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Research Article

ANALYSIS OF THE PRECIPITATION INTENSITY VALUES OF VARIOUS DURATIONS IN TRABZON PROVINCE OF TURKEY BY ŞEN'S INNOVATIVE TREND METHOD

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ABSTRACT

Hydrological and meteorological studies indicate that hydrological processes and water resources are significantly affected by the climate change, particularly with increasing greenhouse gases and temperature. In this study, the trend analyses of the biggest precipitation intensity values in Trabzon, the most populous province of the Eastern Black Sea Basin in Turkey, have been carried out by using Mann-Kendall and Şen's Innovative Trend methods. In line with this purpose; the precipitation intensity data of standard time series from 5 minutes to 24 hours for two meteorological stations in Trabzon (Trabzon and Akçaabat) were used. Before carrying out trend analyses, the Run (Swed Eisenhart) Homogeneity Test was applied to all data and non-homogeneous data were not analysed. Before applying the Mann-Kendall Method, the internal dependency of the data was examined. When the analysis results are reviewed; in Trabzon Meteorology Station an increasing trend for intensities of all-time series has been detected, whereas in the Akçaabat Meteorology Station, a general result of the trend could not be obtained as most the data related to different time series were not homogeneous data.
Keywords: Eastern Black Sea Basin, Mann-Kendall test, Şen's innovative trend method, trend analyses.

1. INTRODUCTION

Precipitation, being one of the important parameters of hydrology, is defined as the fall of the water vapour in the atmosphere onto the ground in solid or liquid form. Systematic increases and decreases in the amount of precipitation, which is one of the most variable parameters among climate elements in terms of time and space, are determinative on climatic change [1, 2].

The most important meteorological factors in the formation of disasters of atmospheric origin are precipitation and features of precipitation. The intensity, duration and frequency of precipitation are the main characteristics. Heavy rainfall can cause sudden floods by increasing peak discharges. Intense rainfalls not only cause flooding; additionally, the water droplets with

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increased kinetic energy intensify the soil erosion that progresses at normal speed, destroy the natural vegetation an d agricultural fields and shorten the dam life as it leads to siltation. The interpreted hydro climatological data produced by statistical studies are a source of light for the decision-makers in the planning and operation of water resources. Therefore, the trend and correlation analyses of meteorological and hydrological data are very important in the preparatory phases of effective water management and disaster relief plans [3, 4].

Eastern Black Sea Basin (EBSB) is frequently exposed to floods due to its topographic structure. In case of floods, many casualties, injuries and property damages occur as the settlements are generally located in floodplains. The dimensions of these floods incurred in the basin, both in terms of economics and of loss of life, are greater than those in other basins in Turkey due to the physical and climatic conditions [5]. In the EBSB, 585 people have lost their lives in 33 big floods and landslides occurred in 81 years, due to heavy rainfall. The effective factors that make the EBSB a natural disaster area are, the geological structure and characteristics of the basin as well as the increasing slope values of morphology with increasing slope values with the sharp elevation of the mountains from the shore, the erosion of the streams with strong flow on this slope and the high precipitation values [2, 6].

Trabzon Province selected as the study area is the most populous city in the basin. For this reason, it is very important to determine the rainfall trend over the years in the stations of this province. Although there are many studies [7-11] carried out to examine the change in total precipitation in the EBSB, including the province of Trabzon; the change in precipitation intensity has only been investigated by Nemli [2]. Saplıoğlu and Çoban [7] conducted the trend analysis of the annual total rainfall values of 18 precipitation gaging stations in Black Sea Region between 1971-2010, applying Mann-Kendall, Regression and Şen's Innovative Trend (ŞIT) methods. Çeribaşı and Doğan [8] conducted a trend analysis applying Spearman's Rho and Mann-Kendall methods for the annual mean rainfall values of the West and East Black Sea basins and Sakarya Basin. The observation period for the stations in the EBSB is between the years 1979 and 2012. Ay and Kisi [9], unlike other studies, examined the change of the monthly total precipitation, and for this purpose chose five of precipitation stations located in different regions of Turkey. They carried out trend analysis using Mann-Kendall and ŞIT methods for the data of the years between 1970 and 2011. In the study conducted by Çanlı [10], seasonal and annual trends were analysed using the monthly minimum, maximum and mean temperature and total precipitation data, with Mann-Kendall and regression methods for the years 1961-2013 in Trabzon, Giresun, Rize and Artvin. The study performed by Polat and Sunkar [11] was to determine the climate characteristics of the Rize Province. The data obtained from the Rize, Pazar, Hopa and Trabzon meteorological stations located in and around Rize between 1970 and 2014 were used. They also conducted trend analysis with Mann-Kendall and Sen's Trend Slope methods for annual mean and total rainfall data. In the study on the precipitation intensity, Nemli [2] carried out the trend analysis of the highest annual rainfall values observed at the 10 meteorological stations in the EBSB. The trend analysis of the data of each meteorological station determined to be homogenous has been performed by using the Mann-Kendall Method and Spearman's Rho Test.

