ANALYSIS OF SPATIO-TEMPORAL CHANGES OF PRECIPITATION TO ESTIMATE R FACTOR IN RUSLE AT KARTALKAYA DAM

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ANALYSIS OF SPATIO-TEMPORAL CHANGES OF PRECIPITATION TO ESTIMATE R FACTOR IN RUSLE AT KARTALKAYA DAM

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ABSTRACT

ANALYSIS OF SPATIO-TEMPORAL CHANGES OF PRECIPITATION TO ESTIMATE R FACTOR IN RUSLE AT KARTALKAYA DAM

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In recent years, soil erosion models have been developed all over the world. The most common model, RUSLE requires a lot of detailed information and extensive laboratory studies. One of the RUSLE parameter, rainfall factor, is identified as the erosivity factor of precipitation. This parameter depends on duration, intensity and frequency of rainfall events. The difficulty in calculating rainfall factor is the lack of minute-based precipitation data in many parts of Turkey. The aim of this study is to calculate R factor based on available precipitation data and determine the sensitivity of the R parameter using different methods with GIS tools in Kartalkaya Dam catchment. Firstly, the relationship between precipitation and physiogeographic parameters of study area is examined and stations are classified based on their location and the main factors cause precipitation. Then, RUSLE rainfall factor is calculated by using minute based data. To estimate rainfall factor based on monthly and annual rainfall data, Modified Fournier Index (MFI) is calculated. The relationship between MFI and R values show that there is a strength correlation between these two parameters with a coefficient determination (R^2) value of 0.78. It has been estimated that compare to mean annual precipitation and rainfall factor relationship (R^2=0.64), MFI calculation significantly improve R-factor estimation.

Rainfall erosivity maps are constructed with calculated R and MFI values and also based on their relation. Due to low number of stations and complexity of environmental features, physio-geographic parameters of study area are also utilized as secondary information in an effort to improve interpolation of rainfall factor. The results show that using elevation as the secondary information significantly improves the estimations over IDW interpolations.

Keywords: Soil erosion, RUSLE, Rainfall Factor, MFI, Kartalkaya Dam.

ÖZ

KARTALKAYA BARAJINDA YAĞIŞIN MEKANSAL VE ZAMANSAL DEĞİŞİMİNİN RUSLE R FAKTÖRÜNÜN KESTİRİLMESİNDEKİ ETKİLERİNİN İNCELENMESİ

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Son yıllarda dünyanın her yerinde toprak erozyonunu hesaplamak için çeşitli modeller geliştirilmektedir. En yaygın olan YETKE-R modeli parametreleri detaylı ve uzun süreli laboratuvar çalışması gerektirmektedir. Bu parametrelerden biri olan yağış faktörü, yağışın erozyon oluşturma gücü olarak tanımlanır. Bu parametre yağışın süresine, şiddetine ve yoğunluğuna bağlıdır. Bu parametreyi hesaplamakla ilgili problem Türkiye'de dakika bazlı yağış verisinin her yerde olmamasıdır. Bu çalışmanın amacı Kartalkaya Barajı havzasındakı mevcut yağış verileri ile R faktörü hesaplamak ve bu parametreyi hesaplamada farklı metodlar kullanarak CBS yardımı ile duyarlılığını belirlemektir. Öncelikle, çalışma alanının yağış ve fizyocoğrafik parametreleri arasındaki ilişki incelenmiş ve istasyonlar konumlarına ve yağışa sebep olan temel faktörlere göre sınıflandırılmıştır. Sonrasında, YETKE yağış faktörü dakikalık veri kullanarak hesaplanmıştır. Aylık ve yıllık yağış verilerine göre yağış faktörünü tahmin etmek için Modifiye Fournier İndeksi (MFI) hesaplanmıştır. MFI ve R değerleri arasındaki ilişki bu iki parametre arasında 0.78'lik (R^2) değeri ile güçlü bir korelasyonun olduğunu göstermektedir. Yıllık yağış miktarı ve yağış faktörü arasındaki ilişki (R^2 = 0.64) karşılaştırıldığında, MFI hesabının R-faktör tahminini önemli ölçüde artırdığı görülmüştür. Hesaplanan R, MFI değerleri ve bu değerlerin ilişkilerine dayanarak yağış faktörü haritaları oluşturulmuştur.

Az sayıda istasyon olması sebebi ve çevresel özelliklerin karmaşıklığı nedeniyle, çalışma alanının fizyo-coğrafik parametreleri, yağış faktörünün enterpolasyonunu iyileştirmek amacıyla ikincil bilgiler olarak kullanılmıştır. Sonuçlar ikincil bilgiler kullanılarak iyileştirilen IDW enterpolasyonlarının tahminleri önemli ölçüde geliştirdigini göstermektedir.

Anahtar Kelimeler: Toprak erozyonu, YETKE-R, Erozyon Oluşturma İndeksi, MFI, Kartalkaya Barajı

To my family *with love and respect*

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R	(Rainfall Factor)
MFI	(Modified Fournier Index)
USLE	(Universal Soil Loss Equation)
RUSLE	(Revised Universal Soil Loss Equation)
IDW	(Inverse Distance Weighted)
TSMS	(Turkish State of Meteorological Service)
SEDD	(Sediment Distributed Delivery)

CHAPTER 1

INTRODUCTION

Soil erosion is defined as detachment of soil particles by the power of water flow or wind. It is one of the most common environmental and agricultural problems globally. Due to transportation of soil components like organic matter, soil fertility decreases. This situation leads to decrease in productivity of forest, rangeland and all other natural ecosystems as well as agriculture (Lal and Stewart, 1990). Globally, it has been estimated that nearly 2 billion hectares of land are affected by human-induced soil degradation (UN, 2000).

Due to its climatic and geographical location, topography, geology and soil structure, erosion is very important in Turkey. In addition to this, Turkey has a number of different climatic regions, which makes it more complicated to calculate and understand erosivity and risks associated with it. Soil erosion is also critical on water resources in terms of siltation and reduction of quality. The deposition of eroded soil which contains nutrients, herbs and fertilizers can shorten life time and productivity of dams.

Due to the extent of damage to so many areas, proper estimation of soil erosion is crucial to formulate effective mitigation plans. To calculate eroded material from land and analyze associated risk, erosion models have been developed in last few decades all over the world (Merritt et al., 2003). Process-based, conceptual and empirical models are the three main types of erosion models. Process-based models are dependent on mathematical equations that describe physical processes and calculate soil loss and sediment yields from land surface characteristics.

One of the most commonly known process-based models are Water Erosion Prediction Project, WEPP (Flanagan and Nearing, 1995) and European Soil Erosion Model, EUSOREM (Morgan et al., 1998). Conceptual models tend to include a general description of catchment processes, without including the specific details of process interactions, which would require detailed catchment information (Sorooshian, 1991). Empirical models are based primarily on the analysis of observations and seek to characterize response from these data (Wheater et al., 1993). Most known empirical models are Universal Soil Loss Equation, USLE (Wischmeier and Smith, 1978) and Revised Universal Soil Loss Equation, RUSLE (Renard et al., 1997).

Rainfall intensity plays an important role in soil loss. Intense rainfall and large rain drops have more erosive power than shorter length rainfall events and small rain drops. The erosive force of rainfall is expressed as rainfall erosivity and is determined by intensity, duration and frequency of rainfall events. Therefore, accurate rainfall data is crucial to properly calculate soil loss. Rainfall is expressed as the R factor in USLE and RUSLE.

The main difficulty in calculating the rainfall erosivity value is the lack of high-resolution temporal rainfall data and limited number of meteorological stations. Availability of high quality data ensures more accurate results. In Turkey, however, temporally high resolution rainfall data is available only for major stations, and only for recent years. The daily or monthly data is generally present but it is generally discontinuous and irregular for many stations. Therefore, a widespread study area was chosen in order to access more stations and consequently more data. Another reason for assigning a widespread area is to better observe the geomorphological characteristics of the area which can be interrelated with the rainfall factor. There are several factors directly or indirectly related to rainfall such as climate, catchment area properties, topography and proximity to the coast.

In this study, a multi-scale model, linking physiographic parameters and rainfall factor, was created to assess the erosion risk in Kartalkaya Dam, Turkey.

1.1. Literature Review

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and its revised version (RUSLE) (Renard et al., 1997) are the most commonly used methods for calculating the average annual soil loss caused by rainfall.

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is based on approximately 1000 test plots data in the United States for many years and widely used worldwide to estimate soil erosion (e.g. Dabral et al., 2008; Kim et al., 2005). Due to limitations of USLE such as not being event based that it was developed to model sheet and rill erosion, RUSLE was developed. The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) maintains basic form of USLE but can calculate estimation of average annual soil loss resulting from raindrop impact and runoff from field slopes, is still most frequently used at large spatial scales (Kinnell, 2010; Panagos et al., 2014a). The RUSLE formula to estimate the average annual soil loss:

$$A = R * K * LS * C * P \tag{1}$$

- A is the computed soil loss per unit area,
- K is the soil-erodibility factor
- LS is the slope length and gradient factor
- C is the cropping management factor
- P is the erosion control-practice factor
- R is the rainfall factor

The soil-erodibility factor K defines the susceptibility of soil to erode. It is affected by infiltration capacity and structural stability of the soil material. LS factor defines the effect of topography, hillslope length and steepness on soil loss. C factor defines the cover and roughness of soil on soil loss. P factor defines the effects of erosion – control activities such as contouring, terracing etc. The factor R is an expression of the erodibility of rainfall and runoff.

The rainfall factor R is a numerical descriptor of the ability of rainfall to erode soil (Wischmeier and Smith, 1959). The original RUSLE R factor is the product of kinetic energy of rainfall event and its maximum 30-min intensity (I30) (Brown and Foster, 1987). Analyses of data indicated that when factors other than rainfall factor are held constant, soil loss is directly proportional to a rainfall factor composed of total storm kinetic energy (E) times the maximum 30-min intensity (I30) (Wischmeier and Smith, 1958). The R-factor accumulates the rainfall erosivity of individual rainstorm events and averages this value over multiple years (Panagos et al., 2015).

Panagos et al., (2015) calculated RUSLE rainfall factor all over the Europe using different temporal resolution data changing from 5 min. to 60 min. The lowest rainfall factor value was belonging to Sweden with the value of 51.4 MJ mm ha^{-1} h^{-1} yr^{-1} and the highest one was belong to Italy with the value of 6228.8 MJ mm ha^{-1} h^{-1} yr^{-1}.

