have been self-correlation modeled.

$$Z(T) = [A]Z(T-1) + [B]\varepsilon(T) \quad (9)$$

Z (T) determines normally value distribution for dry spells and Z(T−1) has also done the same for the former day. Besides, [A] and [B] are K *K matrixes of the parameters under study and ε(T) is white-noise forcing. Z (T) changes with atmospheric variables of rainfall as following:

$$T_k(t) = \begin{cases} \mu_{k,0} + \sigma_{k,0}(t)Z_k(t) & \text{Dry days} \\ \mu_{k,1} + \sigma_{k,1}(t)Z_k(t) & \text{Wet days} \end{cases}$$

Where each Tk refers to a dry variable, sk, o and mk, o are the mean and standard deviation of dry days and sk,1 and mk,1 are the mean and SD for wet days. The seasonal interdependency of the means and SDs are usually calculated through February series. In Richardson models, other atmospheric variables are modeled according to the precipitation. As noted earlier, WG inabilities of Richardson type go back to the length of dry and wet series such as events or a long period like draught or wet period which impact agriculture. For instance, if draught happens at a certain stage of crop growth, it may lead to the failure of the crops. Rasco modeled the WGs at first based on dry and wet series using semi-experimental distribution. In this type, all daily observations must be employed in the simulation process. So, it seems like quite fine[20]. The best-known WGs that ca be put into Rsco or serial are (ARS-WG). This model's theory and basis are variables in Rsco, et al. 1991 article[16]. This model employs semi-experimental distribution for the length of wet and dry days, daily rainfall and sunshine:

$$\text{EMP} = \{a_0, a_i, h_i; i = 0,1,2,\ldots,10\}$$

where EMP is a histogram with 10 outputs of different intensity rainfall.

$$a_{i-1}\left\langle a_i\left[a_{i-1},a_i\right)\right.$$

hi indicates the number of rainfall occurrence in i^{th} distance.

3. Discussion

3.1 Evaluation and Validation of the Model on the Stations under Study

This section aims at evaluating and validating LARS-WG model on Kurdistan stations. This model's capability directly impacts the calculation of this province climate change. Weather Generator was performed using daily statistics in 6 synoptic stations. This occurred by means of only four parameters required of the model: Max temperature, Min temperature, rainfall and shining

The model was implemented comparing old and new data.

The calculation results of BIAS and ABSOLUTE errors on the modeled parameters indicate that the model is strong enough to cover the variance of the parameters under study. According to statistical results saved in all files of the stations, the observed and modeled data are equally generalized and the mean and SD of either collections are statistically significant. This model's power in shining modeling and temperature components is better than rainfall parameter. Model validation based on the calculated errors suggested that the best rainfall simulation in rainfall parameter is observed in Sanandaj station with absolute error of 1.83 and the weakest one in Marivan station with absolute error of 8.22. In the following, there are comparative simulation diagrams for visual interpretation of each station.

Table 2. Bias and absolute error of meteorological parameters of stations under study

Parameter / Station	Precipitation	
	Bias Error	MAE
Bijar	1.04	3
Gorveh	0.38	2.75
Marivan	4.09	8.22
Saghez	3.09	3.65
Sanandaj	–0.43	1.83
ZarrinehObatu	–0.56	4.63

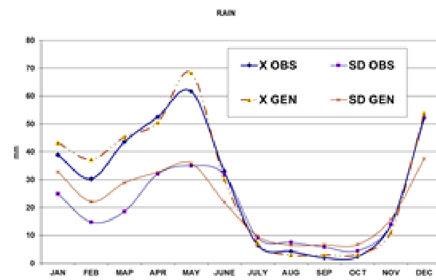

Figure 2. Bijar rainfall simulation diagram.

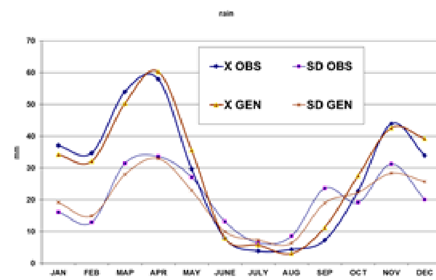

Figure 3. Gorveh rainfall simulation diagram.

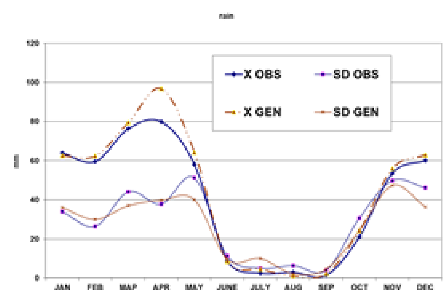

Figure 4. Marivan rainfall simulation diagram.