ŞIT Method selected in this study is a method that can be applied to any length data set and which is not based on any acceptance. It is a non-parametric method that can be applied to the records with lacking values and which is not affected by extreme values. The ability to perform trend analysis for different data classes is one of the most important features that distinguish this method from the others, therefore the method preferred in this study. The Mann-Kendall, which has been most widely used in previous studies, was used to compare the results of ŞIT Method.

In this study, ŞIT Method has been applied for the maximum rainfall intensity values of standard duration in two stations of Trabzon, which is the most populous city of the EBSB. The distribution of the maximum precipitation intensity values in various classes (very low, low, medium, high, very high) has been demonstrated with this method. The results of the method have been compared with the results obtained from Mann-Kendall Method.

2. MATERIALS AND MET HODS

2.1. Study Area and Available Data

Trabzon, is the most populous city in the EBSB. The basin has a surface area of 37551 km^2 and is the most rainfall in Turkey with an average precipitation in depth ranging between 1200 and 1300 mm. The total area of the basin is 24077 km^2 and has an average surface water potential of 14.9 km^3 per year. These values correspond to 7.9% of the water potential of Turkey [2, 12]. Trabzon Province is located between 40º30′-41º30′ northern latitudes and 38º30′-40º30′ east longitudes. Trabzon is a coastal city with an area of 4664 km^2. Moreover, the city has a mild climate with not very hot in summers and not very cold in winters [13, 14]. In the EBSB, the annual total precipitation values in the provinces vary between 820 mm and 2299 mm (1038 mm for Ordu, 1286 mm for Giresun, 820 mm for Trabzon, 2299 mm for Rize) [15].

In this study, the annual maximum precipitation depth measurements (mm) of all standard durations of Trabzon and Akçaabat meteorological stations in Trabzon province have been obtained. Then, these values have been divided by the measurement duration and converted to precipitation intensity (mm/hour). The locations of the two stations used in this study are shown in Figure 1 and their characteristics are shown in Table 1.

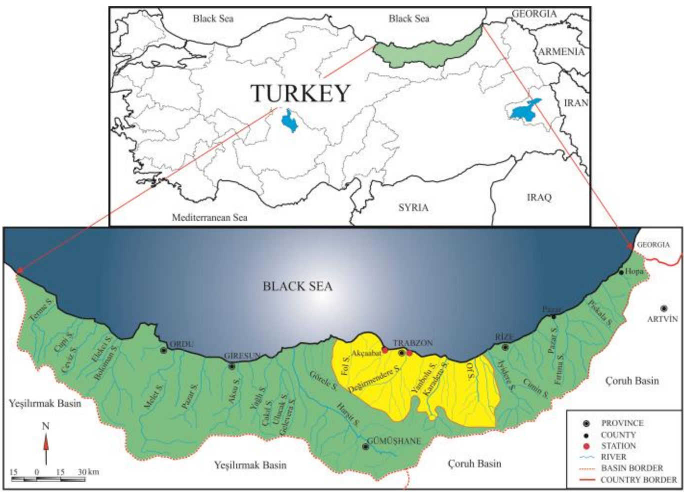

Figure 1. Trabzon Province located in the EBSB

Table 1. The meteorological stations employed in the study

Station Name	Observation Range	Data Length (Year)	Latitude	Longitude
Akçaabat	1972-2010 (except 1990)	38	41° 02'	39° 57'
Trabzon	1957-2010	54	40° 99'	39° 72'

2.2. Methods

2.2.1. Run (Swed-Eisenhart) Homogeneity Test

The Run (Swed-Eisenhart) Homogeneity Test is one of the important methods used to test the homogeneity of data in time series. The run test is used to test the two assumptions that the data to be examined come from the same community and are independent of each other or vice versa. According to the result of this test, if the data is from the same community and independent from each other, these series are called simple random series. Time series data is cut from a certain level (this level can be taken as the mean value, the medium value or the most common value (mode)) and the position of each value in the series, whether above or below this level is determined. The sum of the number of runs from one to the other that is above or below the midpoint is called the run count. The data in the series are consistently above and below the medium value. The number of runs is small if it is below or above for long periods. Such series may not have homogeneity. It is calculated as shown in Equation 1 [2].

