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Investigation on Climate Change in Meteorological Stations of Guilan Province and its Impacts on Water Balance

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Abstract

Climate has always been changing during the lifetime of the earth, and has appeared in the form of the ice age, hurricanes, severe and sudden temperature changes, precipitation and other climatic elements, and has dramatically influenced the environment, and in some cases has caused severe changes and even destructions. Some of the most important aspects of climate changes can be found in precipitation types of different regions in the world and especially Guilan, which is influenced by drastic land conversions and greenhouse gases. Also, agriculture division, industrial activities and unnecessary land conversions are thought to have a huge influence on climate change. Climate change is a result of an abnormality of meteorological parameters. Generally, the element of precipitation is somehow included in most theories about climate change. In the present study, climate change and precipitation abnormalities and their impacts on water balance in Guilan Province have been studied. The stations possessing climate change were determined and ranked. The GIS software was used to present the distribution and severity of climate changes in the province as a map. In the next step, the water balance of five stations was estimated using the Thornthwaite method. To do so, the mean data of thirty years, precipitation elements, temperature, and evaporation were used first, and the second time, the estimation was done using the data of the critical year (climate change in the drought trend). The charts related to the mean and critical years were compared. The highest and most severe climate change in drought trend was observed in Lahijan, and therefore this station was introduced as the sample of climate change. These results can be used in planning and identifying the effects of these changes on the environment.in the study station rankings have been determined based on the significance level in drought trend. The intensity of climate change in drought trend is observable in this ranking.

Keywords: Climate Change, GIS, Guilan, Water balance.

1- Introduction

In today's world, mankind, plants, and animals are most dependent on the climate. But unfortunately, dramatic global changes in climate have had their own consequences and compensating these changes is so difficult and in some cases even impossible. Some of the most important aspects of climate changes can be found in precipitation types of different regions in the world, which is influenced by drastic land conversions and greenhouse gases. Various studies have been conducted regarding this matter, all studying the quality of distribution and the effects of this phenomenon.

Climate change is a dynamic process in which its trend is determined using different tools and methods in different places in the world. It is an ongoing process which has significant impacts on the lives of humans and the environment. There are numerous theories and hypotheses regarding climate change, from its causing factors to its impacts. What we know for sure is that climate change is predominant on earth, but it may be weaker or stronger in various parts of the world which depends on the factors that have caused it. In the 21st century and especially recent decades, climate change has become more intense. Scientists blame industrial activities, agricultural development, urbanization, etc. for this phenomenon. They also believe that by increasing inappropriate human activities, the crisis resulting from climate change will be worsened in all parts of the world. Climate change has various impacts on nature and species. The consequences of climate change can be observed in variation in the amount of rainfall and wind direction, increase of natural disaster occurrences such as storms, whirlwinds and flood, increase of droughts, growth of desert areas, intensification of air pollution, increase of duration and intensity of precipitations, raising water levels in oceans and seas, decrease of snow supplies in mountains, and so on. On the other hand, the increase in consumption and demand for urban, suburban and regional waters lead to an intensification of the climate change phenomenon. Among some of the most important impacts of climate change on nature is its effect on plants generally through mutual action of temperature and carbon oxide raise. However, intense decrease and increase of climatic elements resulting from climate change have been studied in different regions along with its effects. For instance, the monthly average of climatic variables including temperature, radiation, and precipitation under the condition of double carbon dioxide in Tabriz has been predicted using GFDL and GISS General Circulation Methods. The results obtained from stimulating climatic conditions using general circulation methods have been applied in long-term metrology statistics, and then the effects of such conditions on growth, performance and water requirements of sugar beet and potato have been evaluated using OSBOL stimulation model. Various climatic factors such as temperature, wind, humidity, evaporation, perspiration, and precipitation also have a significant impact on the production performance of surface mines. Since the occurrence of these factors is random, it is difficult to control their undesirable outcomes. Most scientists believe the increasing amount of carbon dioxide in the atmosphere which is a result of the combustion of fossil fuels such as oil, gas, and coal, makes our planet so warm that is not explainable with natural changes. As Ronald says, the meteorology pattern analyzed in this study was the most complicated pattern studied to date in which some existing doubts from previous predictions that used simpler patterns have been addressed.