A proper calculation of R-factor in RUSLE formula requires continuous recordings of sub-hourly precipitation data for a period of several years. However, due to unavailability of sub-hourly data or various temporal resolutions of data in study area, normalization of rainfall factor is inevitable. R-factor results calculated from different time-step data, and then conversion factors are generally calibrated to estimate real values (Renard et al. 1997; Yin et al. 2007). The `conversion factor` is used to transform R factor from different resolutions to R factor at 30-min.

In Table 1-1, there is a summary of conversion factors for 10 minute interval values of $(E)_{10}$, $(I30)_{10}$, $(EI30)_{10}$ and $(R30)_{10}$ corresponding breakpoint calculated values of E_{30}, I_{30} and EI_{30} and R_{30}.

Table 1-1: Conversion factors for 10 minute interval data to 30 minute breakpoint values from previous studies

Studies	***E***	***I_{30}***	***EI_{30}***	***R30***
Weiss (1964)	-	1.0435		
Williams and Sheridan (1991)	1.036	1.044	1.09	
S. Yin (2006)	1.022	1.022	1.044	
P. Panagos (2015)	-	-	-	0.8205

There are also other ways such as using a simplistic solution that assumes R-factor is proportional to the total annual rainfall amount especially for some large scale areas. An approach that build-up functions from low temporal data like daily or monthly rainfall volume correlate with R factor also conducted in several studies (Grimm et al. 2003; Bosco et al. 2015). Also some large scale studies use a simplistic solution that assumes R-factor is proportional to the total annual rainfall amount (Diodato and Bellocchi, 2007).

Alternatively, commonly available secondary environmental variables such as climate or elevation is utilized for spatial prediction of rainfall factor in several studies in Europe such as Portugal (Goovaerts, 1999), Spain (Angulo-Martínez et al. 2009) and Greece (Panagos et al. 2016).

The first research on rainfall erosivity parameters in Turkey was conducted by Güçer (1972). Güçer analyzed precipitation total kinetic energy and 30-min interval highest intensities together. USLE-R was calculated using precipitation data from 55 stations between 1957 and 1969. 15 years after this research, Doğan (1987) studied 23,319 precipitation time-depth curves of 60 weather stations between the years 1957 and 1982 and prepared USLE-R map of Turkey. To improve that study, Doğan (2002) studied the data from 96 meteorological stations and calculated erosivity factors and USLE-R values using an empirical equation for Turkey:

$$E = 210.1 + 89 log_{10} I \tag{2}$$

- E, unit kinetic energy
- I, ıntensity of a precipitation event

The RUSLE equation calculates the rainfall factor using a minute-based precipitation data. In most of soil erosion studies, due to lack of high temporal resolution precipitation data, equations based on monthly or daily rainfall data is used (Diodato and Bellocchi, 2010; Bonilla and Vidal, 2011). Several methods have been developed to calculate correlation between daily, monthly or annual precipitation values and rainfall erosivity such as the Fournier index (Fournier, 1960), the Modified Fournier Index (Arnoldus, 1977) and the physically-based A index (Sukhanovski et al., 2002).

The most common method is the Modified Fournier Index (MFI), where R can be calculated from monthly rainfall data. In order to estimate the R factor using monthly and annual rainfall data, Fournier (1960) examined a correlation between erosion and rainfall data and called this method as Fournier Index;

$$F = \frac{p^2}{P} \tag{3}$$

where F is Fournier index, p is the precipitation of wettest month and P is the total annual rainfall.

Fournier Index considers only the month with the highest rainfall, hence, if rainfall amount is relatively constant through year, the index value can decrease with an increasing rainfall. Therefore, Arnoldus (1977) improved this model to Modified

Fournier Index (MFI) using the mean annual and monthly rainfall amount data for each month. Modified Fournier Index formula is;

$$\mathrm{MFI} = \sum_{i=1}^{12} \frac{p_i^2}{P_T} \qquad (4)$$

Where p_i is the monthly precipitation at month i and P_T is the total annual precipitation.

Arnoldus (1977) applied MFI to produce an isoerodent map in metric units for Morocco to find a correlation between R factor and F directly. However, Arnoldus (1977) was not able to reveal same relationship between F and R in every part of study area. After subdividing region sets of climatic zones and taking different regression equations from each zone, a significant relationship was achieved and concluded that MFI should be applied only to locations within homogenous climatic regions.

For United States, Renard and Freimund (1994) developed a relationship between F and R using high-frequency data from 132 stations.

$$R = 0.07397F^{1.847} \qquad F < 55 \text{ mm} \qquad (5)$$

$$R = 95.77- 6.081F +0.4770F^2 \qquad F>55 \text{ mm} \qquad (6)$$

In Turkey, first studies using MFI are conducted by Bayramin et al. (2007). Daily precipitation data from 223 meteorological stations collected between 1975 and 2004 were used to assess the risk of climatic erosion and erosion power of precipitation. As a result, statistically valid MFI, Precipitation Concentration Index PCI and Seasonality Index (SI) maps were obtained. MFI values for 10, 20 and 30 years (MFI_{10}, MFI_{20} and MFI_{30}) were calculated. Afterwards, Günay et al. (2009) enhanced mathematical equations between MFI, PCI and RUSLE-R using DEM and available GIS methods.

Relationship can be defined directly between the rainfall erosivity indices, mean annual precipitation and Modified Fournier index. However, the relationship between these terms cannot be extrapolated to other hydroclimatic regions without considering local climate or physio-geographic data.

Yüksel et al. (2008) calculated erosion risk in Kartalkaya Dam watershed based on COordination of Information on the Environment (CORINE) model.

In CORINE model, rainfall factor is estimated by integrating two climatic indices; Modified Fournier index and Bagnouls-Gaussen aridity index. In the mentioned study, MFI is classified into five classes including (1) very low, (2) low, (3) moderate, (4) high, and (5) very high as shown in Table 1-2.

Table 1-2: Classification of MFI Values

Range of MFI Value	***Class Definition***		***Range of MFI Value***	***Class Definition***
<60	very-low		120-160	high
60-90	low		>160	very high
90-120	moderate			

Tanyaş et al., (2015) applied both RUSLE and SEDD models to calculate annual transported sediment amount within each sub-basin of the reservoir of Kartalkaya Dam. Results of SEDD model were compared with the two different bathymetry maps produced in 1975 and 2005 of the reservoir.

To calculate rainfall factor in RUSLE, due to lack of rainfall data from local stations, R factors were taken from a previous study (Kaya, 2008), where the energy and intensity of each rainfall observed in the years between 1993 and 2004 are computed. Kaya (2008) calculated ExI_{30} and R factor of RUSLE for 252 meteorological stations of Turkey using the rainfall energy and the intensity data.

For spatial interpolation of rainfall, secondary information can help to improve interpolation. Simple kriging with varying local means, cokriging or kriging with external drift can interpolate relation between physio-geographical information and rainfall if datasets size is enough data (Creutin et al., 1988; Raspa et al.,1997). When sample size and density is not enough, interpolations by kriging do not produce reliable results.

Goovaerts (1998) revealed an approach aims to find a statistical relationship between rainfall factor and a set of spatially available covariates. Once covariates relationship established, R factor can be calculated in terms of these parameters.

Goovartes (1999) used another valuable and cheaper source of secondary information is considered: Digital Elevation Model (DEM). Panagos et al., (2015) calculated R-factor around Europe and improved interpolation using covariates such as total precipitation, seasonal precipitation, and precipitation of driest/wettest months, average temperature, elevation and latitude/longitude.

1.2.Study Area

The study area is the Kartalkaya Dam watershed, located in southeastern part of Turkey within the boundary of Kahramanmaraş City. It is one of the most important dams in the region, as it has been supplying irrigation water to the Pazarcık County, and tap water to the city of Gaziantep. The watershed is surrounded by Ceyhan, Asi and Fırat watersheds including six major cities. The drainage area of Kartalkaya Dam covers 3 districts (Pazarcık, Çağlayancerit, Gölbaşı) and 54 villages.

The dam was built on Aksu River for irrigation and for flood prevention for the town of Pazarcık (Figure 1-1). The crest elevation of the dam is 720 m. Elevation in the catchment ranges between 680 meters and 2470 meters.

The climate of catchment area is semi-arid and according to TSMS (2013), the average annual maximum temperature in the district is 35.9 ^{0}C, and average annual minimum temperature is 1.2 ^{0}C.

Kartalkaya Dam started its operation in 1971 and supplies irrigation water to 200,000 acres of farmland. It has a reservoir area of 11 km^2 and a drainage area of 1088 km^2. During the construction, the capacity was calculated as 200.000.000 m^3 but current capacity has decreased to 160.000.000 m^3 as a result of sediment fill.

The bathymetry map of Kartalkaya Dam`s reservoir area was produced in 1975 and it is updated in 2005. Therefore, calculation of soil erosion transportation can be compared to real values in this study area and it makes Kartalkaya Dam as a valuable source for soil erosion studies.

Due to limited availability of rainfall data around the dam and to better observe geomorphologic features that may control rainfall regime; a wider study area was chosen (Figure 1-1). In this enlarged study area, there are 18 meteorological stations which record daily rainfall. 6 out of 18 meteorological stations have a minute based dataset for recent years. Only two of the stations are located within the boundary of the catchment area. Although there are more stations in the study area, due to significant data gaps, those stations were not used in this study. The stations used in this study are listed in Table 2-1.