$$Z = \frac{r - \frac{2N_A N_U}{N_A + N_U} + 1}{\sqrt{\frac{2N_A N_U (2N_A N_U - N)}{N^2 (N-1)}}} \tag{1}$$

The test result is Z, the number of data N, the number of run (change) r, the number of those below the middle level N_A, the number of values that are at the top are expressed as N_U. For the 95% confidence level in the statistics, z score of ±1.96, for the 90% confidence level, z score within the range of ± 1.645 are homogeneous data and the (H0: hypothesis) is accepted [16].

2.2.2. Mann-Kendall Method

Mann-Kendall Method [17, 18], is one of the statistical methods used to determine the degree and direction of the relationship between variables, regardless of whether the variables are dependent or independent. In this method, which permits the presence of missing data, there is no obligation to comply with a certain distribution of data. In the time series x_1, x_2, ..., x_n, the x_i, x_j pairs are divided into two groups. If the number of pairs with $x_i<x_j$ for i<j is shown with P and the number of pairs with $x_i>x_j$ for i>j is shown with M, the Mann-Kendall Method statistic (S) is calculated by the equation given in Equation 2 [19].

$$S = P - M \tag{2}$$

Then, according to Equation 3, the Kendall correlation coefficient (τ) is obtained:

$$\tau = \frac{S}{[N(N-1)/2]} \tag{3}$$

Here N is the number of data. For N ≥ 10 the standard deviation of the S value (σ_s) is calculated by Equation 4:

$$\sigma_s = \sqrt{[N(N-1)(2N+5)/18]} \tag{4}$$

The standard normal Z score is found as indicated in Equation 5. If the absolute value of the calculated Z is less than the $Z_{\alpha/2}$ value of the normal distribution corresponding to the selected α significance level, then the null hypothesis is accepted and it is concluded that there is not a trend in the examined time series; if it is more than the $Z_{\alpha/2}$ value there is a trend in the examined time series and that if the S value is positive (+) there is a trend in the increasing direction and if the S value is negative (-) there is a trend in the decreasing direction [19].

$$Z = \begin{cases} \frac{S-1}{\sigma_s}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sigma_s}, & if\ S < 0 \end{cases} \tag{5}$$

2.2.3. Şen's Innovative Trend Method

Şen [20] has introduced the ŞIT Method in order to assess the climatic trends. This is a method enabling the examination of the changes between consecutive time series. The data are sorted into two separate data groups, equal in length from the initial data, and are sequenced. Then the data are drawn in such a manner that first series is on the horizontal axis and the second series on the vertical axis. Then a 45° line is drawn and comparisons with the marked data are made. When similar time series are placed on horizontal and vertical axes, they will be located on the 1:1 (45°) line. Therefore, if data are scattered on the 1:1 (45°) line in the first and second series drawings, it is understood that there is no trend in the examined series. On the other hand, if the distribution is above the 1:1 (45°) line, there is an increasing trend in time series and if data are in the area below the 1:1 (45°) line, there is a decreasing trend [21].

Another superiority of ŞIT Method is that it enables the division of the analysed data into different classes from small to large (Figure 2). With this review, it is possible for example, to observe the trends of flow rates with high values, which are important for floods, or of low value flow rates, which are important for drought cases. In order to determine the number of different groups of data to be assessed, it is easier to obtain the scattering diagrams of the first and second data groups and then to conclude a result depending on the scattering forms [22].

In this study; ŞIT Method was applied to the intensity data of the standard durations and the data were divided into five different (very low, low, medium, high, very high) classes from small to large. Although it is not necessary to use equal intervals when making the classification, the use of equal intervals is preferred in this study. Besides, the upper and lower limits were determined by the authors. While making classification for different data groups, it is of great benefit to have a detailed examination of the previous studies.

3. RESULTS

3.1. Run Homogeneity Test Results

The Run (Swed-Eisenhart) homogeneity test at 95% confidence level has been applied to the highest annual rainfall data as observed at the standard times of the meteorological stations. While determining the homogeneity of the data with this method, if the Z score which is the test result obtained from Equation 1 is in the value range of 95% confidence level, it is assumed that the data are homogeneous. Non-homogeneous data were not taken into consideration during trend analysis. Mann-Kendall and ŞIT methods were applied to the meteorological station data determined to be homogeneous. The results of homogeneity test in meteorological stations are given in Table 2. Here, homogeneous data are indicated by + (plus), if not by - (minus).