Stern(2007) has studied the effects of climate change on the economy, and his results indicated a severely destructive impact of climate change on the economy of societies. Anderson (2016) suggested in their study that the earth temperature will rise by about 0.74 degrees, which is a result of the greenhouse effect. Stern et al. (2007) suggest in their studies that the destruction of earth is a consequence of global temperature rise. he suggests that the earth crisis, which includes the melting of polar ices, destruction of ecosystems and human gathering spots, temperature raise stress, rising of sea waters, changes in water patterns and resources, etc. is solely a result of climate change.Gidden(2009) has studied the impact of climate change on politics. McMichael at al (2003) claims that climate change has been the biggest threat to the environment in the last half-century. Trenberth(1992)claims that manmade gas mixtures such as CFC (Chlorofluorocarbon), aerosols and sprays, are not the only factors which have an impact on the ozone layer, but the gases from volcano activities during climate changes have also had huge effects on the ozone layer. Lash and Urry (2009) have argued about some schools of thought such as imperialism, neoliberalism and capitalism, and the way of using fuels and carbon emissions, and the attitude and the thought towards consuming the resources. Urry (2007) argues that in today’s modern life and especially after the industrial revolution, and the development of tools in human’s daily life, electronic communications, photographic, marine and oceanic communications, sightseeing tours, railroads, telegram and sewage, all have impacts on climate change.

Schafer (2000) argues that dynamic tools such as machines must be laid away after 30 years of use because of their rustiness and their negative impact on the environment. Houses are also effective in warming the environment from 12 to 24 degrees Celsius.

In addition, the density of 300 micrometers of CO_2 is 0.08 per centigrade.

Khalili (2010) presented the precipitation in different areas of the country as a locational and time change. Nazem Sadat (2006) evaluated the Southern Oscillation Index (SOI) and the autumnal precipitation in Iran. By choosing proper calculation methods, it was found out that correlation coefficients between this index and the autumnal precipitation in Iran are generally negative. It was also found out that the correlation between SOI and autumnal precipitation in the stations of Khoy, Urmia, Tabriz, Zanjan, Saqqez, Sanandaj, Qazvin, Tehran, Arak and Semnan are in the significance level of 1%. Also, the autumnal precipitation in the cities located near the Caspian Sea, such as Bandar-e Anzali, Astara and Nowshahr is significantly affected by the ENSO (El Niño Southern Oscillation) phenomenon. Khanjani (2016) believes that various climatic factors such as temperature, wind, humidity, evaporation, perspiration, and precipitation have an impact on the production process of surface mines.

2- Materials and methods

Guilan province is located in the north of Iran in 37.2774°N and 49.5890°E. The area of the province equals 13810.5 km^2 and possesses the first rank of annual precipitation among other provinces based on the statistics of the Meteorological Organization of I.R. of Iran. Based on the statistics of the studied 30 years (1986-2015), the average annual precipitation has been 1070 millimeters. The average annual precipitation in the 30 years period equals 1393 mm in Astara, 1745 mm in Anzali, 1491 mm in Lahijan, 1369 mm in Rasht, and 1220 mm in Saravan stations. The seasonal precipitation percentage is 15% in spring, 22% in summer, 39% in autumn, and 24% in winter.

Since precipitation and the Mann-Kendall method are the basis of this work, respective formulas and data analyses are presented. Five of them were selected with full data and the data table for the Anzali station was presented in the following section.

where:

t = Kendall statistics

p = sum of the values larger than n_i which come after it.

In this equation, the following equation has been used to evaluate the significance of the statistics “t” and “to” critical statistics:

$$p = \sum_{i=1}^{n} n_i$$

t_g = the value of the standard variable Z compatible with the level of the test, which in the present study t_g =1.96 with a possibility of 95%.

The Mann-Kendall test has also been used to determine the variable type and variation time.

The fifth column (t_i) equals the values smaller than $n_i$row which are before it and in the next column $\sum t_i$ which is the sum of “t_i”s from the top to the respective row. The t'_i column includes the values smaller than n_i which are after it and the $\sum t'_i$ column is the sum of all the “t'_i”s from the bottom to the respective row. In order to calculate the next columns which are E, V, U, E', V', and U'.

$$E = \frac{n_i(n_i - 1)}{4}$$

$$V = \frac{n_i(n_i -)(2n_i + 5)}{72}$$

$$U = \frac{\sum t_i - E}{\sqrt{V}}$$

$$E' = \frac{(N - n_i + 1)(N - n_i)}{4}$$

$$V' = \frac{(N - n_i + 1)(N - n_i)(2(N - n_i + 1) + 5)}{72}$$

$$U' = \frac{-\sum t'_i - E'}{\sqrt{V'}}$$

Then the values of U and E' in each time series are presented using a diagram. The osculation of U and U' curves inside the area of critical values indicates the beginning of variations only when the collision of those two outside the area indicates the trend. Table1 shows a summary of the procedure. In the present study, the critical value in the level of 5% equals 1.96. After drawing graphical diagrams of U and U' which are presented in the shape of curves, the significance is only achieved when U and U' curves cross each other. If these values cross each other inside the critical area of ±1.96, then no trend exists; and if they cross each other outside the critical area, this indicates a trend in the time series.