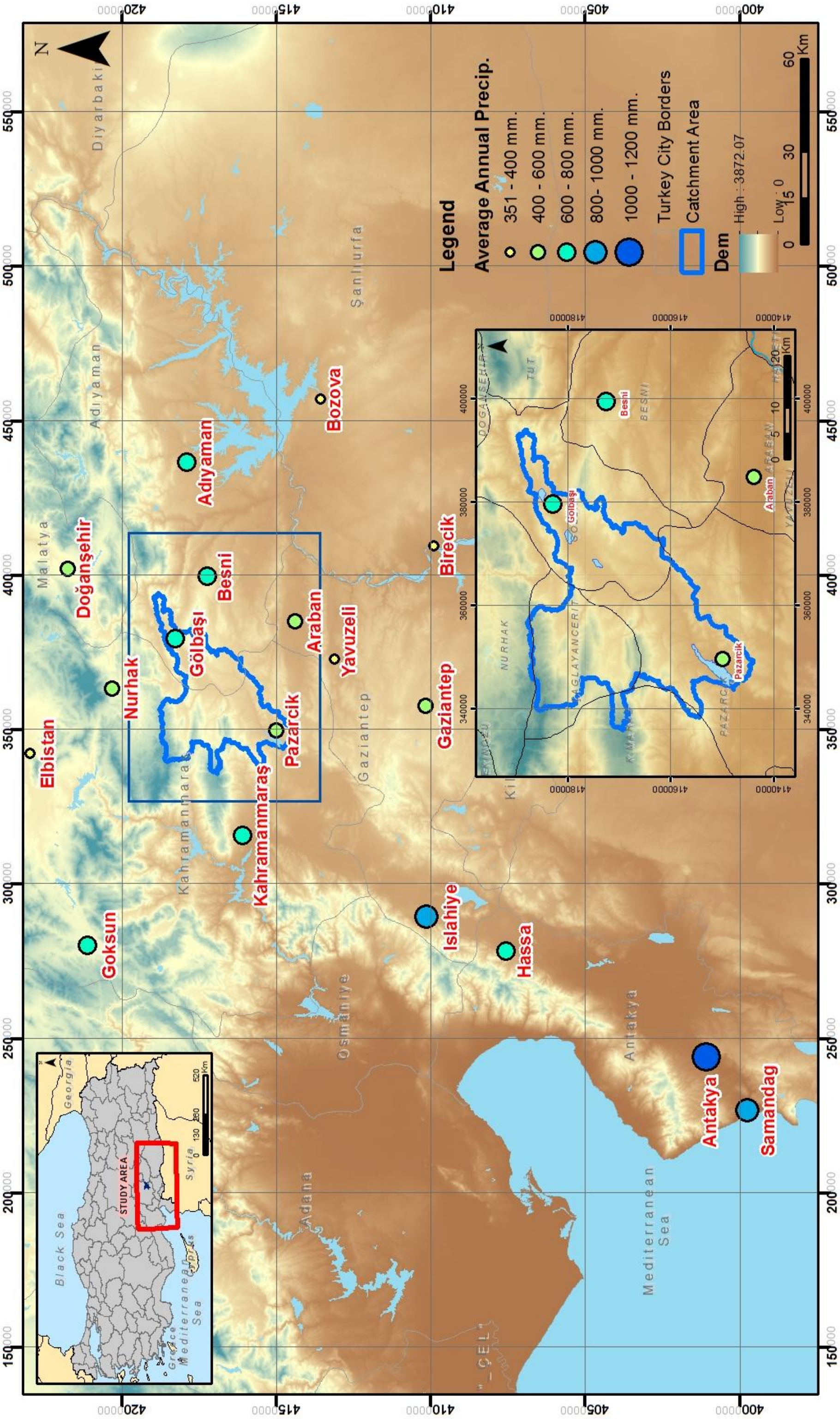


Figure 1-1: Geographic location of the Study Area

1.3. Purpose and Scope of Study

The main purpose of this study is to calculate the rainfall factor within the form of the RUSLE for the Kartalkaya Dam watershed using available precipitation datasets and physiographic data of study area.

Within the scope of this thesis, the rainfall erosivity factor is calculated with two different methods and then various spatial interpolation techniques are used with the help of auxiliary data. Based on the scope, the steps can be listed as:

a) Calculation of rainfall erosivity factor based on 10-minute interval precipitation data and construction of the RUSLE R map using spatial interpolation.

b) Calculation of rainfall erosivity factor based on monthly precipitation data derived from daily data and construction of the MFI map using spatial interpolation.

c) Identification of a relationship between precipitation, elevation and other secondary parameters between RUSLE R and Modified Fournier Index and using this relationship to estimate spatial distribution of rainfall factor throughout the study area.

CHAPTER 2

DATA ANALYSIS

2.1. Meteorological Data

Kartalkaya Dam and its watershed are surrounded by 6 major cities and 18 meteorological stations. In the scope of this study, two main rainfall datasets were employed; daily rainfall data for 18 stations between 1970 and 2015 and minute based rainfall data for 6 stations between 2010 -2015. Both meteorological datasets are compiled by the Turkish State Meteorological Service in September, 2016. The main features of the stations are listed in Table 2-1. The average annual values of stations ranged from 345 to 1091 mm per year. Elevation of stations ranges between 5 to 1344 m.

Table 2-1: List of Meteorological Stations

TSMS ID	**Name of Meteorological Stations**	**Easting**	**Northing**	**Elevation**	**Ann. Ave. Prep.**	**Minute Data**
17265	Adıyaman	436509	4178894	672	687.64	Available
17372	Antakya	243985	4010775	105	1091.54	Available
7609	Araban	384983	4143806	535	474.86	
7259	Besni	399572	4172406	905	779.57	
17966	Birecik	409575	4099120	400	345.68	
7791	Bozova	457200	4135727	622	371.76	
17872	Doğanşehir	402087	4217569	1214	382.52	Available
17870	Elbistan	342382	4229608	1137	554.01	
17261	Gaziantep	357720	4101683	850	506.33	
17866	Göksun	280094	4211047	1344	603.4	
17871	Gölbaşı	379650	4182724	900	733.75	Available
8541	Hassa	278436	4075630	436	679.6	
17965	Islahiye	289489	4101256	518	804.77	Available
17255	Kahramanmaraş	315882	4160817	572	721.39	Available
6574	Nurhak	363261	4203197	1400	567.13	
7430	Pazarcık	349691	4149918	770	548.52	
17986	Samandağ	226849	3997516	5	895.45	
7782	Yavuzeli	372989	4131033	570	404.05	

2.2. Daily Total Rainfall Data

Total daily rainfall data is collected from 18 meteorological stations with a recording length ranging from 7 to 46 years, during the period 1970-2015. The average time series per precipitation station is around 28.61 years between the 1970-2015 years.

A preliminary examination of annual rainfall data, which consist of total daily precipitation, showed that some years had been omitted entirely. Table 2-2 lists the data inventory. Note that blue dashed rows represent available data years. The red checkmarks represent minute based available data years for stations.

Rainfall records with continuous and consistent temporal coverage that fairly represent stations characteristic are not usually available for most locations. Also, as seen in Table 2-2, some of the recordings are very short and data start / end years are different for each station.

The difference in the number of years with data available per station results inaccuracy in the calculation of erosivity. To minimize this, data gaps between the years are eliminated and only continuous data is used. For example, Doğanşehir has no data for two years in 1987 and 1988. Therefore, rainfall data until 1986 is omitted and data after 1988 is used.

Even though the data is continuous, it is really important that the correct time interval that represents the data is chosen. Meteorological stations can be in wet or dry periods for years therefore, using correct time interval represent stations character will improve representative model.

Table 2-2: Available data records through years 1970-2015

	Name of Station																	
Years	**Adı**	**Ant**	**Ara**	**Bes**	**Bir**	**Boz**	**Doğ**	**Elb**	**Gaz**	**Gök**	**Göl**	**Has**	**Isl**	**Kah**	**Nur**	**Paz**	**Sam**	**Yav**
1970	√			√	√		√	√	√	√			√	√				
1971	√			√	√		√	√	√	√			√	√				
1972	√			√			√	√	√	√			√	√				
1973	√			√			√	√	√	√			√	√				
1974	√			√			√	√	√	√			√	√				
1975	√			√		√	√	√	√	√			√	√				
1976	√			√		√	√	√	√	√			√	√				
1977	√			√		√	√	√	√	√			√	√			√	
1978	√			√		√	√	√	√	√			√	√			√	
1979	√			√			√	√	√	√			√	√			√	
1980	√			√			√	√	√	√			√	√			√	
1981	√	√		√		√	√	√	√	√			√	√			√	
1982	√	√		√		√	√	√	√	√		√	√	√			√	
1983	√	√		√		√	√	√	√	√		√	√	√			√	
1984	√	√		√	√	√	√	√	√	√	√	√	√	√			√	
1985	√	√		√	√	√	√	√	√	√		√	√	√		√	√	√
1986	√	√		√	√	√	√	√	√	√	√	√	√	√		√	√	√
1987	√	√	√	√	√	√		√	√	√	√	√	√	√		√	√	√
1988	√	√	√	√	√	√		√	√	√		√	√	√		√	√	√
1989	√	√	√	√	√	√	√	√	√	√		√	√	√		√	√	√
1990	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√	√
1991	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	
1992	√	√	√	√	√	√	√	√	√	√		√	√	√		√	√	
1993	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√	
1994	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√	
1995	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	
1996	√	√			√		√	√	√	√	√		√	√			√	
1997	√	√			√		√	√	√	√	√		√	√			√	
1998	√	√			√		√	√	√	√	√	√	√	√	√		√	
1999	√	√			√		√	√	√	√	√	√	√	√	√		√	
2000	√	√			√		√	√	√		√	√	√	√	√		√	
2001	√	√			√		√	√	√		√	√	√	√	√		√	
2002	√	√			√		√	√	√		√	√	√	√	√		√	
2003	√	√			√		√	√	√		√	√	√	√	√		√	
2004	√	√			√		√	√	√		√		√	√	√		√	
2005	√	√			√		√	√	√		√		√	√			√	
2006	√	√			√		√	√	√		√		√	√			√	
2007	√	√			√		√	√	√		√		√	√			√	
2008	√	√			√		√	√	√		√		√	√			√	
2009	√	√			√		√	√	√		√		√	√			√	
2010	√	√			√		√	√	√		√		√	√			√	
2011	√	√			√		√	√	√		√		√	√			√	
2012	√	√			√		√	√	√		√		√	√				
2013	√	√					√		√		√		√	√				
2014	√	√					√		√		√		√	√				
2015	√	√					√				√		√	√				

Data has been analyzed for long-term fluctuations and changes in dry and wet years for each station. Cumulative deviation from mean annual rainfall was constructed for stations which have a long continuous period to investigate inter annual changes.

As in shown in Figure 2-1, stations generally show the same trend throughout the years. All stations in Figure 2-1 show a downwards trend until 1975. After 1976, Göksun and Islahiye rainfall increased until 1988. On the other hand, Kahramanmaraş and Adıyaman show a downward trend until 1986. Around 1988, a short wet period occurred but then until 1996, drought times were present. Between 1998 and 2004, all the stations, except Kahramanmaraş, recorded a wet period. A 4-year drought period is significant after 2004.

Therefore, the drought period for Kahramanmaraş between 1998 and 2004 were actually wet years for all other stations. In 2004, there was a peak for precipitation in generally all stations but after that it shows downward trend again until 2008. It has been increasing from 2008 to the present day. 2012 is the year that most of stations have the highest amount of precipitation for 55 years.