Table 2. The results of homogeneity test in meteorological stations

Duration	5m	10m	15m	30m	1h	2h	3h	4h	5h	6h	8h	12h	18h	24h
Trabzon	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Akçaabat	+	+	–	–	–	–	–	–	–	–	–	–	+	+

Note: m: minute, h: hour

3.2. Mann-Kendall Method Results

For this method, first of all an autocorrelation analysis at 5% significance level was performed on all homogeneous data of Trabzon and Akçaabat Meteorology Stations. Thus, serial correlation which causes the formation of a non-actual trend could be detected and destroyed. This method is only a preliminary analysis carried out for the Mann-Kendall Method. The r values of the serial correlations in Trabzon Meteorology Station are given in Table 3. As there were a lot of missing data belonging to Akçaabat Meteorology Station, autocorrelation analysis of this station work has not been performed.

When Table 3 is examined, it is seen that there is no serial correlation in terms of 5% significance level in the biggest precipitation intensities of Trabzon Meteorology Station for all standard durations. For the Mann-Kendall Method, an increasing trend was observed for precipitation intensity with the durations of 5, 15, 30 minutes and 1, 2, 3, 4, 5 and 6 hours in terms of 95% confidence level (Table 4) at the Trabzon Meteorology Station. Any increasing or decreasing trend was not found in the intensities of the rainfall in all other time durations. The results of the Mann-Kendall method at the Akçaabat Meteorology Station are given in Table 5. When the table is examined, no trend has been seen in the precipitation intensity of the four durations which were determined to be homogeneous in terms of 95% confidence levels. The fact that most of the data in this station is not homogeneous has prevented a station-based assessment of the trend.

Table 3. r values of serial correlation

Precipitation Duration							2/(N^0.5)
5m	10m	15m	30m	1h	2h	3h	
-0.075	-0.076	-0.005	0.061	0.043	0.142	0.132	
4h	5h	6h	8h	12h	18h	24h	0.272
0.105	0.085	0.12	0.072	0.084	0.135	-0.058	

Note: N: data number

Table 4. Trabzon Meteorology Station precipitation intensity trend analysis results

Time	Z	UP TO 95% TREND		Duration	Z	UP TO 95% TREND	
		YES	NO			YES	NO
5m	2.635	+		4h	2.373	+	
10m	0.993		x	5h	2.619	+	
15m	2.007	+		6h	2.723	+	
30m	2.425	+		8h	1.880		x
1h	2.134	+		12h	1.679		x
2h	2.126	+		18h	1.112		x
3h	2.305	+		24h	0.83		x

Table 5. Akçaabat Meteorology Station precipitation intensity trend analysis results

<table>
<tr><th rowspan="3">Time</th><th rowspan="3">Z</th><th colspan="2">UP TO 95%</th><th rowspan="3">Duration</th><th rowspan="3">Z</th><th colspan="2">UP TO 95%</th></tr>
<tr><th colspan="2">TREND</th><th colspan="2">TREND</th></tr>
<tr><th>YES</th><th>NO</th><th>YES</th><th>NO</th></tr>
<tr><td>5m</td><td>-1.005</td><td></td><td>x</td><td>4h</td><td rowspan="5" colspan="3">DATA NOT HOMOGENE</td></tr>
<tr><td>10m</td><td>-0.617</td><td></td><td>x</td><td>5h</td></tr>
<tr><td>15m</td><td rowspan="5" colspan="3">DATA NOT HOMOGENE</td><td>6h</td></tr>
<tr><td>30m</td><td>8h</td></tr>
<tr><td>1h</td><td>12h</td></tr>
<tr><td>2h</td><td>18h</td><td>-0.218</td><td></td><td>x</td></tr>
<tr><td>3h</td><td>24h</td><td>-0.278</td><td></td><td>x</td></tr>
</table>

3.3. Şen's Innovative Trend Method Results

As an expert opinion in the classification of scatter distributions is required, there may be different assessment conditions in the classification of the data. The data used in this article are grouped as "very low", "low", "medium", "high" and "very high" values. In Figure 2, a general classification graph is shown. In this graph, a different coloration is used for each class range in order to allow a clear view of the regions of the classifications; yellow shows too low, blue low, pink medium, green high and red very high. Secondary lines on the axes are used for classification in the figures where the results are shown.