Table 1. Method of Mann- Kendall

n_i	Year	Precipitation	Rank	t_i	$\sum t'_i$	t'_i	$\sum t'_i$	E	V	U	E'	V'	U'
1	1960			Ranks		Ranks	The sum						
2	1961			lower	The sum	lower	of t_i s to						
3	1962			than	of t_i s to	than	the						
.	.			n_i	the	n_i	respective						
.	.			which	respective	which	level						
44	2003			are	level	are	(from the						
45	2004			before		after	end of the						
46	2005			it		it	table)						

Water Balance

Five stations of Guilan province which were picked out based on precipitation index in clustering method, including Manjil, Shanderman, Lahijan, Rudkhan Castle, and Anzali. The soil capacity is about 200 millimeters and lowers in some regions. Keep in mind that Torenth White measured soil moisture capacity as 300 and drought as 200 millimeters in New Jersey which is a humid region, and this indicates a low water capacity in the studied soils (Guilan). It should also be pointed out that in the presented tables T = average monthly temperature, I = thermal coefficient, PE = balanced evaporation and transpiration, UP = unbalanced evaporation and transpiration, P-PE = remaining water from precipitation after evaporation, ΔSt = monthly variations, S = water surplus, RO = runoff, TC = temperature, ACC = highest water requirement, D = water shortage, P = total monthly precipitation, ST = water remaining in soil. Also, in every figure, the water balance regarding that station has been illustrated.

Precipitation time variations in Guilan province using the Mann-Kendall test

The annual Mann-Kendall test has been developed and studied for the weather stations of the province with respect to the data 30 years precipitation diagrams. Annual precipitation series have been studied using the Mann-Kendall test in order to determine the amount of precipitation time variations in the studied weather stations.

Anzali station

Time variations in Anzali station indicate one increasing oscillation outside the significance level and three decreasing oscillations. The first one occurred in 1991 when the annual precipitation was 1502 millimeters. The next ones were observed in 2005 and 2006. In 2005, the amount of oscillation was equal to 405 millimeters less precipitation compared to the 30 years average of 1773 mm and in 2006 this decrease was 300 mm. Figure1 shows climate change according to the data in Table2 at Anzali Station.

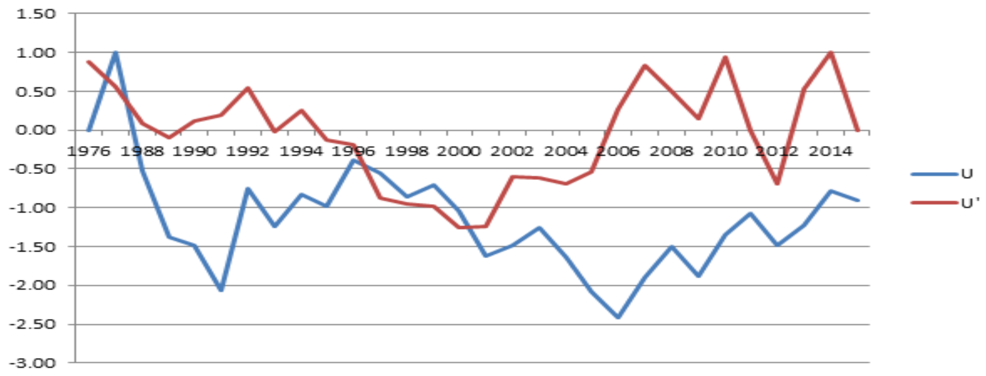

Fig. 1. Climate change diagram for Anzali station

Table2. Estimative statistics of climate change in Anzali station (Role model)