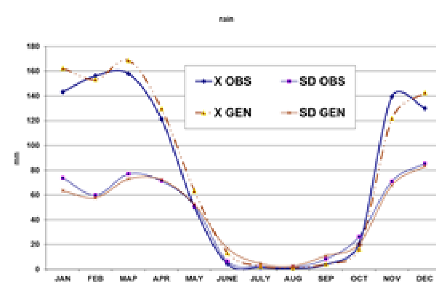

Figure 5. Saghez rainfall simulation diagram.

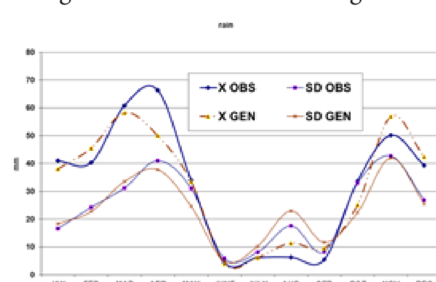

Figure 6. Sanandaj rainfall simulation diagram.

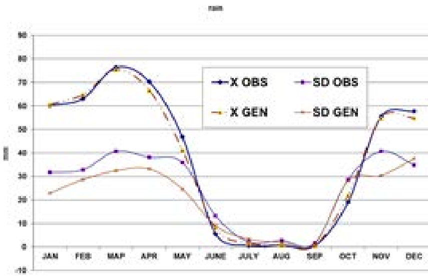

Figure 7. Zarrineh rainfall simulation diagram.

3.2 Spatial Description of Kurdistan Heavy Rainfall Changes

The map for changes of heavy rainfall mean in January shows that central parts of the province would face a decrease of 0.1 day in the mean of heavy rainfall. On the other hand, West strip and South-Eastern corner face an increase in the mean of heavy rainfall by 0.16 day. The maximum increase and decrease in the mean of heavy rainfall are seen in Marivan and Sanandaj stations respectively. Results of examining the heavy rainfall mean in February showed that the amount of heavy rainfall increases across the province. This rise ranges from 0.02 day in the Western and Eastern strip of the province to 0.2 day in the central part. In March and late winter, heavy rainfall mean sees a fall of 0. Day in Northeastern and other parts of the province face an increase of 0.1 day. The highest amount of rainfall in the heavy rainfall mean happens in the Southeastern of the province. In April, the Western part faces 10 days of decrease in the mean of heavy rainfall and the Eastern part along with the North Western corner see 0.1 day rise. The max rate of increase is seen in Bijar station. In May, it is only the Western corner of the province experiencing an increase in the mean of heavy rainfall up to 0.3 day. Other parts of the province do not see any tangible changes. In June, the Western and South Eastern corner will see an increase about 0.03 day whereas there are no tangible changes in the rest of the province. In July, it is only the Northern corner of the province which experiences heavy rainfall having an increase by 0.06 day in the subsequent period. The story of heavy rainfall mean and its changes in August is the same as in July. In September and late summer, there are heavy rainfall in Northern and Western corners and both will see an increase of 0.02 day in the mean of heavy rainfall. In early autumn and October, the Western part will see an increase by 0.12 day in the mean of heavy rainfall and the Eastern part will see a decrease by 0.02 day.

The Max precipitation in the heavy rainfall mean goes to Marivan statin. In November, the Northern half of the province has an increase of 0.2 day and the Southern half has a decrease of 0.12 day in the heavy rainfall mean. The highest amount of increase is seen in Zarrineh station. In December, heavy rainfalls mean increases throughout the province. The highest amount of increase in the mean of heavy rainfall is seen in Western strip and especially Marivan station with about 0.16 day.

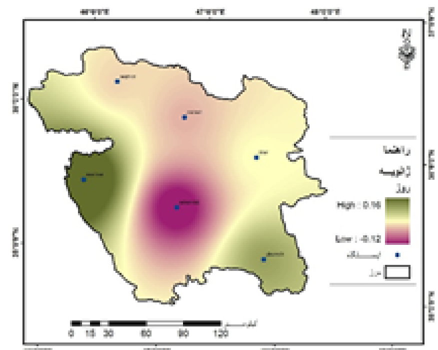

Figure 8. Zoning changes in January heavy precipitation.

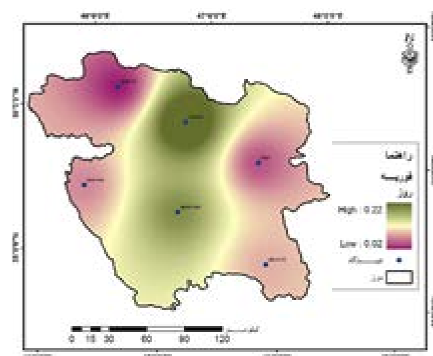

Figure 9. Zoning changes in February heavy precipitation.