Birecik has a 345.68 mm average annual precipitation between 1984 and 2012. It has a dry period until 1996. After 1996, an increasing precipitation trend is evident. Although Birecik has less annual precipitation compared to Kahramanmaraş, it has a more regular precipitation distribution through time. The drought times of Kahramanmaraş, Gölbaşı and Islahiye between 2004 and 2008 are the wettest year for Birecik station. The reason behind these differences can be physiographic parameters of the study area. Birecik is a very terrestrial station compared to others so drought years in that stations may not affect precipitation in Birecik.

Although their precipitation is nearly the same, Kahramanmaraş elevation is lower compared to Gölbaşı. In general, precipitation has a tendency to increase with elevation proportionally because of the air to be lifted vertically and condensation occurs with adiabatic compression. Therefore, it is expected that Kahramanmaraş has less precipitation due to elevation. Considering both drought and wet time trend differences and elevation, a secondary effective source for precipitation may be the reason of Kahramanmaraş precipitation capacity.

Samandağ and Antakya have generally the same trend through the years (Figure 2-2). After 1996, both of them presented in wet periods. While they show a rising trend between 2007 and 2011, Birecik and Gaziantep show a descending trend.

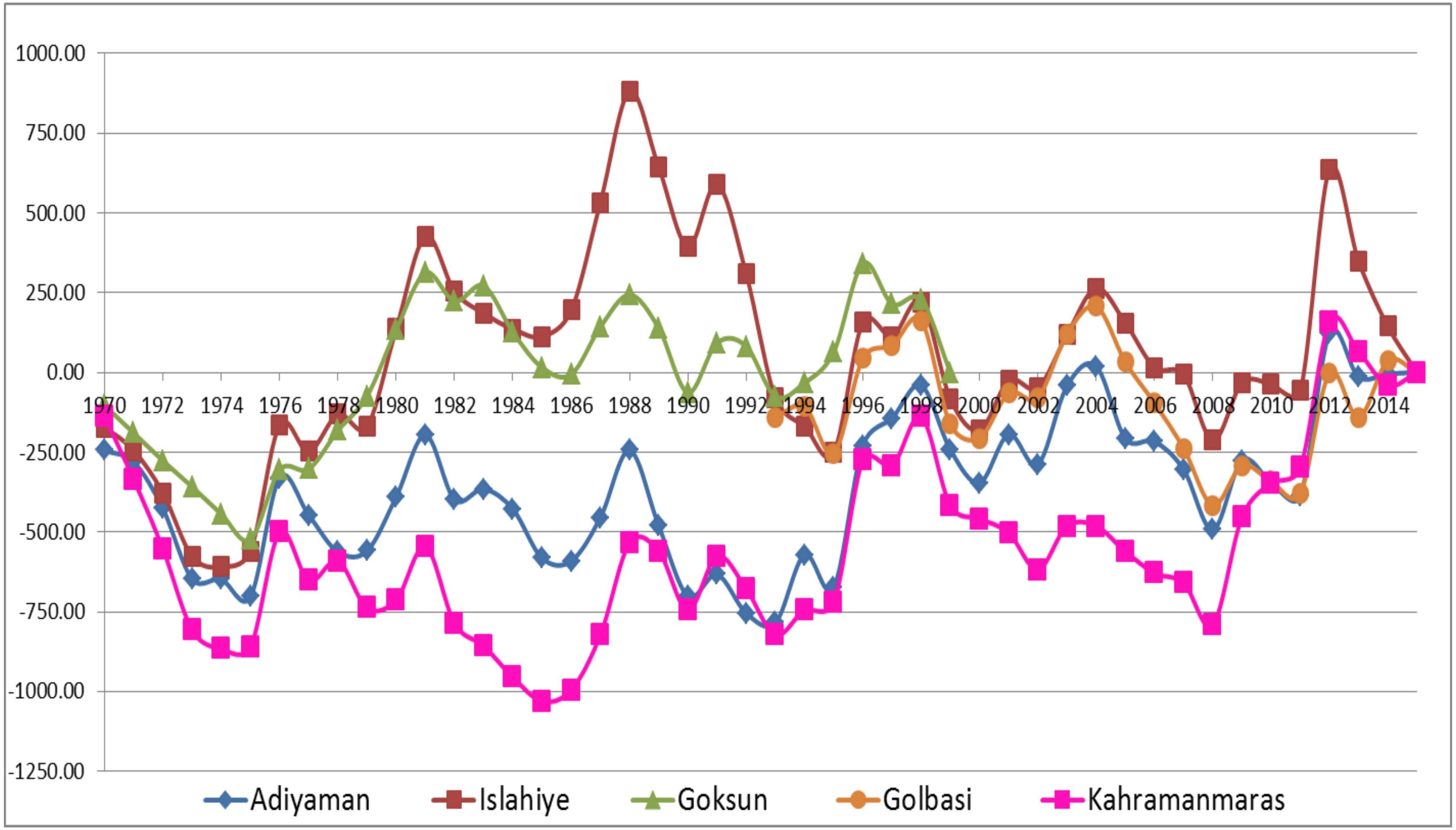


Figure 2-1: Cumulative Deviation from Mean Annual Rainfall for stations Adıyaman, Islahiye, Göksun, Gölbaşı and Kahramanmaraş

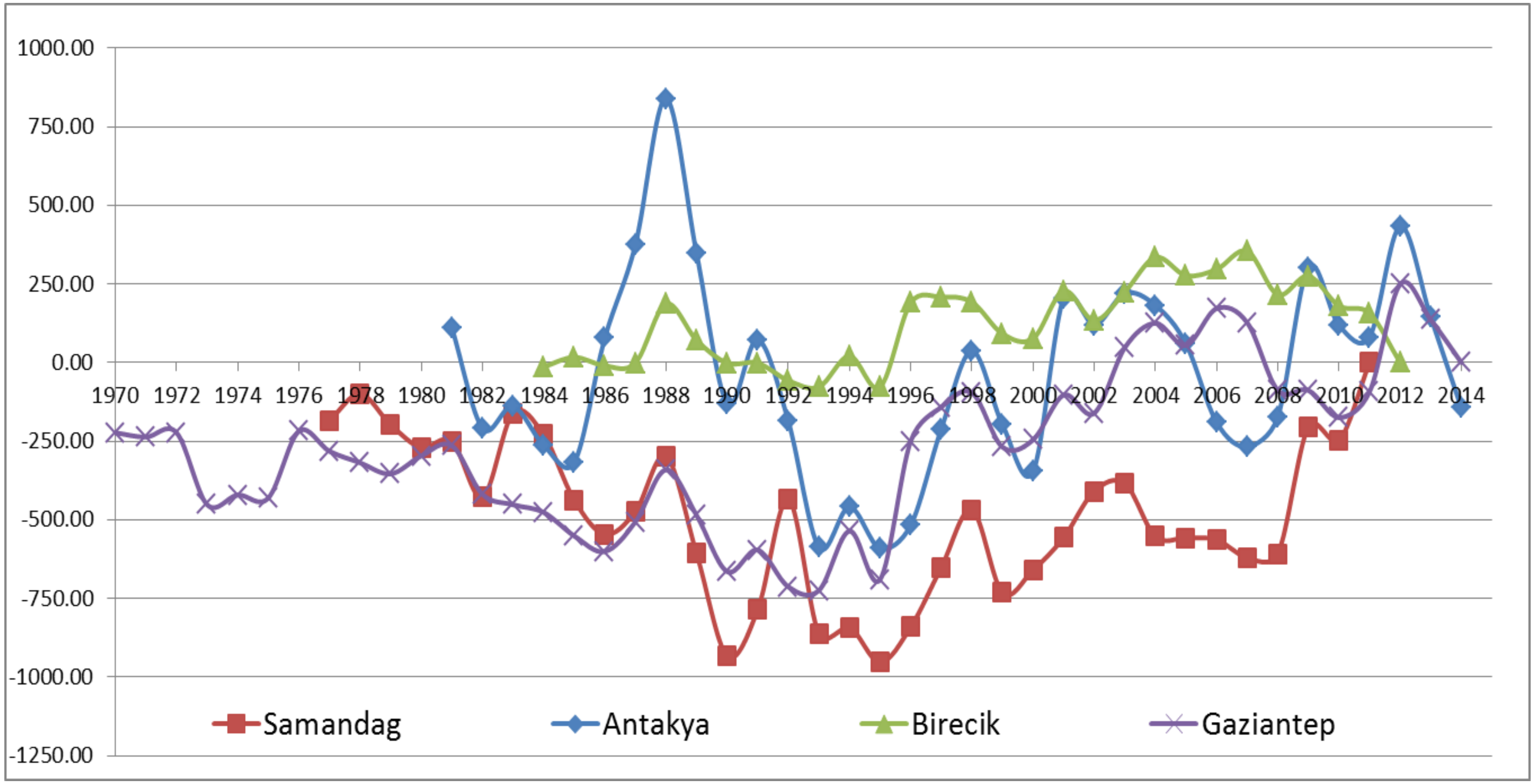


Figure 2-2: Cumulative Deviation from Mean Annual Rainfall for stations Samandağ, Antakya, Birecik and Gaziantep

This analysis showed the regression results between monthly calculations and minute based calculations may be sensitive if data period does not cover the same or different period. Thus, the decision was to consider the complete rainfall data set that was available for each rainfall station.

About half of Turkey is classified as having a continental climate, with peak precipitation occurring in late spring or early summer, whereas the west and southern parts have Mediterranean climate with both winter and late spring precipitation peaks (Şensoy et al., 2008). After analyzing drought and wet periods, monthly wettest seasons and drought season were examined. The graphs showing average monthly precipitation value for stations are listed in Appendix A. The wet and dry periods in a year reveals the rainfall regime of that station. The study area receives most of the rainfall in the winter season due to mean temperature, usually below 5°C, and there is little evaporation. But summer rainfall is very limited and not enough to prevent water deficit resulted from increased temperature and evaporation. January, February and March are the months, which have the most rainfall. April and May have an average rainfall; still Antakya is the station that receives the highest precipitation. Yavuzeli and Birecik have the lowest precipitation amount during spring. Compared to other stations, Göksun receives higher precipitation in summer months.

In September, Samandağ and Antakya have an average almost two times higher than other stations. Therefore, it is expected that rainfall factor for these months for these two stations will be significantly more than the other. October, November and December also have a large proportion of the total annual precipitation. While it is important to analyze how much the total amount of rainfall changed over the years or months, it is also significant to consider frequencies of heavy and light rainfalls. Although, average annual rainfall is similar, the frequency of precipitationscan vary significantly. The differences of erosive powers are highly significant if the total precipitation is 40 mm for a month compared to 40 mm per event.