Year	Annual	Rank	t_i	Sum of t_i	t_i'	Sum of t_i'	E	V	U	E'	V'	U'
1986	1981.8	25	0	0	24	242	0	0	0.00	217.50	785.42	0.87
1987	2336.2	29	1	1	27	218	0.5	0.25	1.00	203.00	710.50	0.56
1988	1821.1	19	0	1	18	191	1.5	0.91	-0.53	189.00	640.50	0.08
1989	1566.8	9	0	1	8	173	3	2.1	-1.38	175.50	575.25	-0.10
1990	1705	13	1	2	11	165	5	4.1	-1.49	162.50	514.58	0.11
1991	1501.7	6	0	2	5	154	7.5	7.08	-2.07	150.00	458.33	0.19
1992	2662.1	30	6	8	23	149	10.5	11.08	-0.75	138.00	406.33	0.55
1993	1566.7	8	1	9	6	126	14	16.33	-1.24	126.50	358.42	-0.03
1994	1944	23	5	14	17	120	18	23	-0.83	115.50	314.42	0.25
1995	1787.4	16	3	17	11	103	22.5	31.25	-0.98	105.00	274.17	-0.12
1996	2098.4	28	8	25	19	92	27.5	41.25	-0.39	95.00	237.50	-0.19
1997	1760.4	14	4	29	9	73	33	53.17	-0.55	85.50	204.25	-0.87
1998	1701.9	12	3	32	8	64	39	67.17	-0.86	76.50	174.25	-0.95
1999	1817.8	18	7	39	10	56	45.5	83.42	-0.71	68.00	147.33	-0.99
2000	1593.3	10	3	42	6	46	52.5	102.08	-1.04	60.00	123.33	-1.26
2001	1237.8	1	0	42	0	40	60	123.33	-1.62	52.50	102.08	-1.24
2002	1785.2	15	8	50	6	40	68	147.33	-1.48	45.50	83.42	-0.60
2003	1805.4	17	10	60	6	34	76.5	174.25	-1.25	39.00	67.17	-0.62
2004	1560	7	2	62	4	28	85.5	204.25	-1.64	33.00	53.17	-0.68
2005	1367.6	2	1	63	0	24	95	237.5	-2.08	27.50	41.25	-0.55
2006	1473	5	2	65	2	24	105	274.17	-2.42	22.50	31.25	0.27
2007	1981.2	24	17	82	6	22	115.5	314.42	-1.89	18.00	23.00	0.83
2008	1921.6	22	16	98	5	16	126.5	358.42	-1.51	14.00	16.33	0.50
2009	1442.6	4	2	100	1	11	138	406.33	-1.88	10.50	11.08	0.15
2010	2009.8	27	21	121	5	10	150	458.33	-1.35	7.50	7.08	0.94
2011	1903.6	21	17	138	3	5	162.5	514.58	-1.08	5.00	4.10	0.00
2012	1424.8	3	2	140	0	2	175.5	575.25	-1.48	3.00	2.10	-0.69
2013	1847.6	20	18	158	1	2	189	640.5	-1.22	1.50	0.91	0.53
2014	1981.5	26	24	182	1	1	203	710.5	-0.79	0.50	0.25	1.00
2015	1605.1	11	10	192	0	0	217.5	785.42	-0.91	0.00	0.00	0.00

Rasht station

Studying the Mann-Kendall diagram for Rasht reveals two decreasing and three increasing trends which are not oscillations at a significant level. Precipitation trend in the 30 years statistical period indicates a direct line with zero regression coefficient. In other words, this station has experienced a more monotonous trend compared to the others. Figure2 shows climate change at Rasht station.