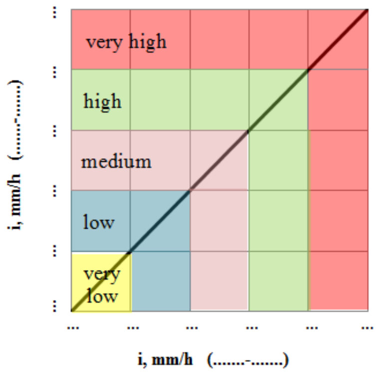

Figure 2. Classification of trend graphs according to ŞIT Method

According to ŞIT Method, precipitation intensity trend graphs for Trabzon in all standard durations, and for Akçaabat in the durations of 5, 10 minutes and 18 and 24 hours were given in Figures 3 and 4, respectively. The fact that the data in Akçaabat station were not homogeneous prevented the detailed assessment also of this method in terms of trend, as the Mann-Kendall.

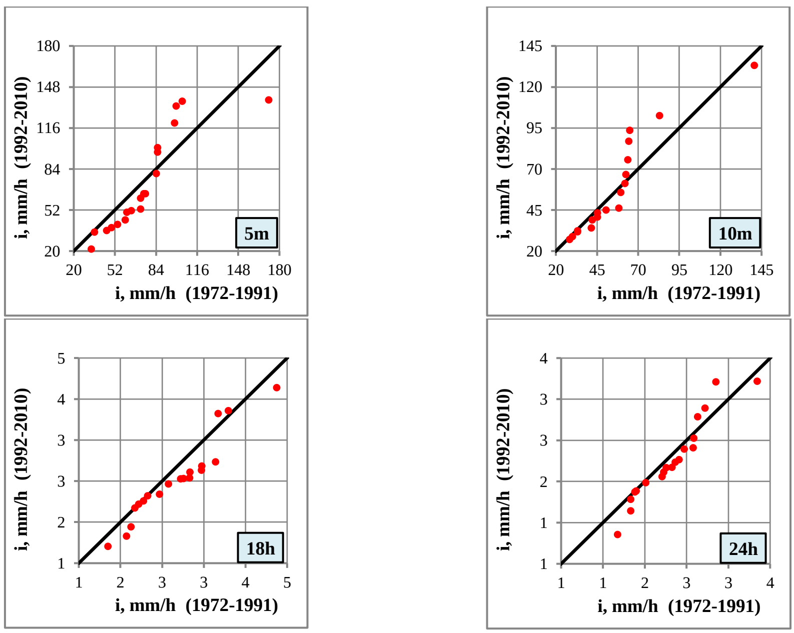

Figure 3. Trend graphs of maximum annual rainfall of Akçaaat station according to ŞIT Method

According to ŞIT Method, the changes in the five different classes obtained by examining the trend graphs of the precipitation intensity of Trabzon and Akçaabat stations (Figures 3 and 4) are presented in Table 6. When the table is examined; for Trabzon station there is a generally increasing trend, similar to the result of the Mann-Kendall Method. Although there was no trend for Akçaabat station in the Mann-Kendall Method, there were different trends which vary according to duration and class in ŞIT Method.