RUSLE model defined a storm event “erosive” if rainfall volume exceeds 12.7 mm. Therefore, total daily rainfall doesn’t show whether it is erosive event or not and cannot give exactly proportional to rainfall factor but it is still representative.

Table 2-3 shows distribution of total daily rainfall rate in categories between 1993 and 2010. Row wise coloring indicates green colors show lowest distribution ranks in corresponding interval while red ones show highest distribution for that interval. Samandağ is the one receives the most total daily rainfall for interval 48-54 mm, although it is the lowest for interval 1-6 mm. It is also noted that Antakya has the highest value (511), Elbistan has the lowest value (149) when accumulating number of days rainfalls exceeding 12 mm. Therefore, it is expected that rainfall factor of Antakya will be higher than of Elbistan.

Table 2-3: Distribution of Total Daily Rainfall Amount between 1993 and 2010

Intervals	Adı.	Ant.	Bir.	Doğ.	Elb.	Gaz.	Göl.	Isl.	Kah.	Sam.
1-6mm	536	516	514	701	689	595	564	563	569	489
6-12mm	257	281	208	265	245	267	270	266	289	308
12-18mm	137	162	86	129	89	129	147	149	163	141
18-24mm	88	133	33	67	34	72	86	89	94	102
24-30mm	46	72	22	19	15	40	44	58	53	62
30-36mm	31	51	15	13	2	24	30	37	34	39
36-42mm	28	36	1	7	8	11	20	24	20	24
42-48mm	13	18	2	3	1	6	12	15	12	14
48-54mm	6	8	0	1	0	7	12	10	7	13
54-60mm	6	8	0	0	0	1	5	7	6	10
60-66mm	3	15	0	2	0	1	2	5	1	9
66-72mm	2	4	0	0	0	1	1	2	1	5
72-78mm	2	4	0	0	0	0	0	1	1	3
>78mm	0	20	0	0	0	0	3	0	0	11
Number of days >12mm	**362**	**511**	**159**	**241**	**149**	**292**	**359**	**397**	**392**	**422**
Ave. Prep. btw 1993-2010	**710.52**	**1108**	**358.9**	**511**	**386.4**	**583.9**	**714.8**	**807.3**	**739.9**	**905.8**

Figure 2-3 shows total daily precipitation frequency distribution between 1993 and 2010. Doğanşehir and Elbistan have the highest frequency of 1-6 mm band but they have a few events in higher amount. Samandağ represents the opposite condition; it has the lowest frequency in 1-6 mm band, although it has one of highest frequency of higher amount of precipitation.

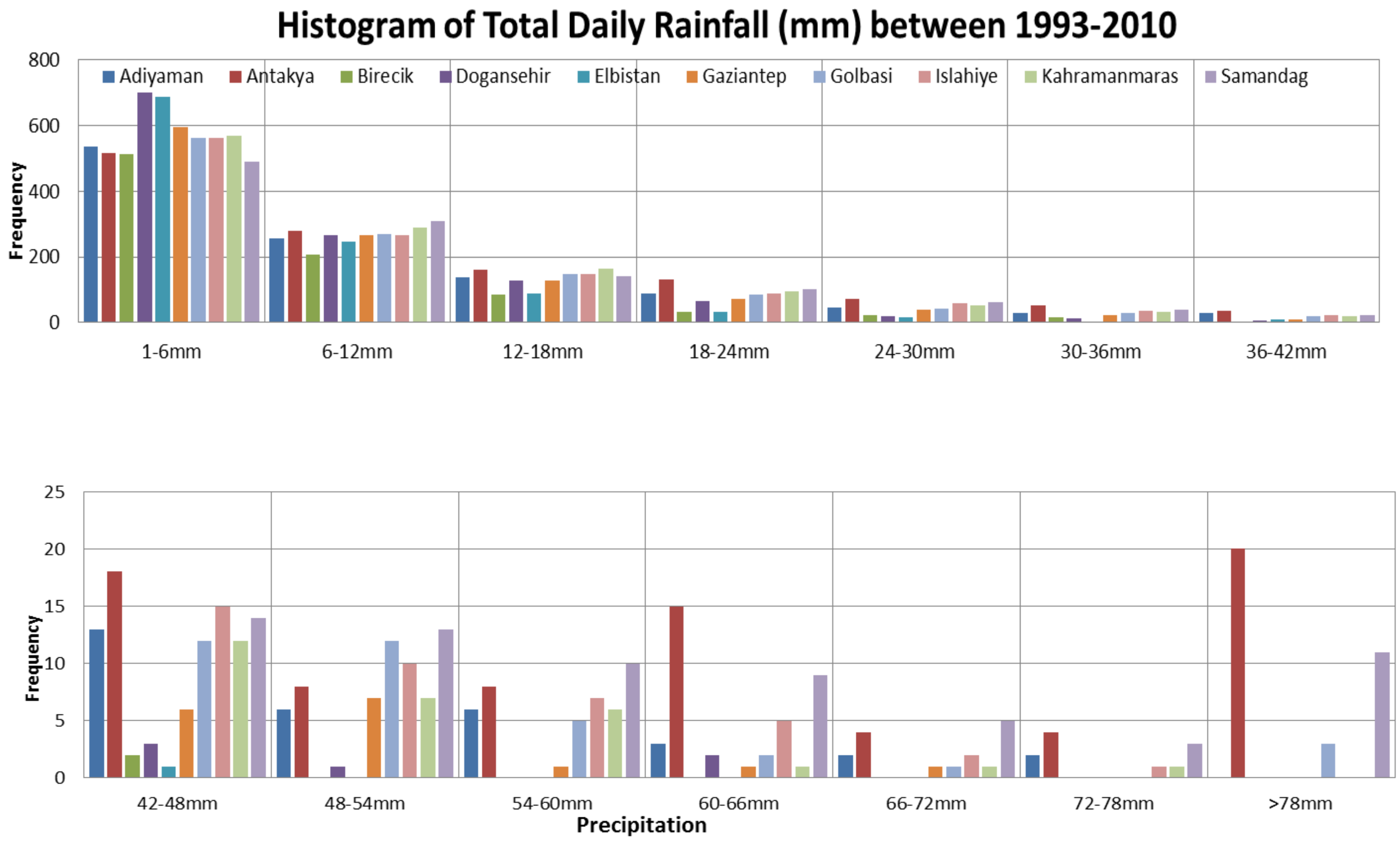


Figure 2-3: Distribution of Total Daily Rainfall (mm) between the years 1993 and 2010

2.2.1. Minute Based Rainfall Data

It is not possible to get a high resolution temporal precipitation data for every station in Turkey. Only major meteorological stations recently started recording minute-based data. Six major meteorological stations, namely Adıyaman, Antakya, Doğanşehir, Islahiye, Gölbaşı and Kahramanmaraş in study area have a 10-minute interval data between 2010 and 2015. The data is acquired from Turkish State Meteorological Service in January, 2017.

2.3. Physio-geographic Data

Precipitation in Turkey presents complex interrelationship between topography, elevation and local orographic features. Despite elevation is the main agent of the annual precipitation amount, climatic variability and proximity from sea may influence rainfall regime.

2.3.1. Digital Elevation Model

The 25 m cell sized digital elevation model (DEM) of the catchment area is produced by using the 1:25 000 scale topographical maps (Figure 2-4). Based on the DEM, the internal relief of the catchment is 1750 meters and ranges between 680 to 2470 meters. For the widespread area, ASTER DEM with a resolution of 30 meter is used.

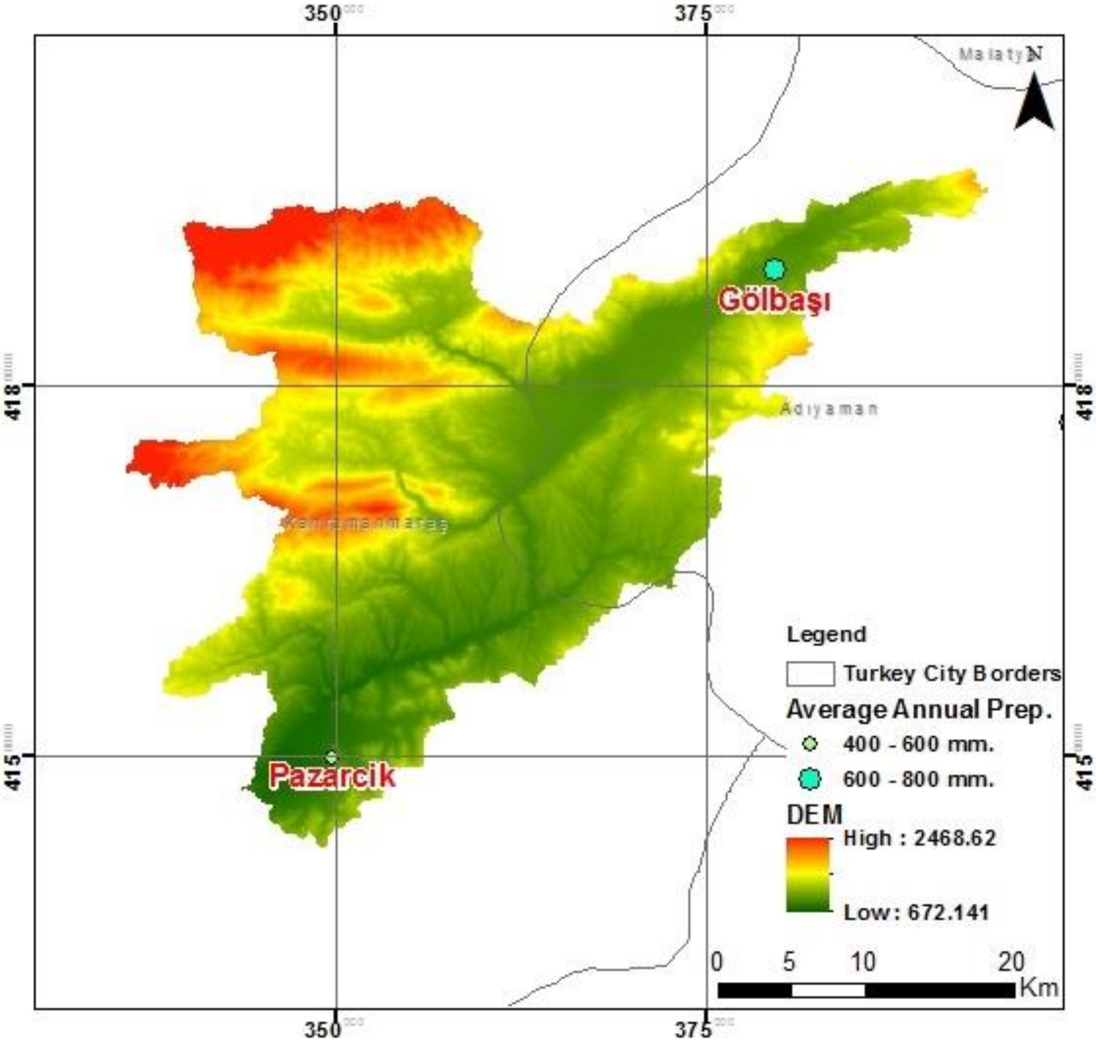


Figure 2-4: Digital Elevation Model of Kartalkaya Dam Catchment Area

2.3.2. Distance from the sea

Turkey is surrounded by sea on three sides. The Mediterranean Sea is the primary source for moist air masses causing the abundant rainfall over the windward slopes of the coastal mountain ranges and the interior mountains of the country (Türkeş, 1996). Therefore, proximity to coastal areas is considered as the one of the climatic controls of precipitation.