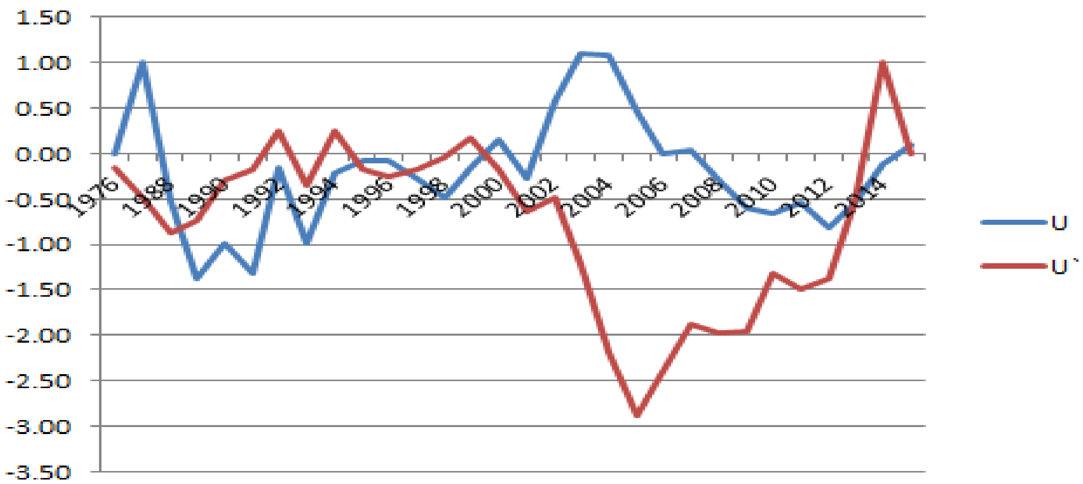

Fig. 2. Climate change diagram for Rasht station

Lahijan station

An increasing trend of precipitation can be observed in Lahijan during the 30 years period in the Mann-Kendall diagram (See Figure 3). The diagram for this station indicates a decreasing oscillation out of significance level and an increasing oscillation in a period of time which is slightly out of the significance level. This time period belongs to 2003-2004. Precipitation in 2003 was 745 mm more than the total average (1491). In 2004, precipitation was 95 mm more than the 30 years average.

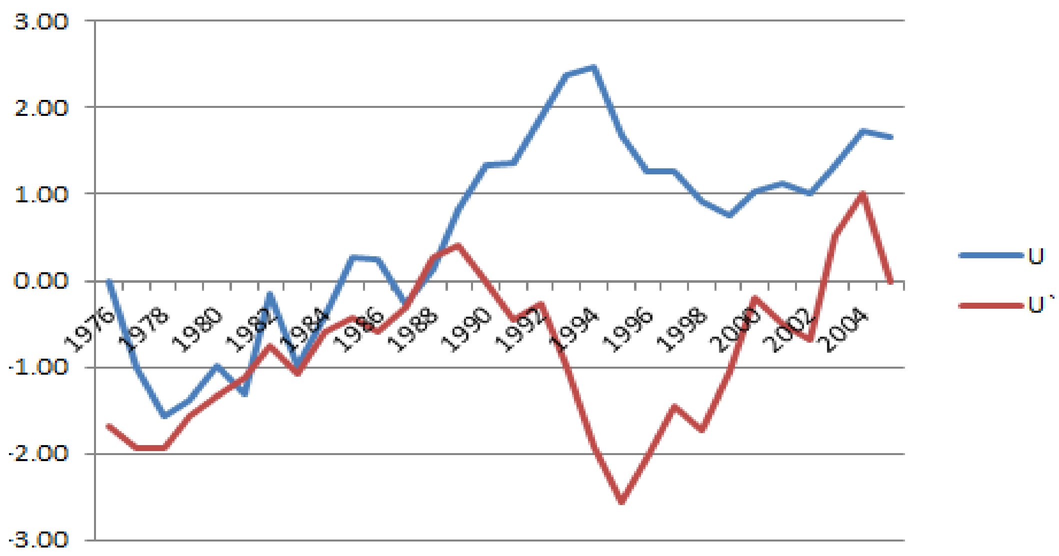

Fig. 3. Climate change diagram for Lahijan station

RudkhanCastle station

As shown in Figure4, Time variations in Rudkhan Castle station indicate two increasing and two decreasing oscillations out of the significance level. The increasing precipitation trend possesses a regression coefficient of 0.01. Decreasing and increasing oscillations are not significant.