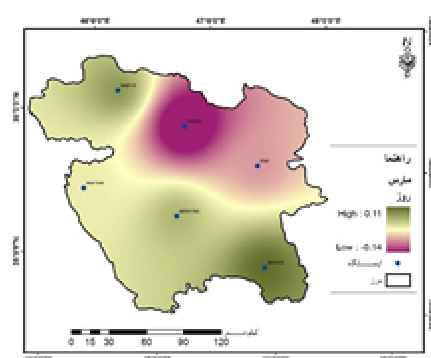

Figure 10. Zoning changes in March heavy precipitation.

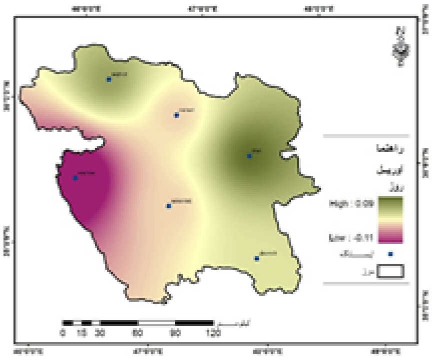

Figure 11. Zoning changes in April heavy precipitation.

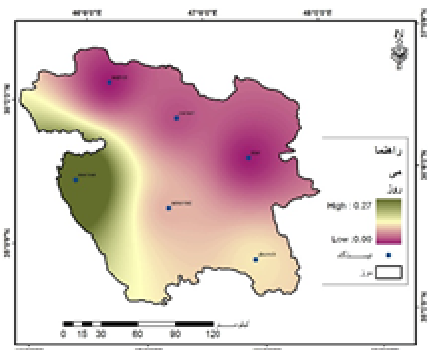

Figure 12. Zoning changes in May heavy precipitation.

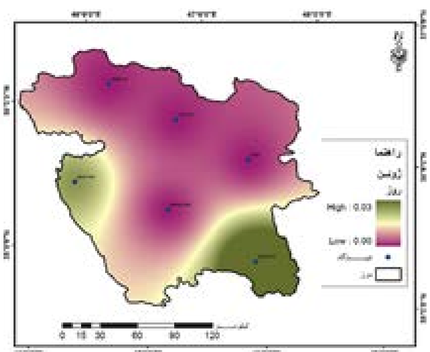

Figure 13. Zoning changes in June heavy precipitation.

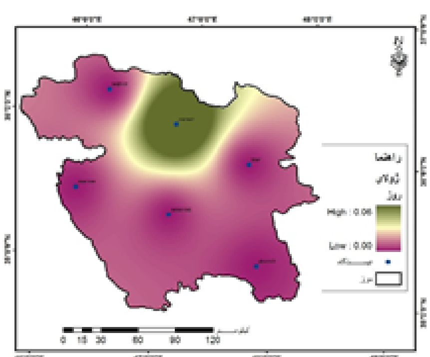

Figure 14. Zoning changes in July heavy precipitation.

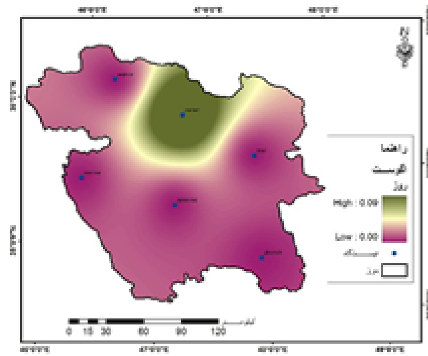

Figure 15. Zoning changes in August heavy precipitation.

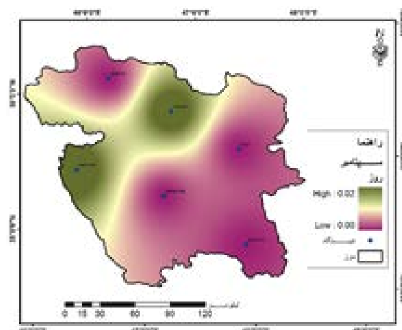

Figure 16. Zoning changes in September heavy precipitation.

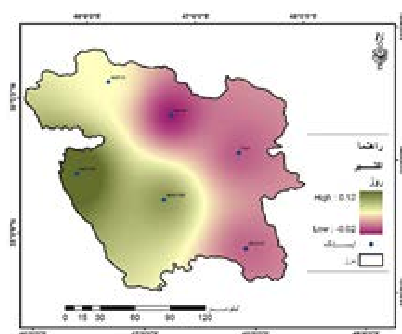

Figure 17. Zoning changes in October heavy precipitation.