The sea affects the climate of the region. Coastal areas are cooler and wetter than inland areas. Clouds form when warm air from basin areas meets cool air from the sea. Moving away from the sea affects and influences both temperature and rainfall. To understand the precipitation fluctuations from coastline to watershed, 25 m cell size, distance from sea raster is produced by using the shoreline in Figure 2-5.

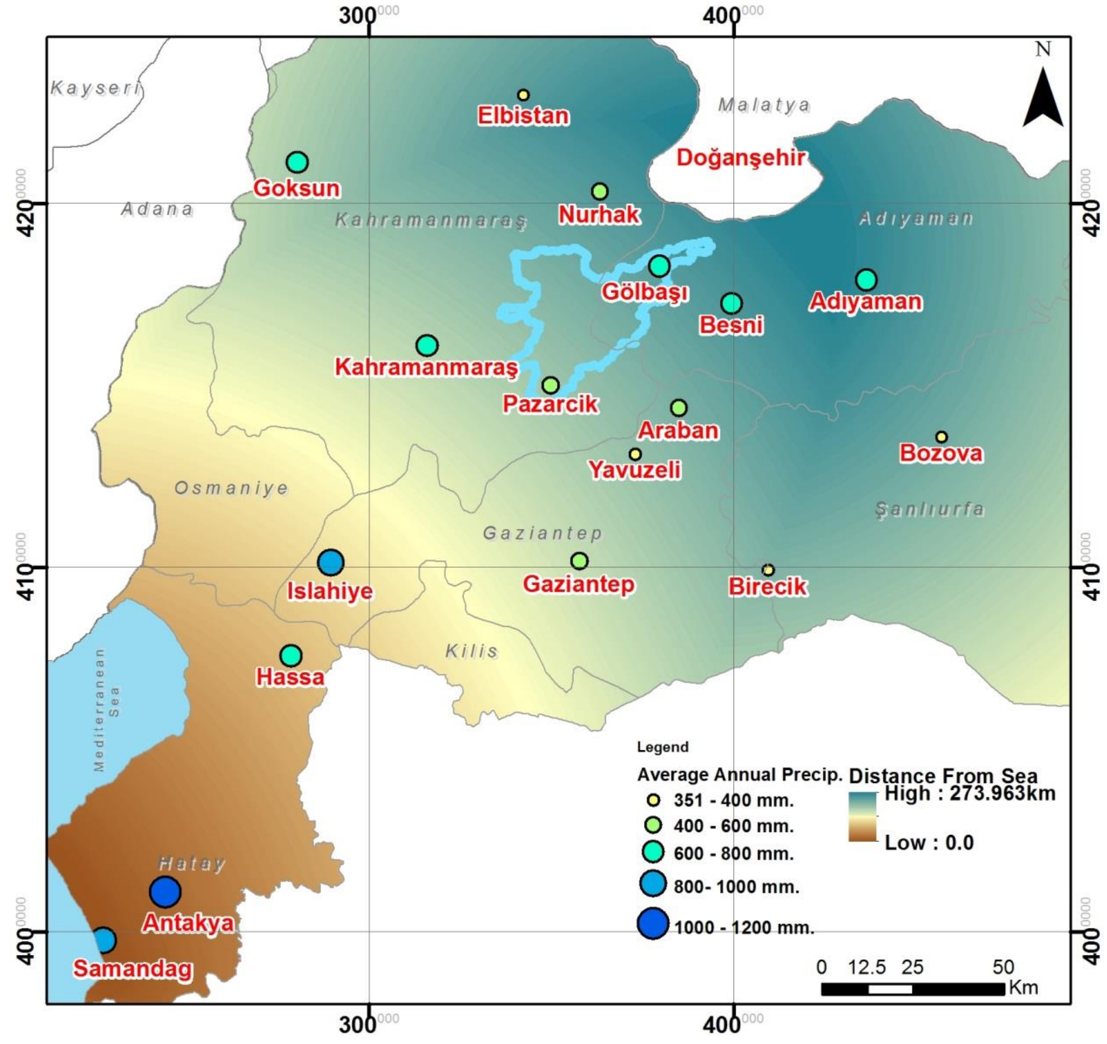


Figure 2-5: Raster map showing meteorological stations distance from sea

2.3.3. Features of the catchment area

Ceyhan River Watershed covers an area about 1060 km^2 and feeds Kartalkaya Dam. The watershed has a mountainous catchment with deep valleys in the north and gentle slopes to the south. The catchment area has a semi-arid climate. The highest temperature of the catchment is 39,5^{O}C and lowest temperature is 1,2^{O}C (DMI, 2013).

2.4. Relation between rainfall and physiographic data

Elevation is an important factor controlling precipitation in Turkey. Therefore, digital elevation models are important sources of information for developing soil erosion models, in particular for regions where rainfall stations are widely dispersed. Due to limited availability of rainfall data and meteorological stations, one of the most common approaches consists of deriving the precipitation value directly from elevation through the watershed (Goovaerts, 1999)

Another straightforward approach is to interpolate the available precipitation data directly using Thiessen polygons or inverse distance method. To ensure unbiased estimation, using secondary variables can improve estimation instead of direct interpolation. This study has reviewed different ways to incorporate information from auxiliary variables in interpolation of rainfall data.

Measured rainfall data are important to model and calculate erosion. To analyze rainfall data, the best method is to combine all available information on rainfall including data from hourly point observations, minute based information, physiographic factors such as elevation, and applying interpolation or merging methods.

In general, precipitation is affected by topography and elevation. Higher elevation areas like mountains drain air of its moisture. As the air rises up the hill of the mountains, it cools and loses its ability to hold water, condenses and falls as a raindrop. Therefore, the most susceptible areas to erosion are located at higher elevations and usually coincide with steep slopes.

There is a common trend between elevation and precipitation and as elevation increases the rainfall factor or precipitation also increases. However, in contrast to the general trend, the relations between stations average precipitation and elevation is inversely proportional within the study area. Results from the stations within the study area have shown that as elevation increases, precipitation decreases. This reverse relationship cannot be used for interpolation in all of the study area stations.

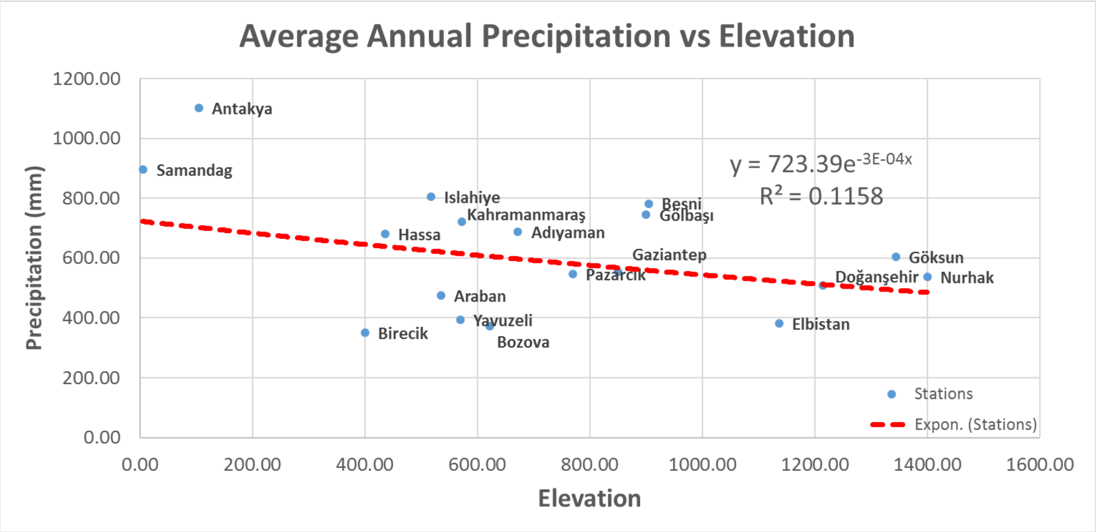


Figure 2-6 : Relationship between meteorological stations annual precipitation and elevation

As shown in Figure 2-6, precipitation is decreasing with an increase in elevation within the study area. Nurhak Station has the highest elevation value and only receives 537 mm. average annual precipitations per year. Although Samandağ and Antakya have the lowest elevations, they have the highest precipitation compared to inland stations such as Birecik and Bozova. Also, Islahiye receives 804.77 mm average precipitation although its elevation is lower than Besni and Gölbaşı.

When stations were grouped by geographic location and annual precipitation, it is shown that elevation is the main controlling factor for some parts of the study area but it is not the main control of precipitation in the remaining parts.

This inverse relationship between precipitation and elevation may be explained by the fact that, rainfall that is influenced by sea could be more significant close to coastal areas, but decreases with distance, finally becomes less significant compared to elevation.

The reason for that relationship is, as shown in Figure 2-7, moist air travelling inland from the coastline to the catchment area, comprising mountain ranges to the west and relatively flat areas to the east will not travel across the mountainous terrain on the west and will instead cross the relatively flat region until it reaches the Kahramanmaraş Region.

This is similar to the effect of the Taurus Mountains where Mediterranean air masses are unable to penetrate inland resulting in heavy rainfall along the coastline. These air masses are unable to retain moisture content and release precipitation along mountains.