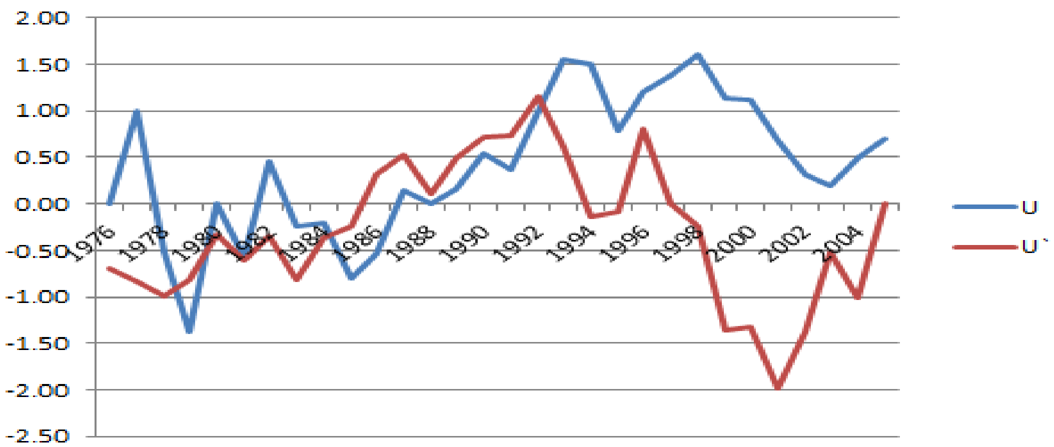

Fig. 4. Climate change diagram for Rudkhan Castle station

Manjil station

As you can see in Figure 5, This station has two increasing oscillations out of the significance level and two decreasing oscillations which were once out of the significance level in 2012 with precipitation equal to 230 mm, which indicates a 35 mm decrease compared to the 30 years precipitation average. The precipitation trend has been a decreasing one with a regression coefficient of 0.1 and is considered as the most intense decreasing trend among all other stations.

In the diagram, “C” indicates oscillation, “T” is for trend, “+” is an increasing trend, is a decreasing trend, “I” is a sudden increase and “D” indicates a sudden decrease.

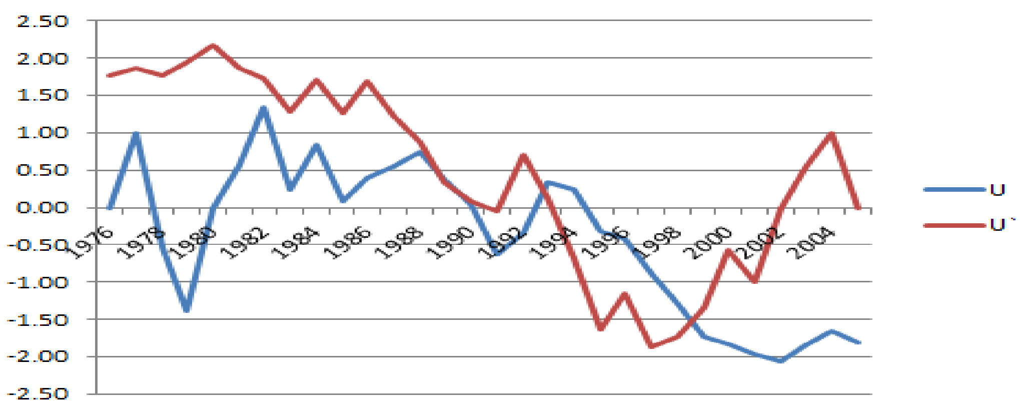

Fig. 5. Climate change diagram for Manjil station

Table3. Annual precipitation trend change times in the studied stations

Station	Annual
Anzali	1991 CD,2005-2006 CD
Rasht	Fluctuations are not significant.
Lahijan	2003-2004 CI
Rudkhan Castle	Fluctuations are not significant.
Manjil	2012CD

By studying the Mann-Kendall diagram of the studied stations in the 30 years statistical period it was found out that there has been precipitation decreasing trend in Anzali and Manjil stations from 1986 to 2015, and no increasing trend was observed in Lahijan, Rudkhan Castle and Rasht stations. Lahijan is among those experiencing a decreasing one. Table 3 indicates this.

Water Balance in Lahijan

The study of the water balance of Lahijan Station is as follows. It should be noted that in the prepared table of the station is a:

T = average monthly temperature
I = thermal coefficient
PE = Modified Evaporation and Overflow
UP = unmodified evaporation and overheating
P-PE = remaining water from precipitation after evaporation
ΔSt = changes from month to month
S = excess water
RO = Runoff
TC = temperature
ACC = Most water requirement
D = water shortage
P = total monthly precipitation
St = Residual water in the drain

According to Table 4, The highest temperature was 24.5˚C in August and the lowest was 6.39˚C in February. The highest temperature coefficient was 11.09 and the lowest was 1.45 millimeters in February. The highest UP was 3.8 in July and the lowest equals 0.4 in February. The highest P was 240.9 in September and the lowest was 92.7 in June. The highest PE is 142.5 in July and the lowest is 10.3 in February. The highest P-PE is 159.75 in October and the lowest is -40.2 in July. The highest ACC is -93.89 in August and the lowest was observed in April and May. The highest ΔSt is -33 in July and the lowest occurs in wet months until May. The highest AE is 135.3 in July and the lowest is 10.32 in February. The highest water shortage is 11.69 in June and the lowest is seen in wet months until May.

The highest amount of water surplus is 159.75 in October and its lowest occurs in August and equals zero. The highest water runoff is 113.86 in December and the lowest is 7.11 millimeters in August. AE, TC, I, UP and PE of this station are lower than the other two, but this station possesses a higher D and runoff compared to the others. Also, it has less water shortage than the other two stations. The remaining water in the soil is also high and water crisis occurs in July and August, and there is a good water balance from March until May.