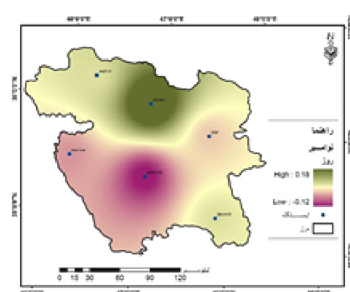

Figure 18. Zoning changes in November heavy precipitation.

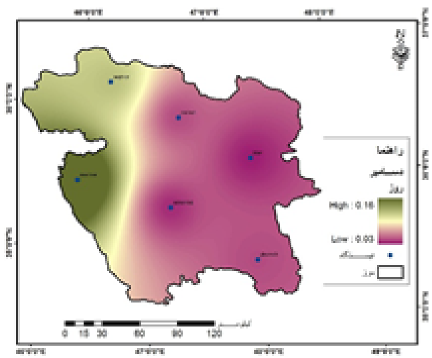

Figure 19. Zoning changes in December heavy precipitation.

In 2015, the state of heavy precipitations ranges from 0 day in the East to 11 days in the West of the province. In 2015, the only extension of heavy precipitations is seen in the Western strip. During this year, the extension of heavy precipitations is limited to the Western corner I which the annual frequency reaches up to 13 days whereas the Min cores are seen on the East, Center and South-East of the province. By 2035 the extension of heavy precipitations will have decreased and its Max lies in the West and North- West of the province for 3 days. The Min core is also on the South East of the province.

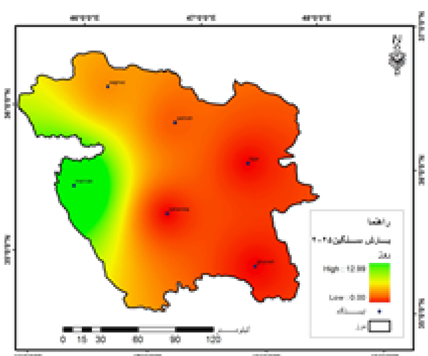

Figure 20. Zoning heavy precipitation in 2015.

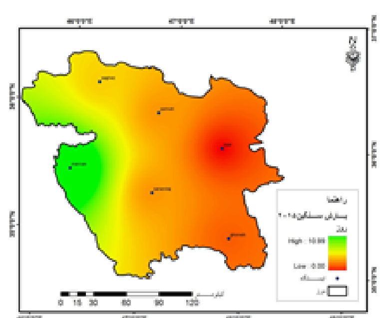

Figure 21. Zoning heavy precipitation in 2015.

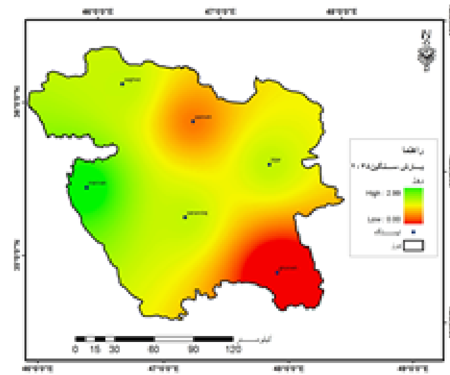

Figure 22. Zoning heavy precipitation in 2035.

4. Conclusion

Validation of the model based on the calculated errors showed that the best rainfall simulation belonged to Sanandaj station with the absolute error of 1.83 and the weakest one was of Marivan's with the absolute error of 8.22. The evaluation of rainfall changes indicated that the Western and Eastern part of the province would face an increase and decrease respectively in their mean of monthly precipitations. These changes range from 6mm decrease in Central parts to 52mm increase in the Western strip of the province. Marivan would have the highest increase in the average rainfall. And Sanandaj and Zarrineh stations would have the highest decrease in their scope. Evaluation of shining changes suggested that the Western half faces subtle changes or to a certain extent a decrease in the mean of sunny hours and it will have an increase in the mean of sunny hours up to 0.1 hr. the highest decrease and increase are respectively seen in the North-Western and North-Eastern corner of the province. The average heavy rainfall for Kurdistan province is increasing for the subsequent climate period ranging from 0.1 day in Central and North-East parts to about 0.7 in the other parts of the province. The highest rate of increase in the average heavy rainfall is seen in the Western corner and at Marivan station. The state of heavy precipitations in 2015 is the only extension of heavy rainfall in the Western strip of the province. In 2025, the range of heavy precipitations is limited to the Western corner, the frequency of which reaches to 13 days annually whereas the MIN cores are seen on the East, Center, and South-East of the province. By 2035, the extension of heavy precipitations would have decreased and its max lain in the West and North-West of the province for 3 days. Its Min core also would be on the South-East Kurdistan.

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