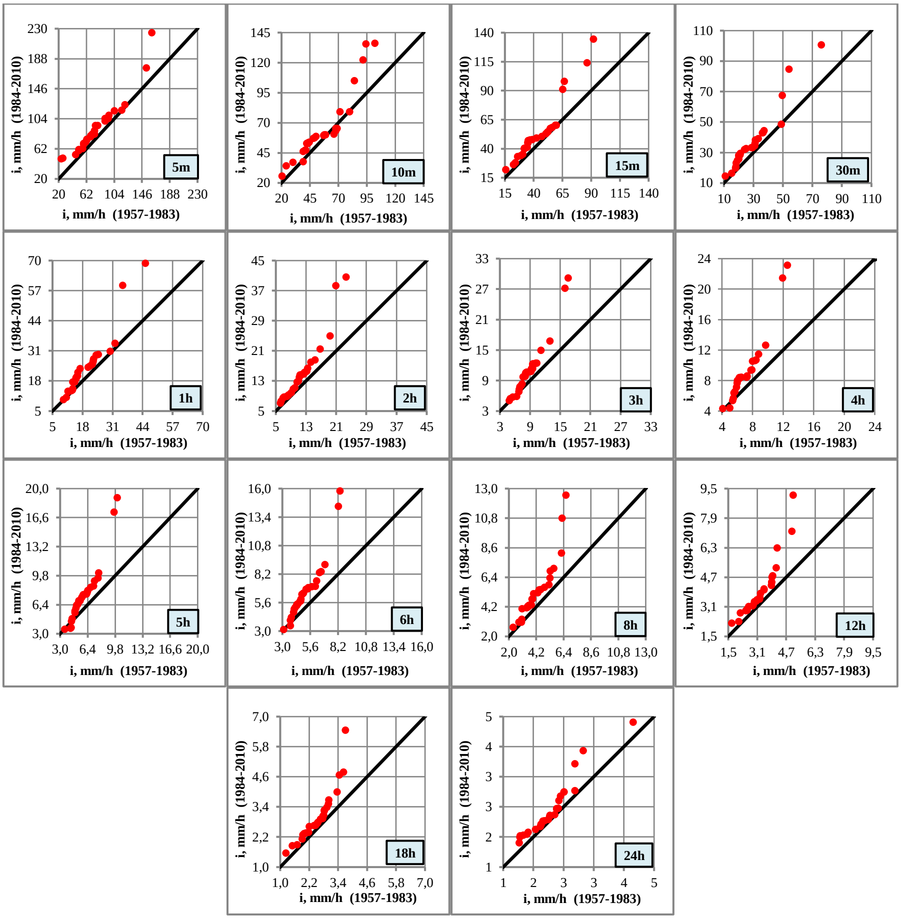

Figure 4. Trend graphs of maximum annual rainfall of Trabzon station according to ŞIT Method

It has been observed that the increase in the high and very high precipitation intensity values for all-time series in Trabzon station was very high compared to the other classes. Especially in all-time series between 2 hours and 18 hours, the highest values in the period between 1984 and 2010 almost doubled the values in the period 1957-1983. Considering the size of the basins in the region, the excessive rise in precipitation intensities experienced during these periods will cause large floods to occur also with the effect of urbanization.

4. CONCLUSION

In this study, the trend analysis of the greatest precipitation intensities observed at standard time series in Trabzon and Akçaabat Meteorology Stations in the Trabzon province in the EBSB was carried out. Firstly, the data obtained from the stations were examined by applying the Run (Swed Eisenhart) Homogeneity Test. In stations with homogenous data, Mann-Kendall and ŞIT methods were used for trend analysis.

When the test results were evaluated, mostly an increasing trend was detected in the intensities of all durations in Trabzon Meteorology Station. In Akçaabat Meteorology Station, a station-based trend analysis could not be carried out due to the fact that most of the data in standard durations were not homogeneous. When the trend status depending on the rainfall durations was analysed, it has been observed that there was no significant difference in terms of percentage of trend incidence between the short duration (up to 1 hour) and long-duration (1-24 hours) rainfall. In the trend analysis of various classes made using ŞIT Method, large increases of up to two times for high and very high data class were seen, especially in all-time series between 2 hours and 18 hours.

Table 6. Classification of precipitation intensities for ŞIT Method

Station	Data Range	Duration													
		5m	**10m**	**15m**	**30m**	**1h**	**2h**	**3h**	**4h**	**5h**	**6h**	**8h**	**12h**	**18h**	**24h**
Trabzon	Very high	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗
	High	↗	↗	↗	↗	–	–	↗	–	–	–	↗	↗	↗	↗
	Medium	↗	↗	–	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗
	Low	↗	↗	0	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗
	Very low	↗	↗	↗	↗	0	↗	↗	↗	↗	↗	↗	↗	↗	↗
Akçaabat	Very high	↘	↘	–	–	–	–	–	–	–	–	–	–	↘	↗
	High	↗	↗	–	–	–	–	–	–	–	–	–	–	↗	↗
	Medium	↗	↗	–	–	–	–	–	–	–	–	–	–	↘	↘
	Low	↘	↘	–	–	–	–	–	–	–	–	–	–	0	0
	Very low	↘	0	–	–	–	–	–	–	–	–	–	–	↘	–

Descriptions: ↗ Increasing trend; ↘ Declining trend; (0) No trend; (–) No data

As the result of the study; it is being thought that the flood probability will gradually increase due to the increase in the intensity of rainfall in the coming years, as a generally increasing trend is determined regarding the greatest precipitation intensities related to the standard durations of rainfall in Trabzon. Two stations considered in the study are located at the seaside. In order to robustly determine the trend of precipitation in the province, it is necessary to take a long-term precipitation measurement at the upper elevations. The impact of climate change on the whole basin rainfalls and runoffs should urgently be investigated and measures regarding the possible negative effects should be promptly taken.

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