Therefore, inland areas with higher elevation receive less precipitation compared to coastal areas. This is the reason why areas of low elevation, but in close proximity to the coastline such as Antakya, Hassa, Islahiye have higher levels of precipitation compared to basin stations. This is demonstrated at Kahramanmaraş, which is affected by the moist air coming from sea due to its location in front of high elevations. It has an elevation of just 572 m, but receives a high volume of average total annual precipitation due to the effect of air masses coming from both the sea and elevation.

If elevation were the only factor influencing rainfall, being independent from distance to sea, rainfall would increase with distance from the sea, since terrain at higher altitudes is typically found further away from the sea than that at lower altitudes.

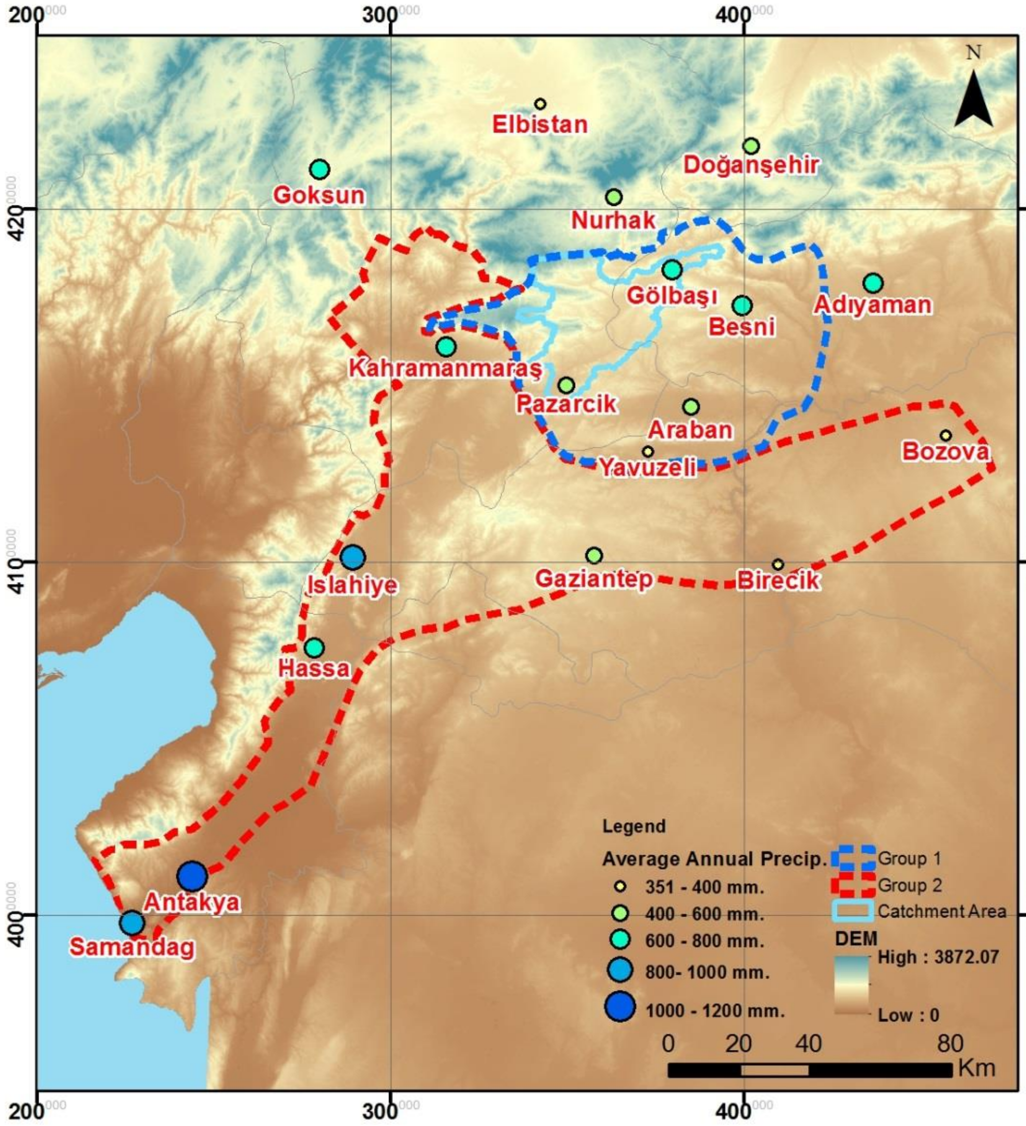


Figure 2-7: Meteorological Stations grouped by main erosive factor cause rainfall

When stations within the study area were grouped by geographic location and annual precipitation, it is shown that elevation can be a factor for some part of study area, but it is not the main cause of rainfall in everywhere. The comparison of the study area stations physiographical attributes and precipitation can be divided two groups based on the main erosive agent.

For the area located within the blue line in Figure 2-7, the relationship between the elevation and level of precipitation is strong enough for using elevation as secondary parameter.

These stations also shown in Figure 2-8, such as Pazarcık, Yavuzeli, Araban, Gölbaşı and Besni precipitation levels have a high correlation with elevation. They will be named as Group 1 stations in next chapters.

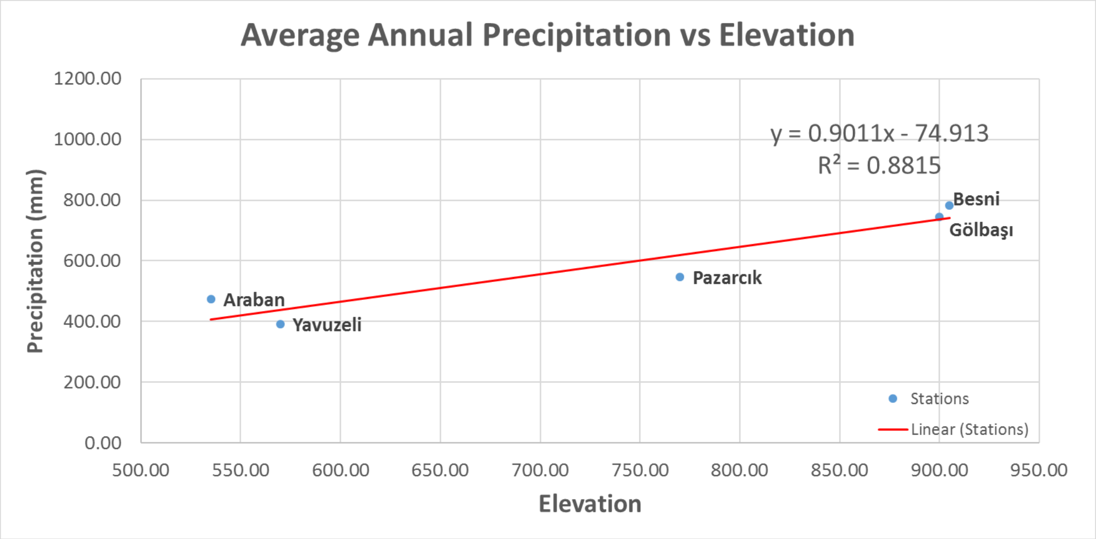


Figure 2-8: Relationship between Annual Precipitation and Elevation for Group 1

The stations within red line in Figure 2-7 such as Samandağ, Antakya, Hassa, Islahiye, Kahramanmaraş, Gaziantep, Birecik and Bozova, average annual precipitation is decreasing away from the sea respectively. Also, Figure 2-9 demonstrates the relationship between precipitation and distance from sea for those stations. They will be named as Group 2 stations in next chapters.

The analysis presented has proved that precipitation within the study area does not only relate to elevation and is also controlled by the distance from the coastline.

After rainfall factor has been calculated using available dataset, the same relationships between physiographic parameters and calculated rainfall factor will be investigated in next chapters.

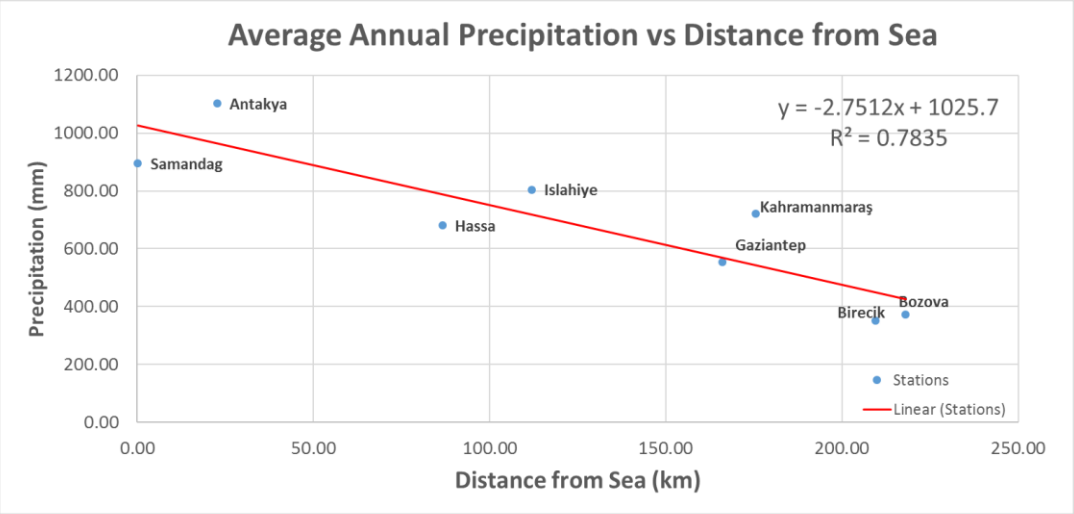


Figure 2-9: Relationship between Annual Precipitation and Distance from Sea for Group 2

CHAPTER 3

METHODOLOGY

3.1. Rainfall factor estimation methods

The rainfall erosivity factor (R) can be calculated in several ways. For this study, due to the limitation in the available data which comprises only 10 minute data for 6 station and daily data for 18 stations the two most common methods were used: The flow diagram presented in Figure 3-1 explains the steps for estimation of rainfall factors.