Table 4: Lahijan Water balance

	October	November	December	January	February	March	April	May	June	July	August	September
TC	18.25	24.03	9.88	7.49	7.39	7.58	12.53	16.77	12.11	23.58	24.54	22.21
I	7.13	4.75	2.81	1.85	1.45	1.89	4	6.15	8.85	106.8	11.09	8.91
UP	2.5	1.6	0.9	0.6	0.4	0.6	1.4	2.1	3.1	3.8	4	3.3
PE	72.75	40.8	22.41	15.48	10.32	18.54	47.32	0	114.39	142.5	140.9	101.97
P	216.4	166.4	139.4	109.5	114.4	118.9	95	74.76	92.7	102.3	108.4	240.99
P-PE	232.5	125.6	116.99	94.02	104.08	100.46	47.63	113.6	-21.69	-40.2	-32	138.99
ACC								-38.84	-21.69	-61.89	-93.89	
st	200	200	200	200	200	200	200	200	180	147	125	200
st^	0	0	0	0	0	0	0	0	-20	-33	-22	+75
AE	72.75	40.8	22.41	15.48	10.32	18.54	47.32	74.76	102.7	135.3	130.4	101.97
D	0	0	0	0	0	0	0	0	11.69	7.2	10	0
S	159.75	125.6	116.99	94.02	104.08	100.36	47.63	38.84	0	0	0	63.99

RO	95.87	110.74	113.86	103.94	104.01	102.19	74.9	56.87	28.45	14.22	7.11	31.99

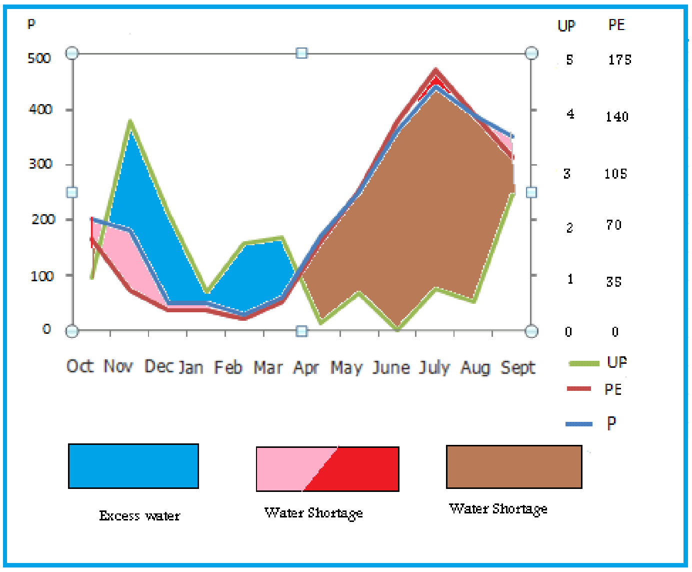

Fig. 6: Drought Water Balance diagram for Lahijan

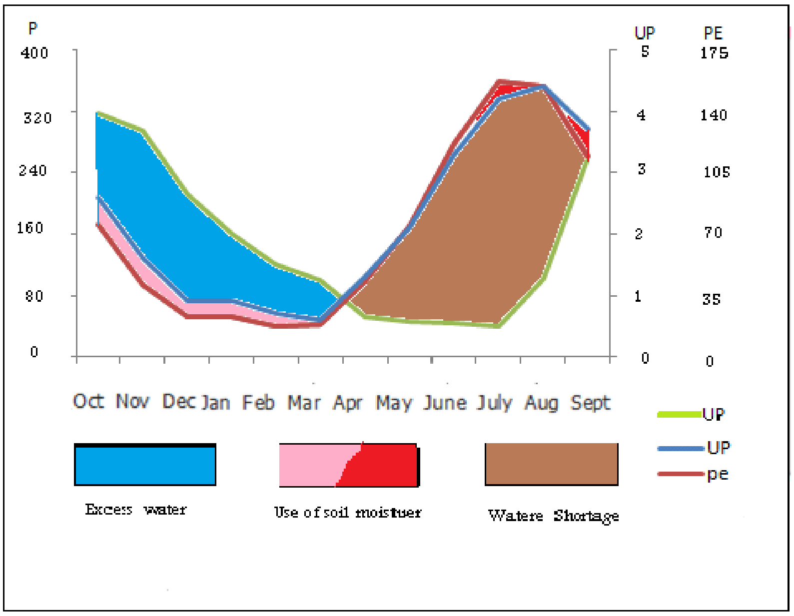

Fig. 7: Average Water Balance diagram

While studying the water balance in two stations of Lahijan, it was found out that in average water surplus starts from the end of September and beginning of October, and continues until almost the end of March; but under drought conditions, it starts from the middle of November and continues until the end of March. As much as water surplus is more than drought, water shortage in drought diagram is more than the average diagram. Considering these conditions, soil moisture consumption in dry conditions is more than average condition. Although soil moisture consumption is present in almost all seasons, low moisture consumption is marked with pink and high consumption is marked with red in the diagrams in order to distinguish the two(As shown in Figure 6).

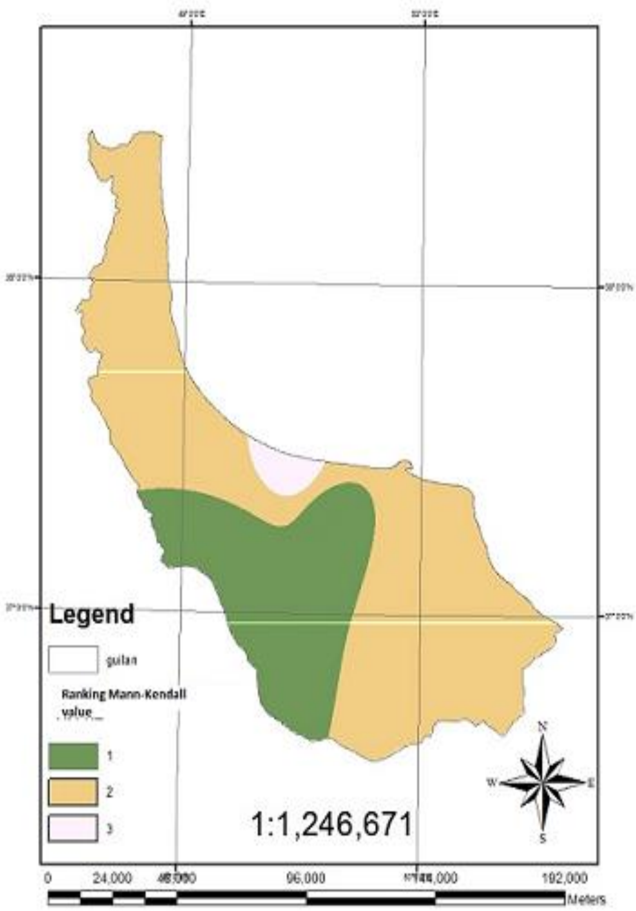

Fig.8. Map of climate change of the Guilan province

3- Conclusion

In the present study, five weather stations have been picked and studied out of 13 weather stations of Guilan. A number of tables have been developed based on the Mann-Kendall method. Also, a diagram has been obtained based on U and U' which indicates rises and falls from the balance line, and it may be beneath or above the significance line.

U and U' collide in this rise and fall. This collision might be severe or weak depending on the distance to the significance line. When the lines cross the significance line, especially after collisions, climate change occurs, and the farther it is from the significance line it becomes more intense. In diagrams for Anzali, Rasht, Lahijan, and Manjil, they have crossed the significance line. In the Anzali diagram, all the occurrences that have crossed the significance line are in a negative trend, or in other words, drought. It can be observed in the diagram of Rasht that this city has experienced two consecutive dry years by crossing the significance line twice. In Lahijan diagram, one line is above and the other is under the significance line. Manjil station which holds the fourth rank is inside the negative area below the significance line with a decreasing trend. And in Rudkhan Castle, almost there is no crossing of the line, or in other words no climate change. Although there are about five rises and falls in every station, but none of them is higher than the significance level. The base in the present study is the trend below the balance line in the respective negative area, i.e. an emphasis on drought.

Station rankings have been determined based on the significance level in drought trend. The intensity of climate change in drought trend is observable in this ranking. Then the locations with climate change have been determined on the map using the GIS software and the intensity of these changes has also been pointed out along with their area Figure 7 shows the Average Water Balance diagram and Figure 8 shows the climate change graph in Guilan province. The results of this study are applicable in all the considerations regarding the environment, civil engineering, jungles, fishery, agriculture, hydrology, and so on. What we know for certain is that areas with intense climate change provide us with the conditions needed to study the changing phenomena, and these phenomena can easily be studied with a correlation of climate.

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