- Modified Fournier Index using total monthly precipitation values
- Calculation of RUSLE R formula using 10-minute precipitation value

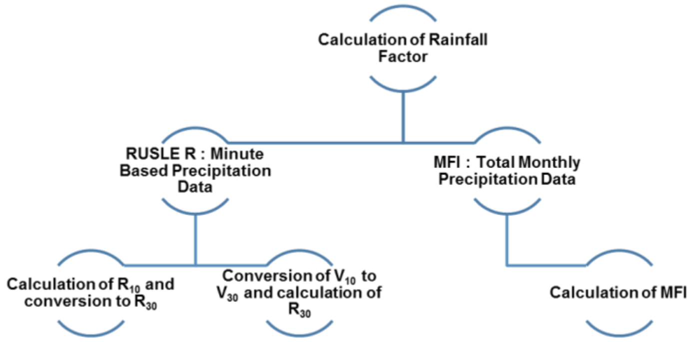


Figure 3-1: Flowchart for rainfall factor estimation

3.1.1. Calculation of RUSLE Form Rainfall Factor

10-minute data for stations Antakya, Adıyaman, Doğanşehir, Gölbaşı, Islahiye and Kahramanmaraş were collected for the period of 2010-2015. In RUSLE, R factor is computed as a sum of R factors of individual erosive events in a year. However, Wischmeier and Smith (1978) suggested a set of standard criteria for the RUSLE method in specifying erosive rainfall events.

According to RUSLE, an event is erosive if these three criteria are met;

(i) the cumulative rainfall is greater than 12.7 mm, or

(ii) the cumulative rainfall has at least one peak greater than 6.35 mm in 15 min.

(iii) Two consecutive storms are considered different from each other if the cumulative rainfall is less than 1.27 mm. in a period of 6 hours.

Therefore, the data was filtered to take into consideration the criteria and only rainfall events that met these criteria have been considered. Table 3-1 shows the number of RUSLE erosive rainfall events per station between 2010 and 2015. An average of 13.16 erosive rainstorms per year was observed, ranging from 10.16 at Doğanşehir station to 15.3 at Antakya station.

Table 3-1: Number of Erosive Rainfall Events in 2010-2015

	Number of Rainfall Event					
Station Name	2010	2011	2012	2013	2014	2015
Antakya	10	14	24	15	11	18
Adıyaman	9	9	22	8	14	20
Doğanşehir	7	7	15	9	11	12
Islahiye	4	10	25	17	6	13
Gölbaşı	10	13	20	12	15	13
Kahramanmaraş	14	15	18	12	13	9

The erosive power of a storm is defined as rainfall erosivity factor (R-factor) based on duration, magnitude and intensity of each rainfall storm.

$$R = \frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{mj}(EI_{30})_k \qquad (7)$$

- R, average annual rainfall erosivity
- E, total storm kinetic energy
- I_{30}, maximum 30-min rainfall intensity
- n, the number of years used to calculate R
- m_j, the number of erosive events of a given year j
- k, the number of storms in a year
- j, number of years to calculate the average

According to the Equation (7), R-factor is the sum of EI_{30} value of erosive events during a time interval. In formula, EI_{30} is calculated by multiplication of total storm kinetic energy and maximum 30-min rainfall intensity of an erosive storm. The most robust method to calculate EI_{30} is to take the breakpoint rainfall intensity data manually collected from rain gauges, which are produced in the form of graphical charts. The graphical charts show both the time and cumulative rainfall depth as originally recorded by the pluviometer type rain gauges. The differences between the two consecutive data pairs represent a breakpoint of rainfall event.

Due to difficulty in obtaining this data, EI_{30} calculation methods have been developed by using alternative data like yearly, monthly and daily rainfall data (Ateshian, 1974; Arnoldus, 1977; Richardson et al., 1983; Ferro et al., 1991; Renard and Freimund, 1994; Yu and Rosewell, 1996b; Zhang et al., 2002).

Generally, automatically recorded fixed interval rainfall data is available in many areas in Turkey. There are several studies that use fixed time interval precipitation data, such as 10-min or 60-min, to calculate EI_{30} using a conversion factor.

In RUSLE (Renard et al., 1997), both 60-min and 15-min temporal resolution rainfall data have been used to extrapolate data for a wider area. Renard (1997) introduced that regression slope coefficients varying from 1.08 to 3.16 between $(EI_{30})_{15}$ and $(EI_{30})_{60}$. Panagos (2015), also collected rainfall data from 5 to 60-min for all over Europe and calculate R using different resolutions.

For this study, data for 10 minute rainfall volume (mm) were aggregated to 30 minute rainfall volume periods and the R- factor was calculated using both 10-min and 30-min resolutions. Conversion functions from previous studies were used for the calibration of different temporal resolutions. The 30-min (0.5-h) intensity, I_{30} ($mm \cdot h^{-1}$) was calculated according to Equation (8).

$$I_{30} = \frac{P_{30}}{0.5h} \tag{8}$$

Then, unit rainfall energy (e_r) is calculated of each 30 minute using Equation (9).

$$e_r = 0.29 * \lceil 1 - 0.72 * \exp(-0.05 * i_r) \rceil \tag{9}$$

Unit rainfall energy e_r multiplied by rainfall volume v_r (mm) during a time period gives kinetic energy of each rainfall interval (Eqn. 10). According to Equation (11), R-factor is the product of kinetic energy of a rainfall event (E) and its maximum 30-min intensity (I_{30}) for each storm in “n” year period (Brown and Foster, 1987).

$$\text{KEJ} = (e_r * v_r) \tag{10}$$

$$EI_{30} = (\textstyle\sum_{r=1}^{0} e_r * v_r) * I_{30} \tag{11}$$

To calculate EI_{30}, 10 minute data intervals are combined to give 30 minute data sets, which are used calculate R_{30} directly without taking into account a calibration factor.

Table 3-2 presents calculation of one erosive event`s rainfall factor R_{30} which took place on 31th of January, 2015 for Islahiye station. P_{30} is the accumulated precipitation of three continuous 10-min intervals. Due to time intervals some recorded data pairs have different gaps such as 20 min or 1 hour, time interval data also converted minute based. Just like, a rainfall started at 0:30 AM and finished at 14:40 PM (Table 3-2). Although there is a no precipitation period between 6:00 AM and 9:40 AM, it still meets the RUSLE criteria because gap is less than 6 hours and cumulative rainfall precipitation is 16.60 (> 12.7 mm). 30-min intensities are calculated based on 30 minute total precipitation divided by duration of time (Equation 8). Then, unit rainfall energy is calculated using Equation 9. By multiplying unit rainfall energy by total precipitation volume for 30min, kinetic energy for each 30 minute interval is calculated (Eqn. 10).Maximum 30-min intensity occurs between 13:10 and 13:40 with 2.60 mm rainfall at a rate of 5.20 mm/h. The total kinetic energy of rainfall storm is 1.77 MJ/ha, so the rainfall factor R of this erosive event is 9.18 MJmmha^{-1} h^{-1} yr^{-1}.

Table 3-2: Calculation of I_{30}, KEJ and R_{30}

ISLAHIYE STATION – 31 / 01 /2015						
Time	***V_{10}(mm)***	***V_{30} (mm)***	***Time(in hour)***	***I_{30}***	***e_r***	***KE_j***
0:30	0.40					
0:40	0.40					
0:50	0.00	0.80	0.50	1.60	0.10	0.08
1:00	0.20					
1:10	0.20					
1:20	0.20	0.60	0.50	1.20	0.09	0.06
1:30	0.80					
1:40	0.80					
1:50	0.00	1.60	0.50	3.20	0.11	0.18
2:00	0.00					
2:10	0.00					
2:20	0.00	0.00	0.50	0.00	0.08	0.00
2:30	0.20					
2:40	0.20					
2:50	0.00	0.40	0.50	0.80	0.09	0.04
3:00	0.00					
3:10	0.20					
3:20	0.20	0.40	0.50	0.80	0.09	0.04
3:30	0.60					
3:40	0.60					
3:50	0.00	1.20	0.50	2.40	0.10	0.13
4:00	0.00					
4:10	0.20					
4:20	0.00	0.20	0.50	0.40	0.09	0.02
4:30	0.60					
4:40	0.60					
4:50	0.20	1.40	0.50	2.80	0.11	0.15
5:00	0.00					
5:10	0.00					
5:20	0.20	0.20	0.50	0.40	0.09	0.02
5:30	0.40					
5:40	0.40					
5:50	0.20	1.00	0.50	2.00	0.10	0.10
6:00	0.00					
6:10	0.00					

Table 3-2 (cont’d),

ISLAHIYE STATION – 31 / 01 /2015						
Time	***V_{10}(mm)***	***V_{30} (mm)***	***Time(in hour)***	***I_{30}***	***e_r***	***KE_j***
6:20	0.00	0.00	0.50	0.00	0.08	0.00
6:30	0.00					
6:40	0.00					
6:50	0.00	0.00	0.50	0.00	0.08	0.00
7:00	0.00					
7:10	0.00					
7:20	0.00	0.00	0.50	0.00	0.08	0.00
7:30	0.00					
7:40	0.00					
7:50	0.00	0.00	0.50	0.00	0.08	0.00
8:00	0.00					
8:10	0.00					
8:20	0.00	0.00	0.50	0.00	0.08	0.00
8:30	0.00					
8:40	0.00					
8:50	0.00	0.00	0.50	0.00	0.08	0.00
9:00	0.00					
9:10	0.00					
9:20	0.00	0.00	0.50	0.00	0.08	0.00
9:30	0.20					
9:40	0.20					
9:50	0.00	0.40	0.50	0.80	0.09	0.04
10:00	0.00					
10:10	0.20					
10:20	0.20	0.40	0.50	0.80	0.09	0.04
10:30	0.80					
10:40	0.80					
10:50	0.20	1.80	0.50	3.60	0.12	0.21
11:00	0.20					
11:10	0.00					
11:20	0.00	0.20	0.50	0.40	0.09	0.02
11:30	0.60					
11:40	0.60					
11:50	0.20	1.40	0.50	2.80	0.11	0.15
12:00	0.40					
12:10	0.20					
12:20	0.20	0.80	0.50	1.60	0.10	0.08
12:50	0.20					
13:00	0.00					
13:10	0.20	0.40	0.83	0.48	0.09	0.03
13:20	0.20					
13:30	1.20					
13:40	1.20	2.60	0.50	**5.20**	0.13	0.34
13:50	0.20					
14:00	0.20					
14:10	0.00	0.40	0.50	0.80	0.09	0.04
14:20	0.00					
14:30	0.20					
14:40	0.20	0.40	0.50	0.80	0.09	0.04
	P_{total}	**16.60**	**MAX I_{30}=**	**5.2**	**Sum**	**1.77**
R= 9.18 MJmmha−1 h−1 yr−1.						

An alternative method to calculate EI_{30} is to use conversion factors from previous studies. Panagos (2015) developed a conversion factor for a homogenized R factor based on results in Europe using various time-step data. For converting 10-min rainfall factor data to 30-min rainfall factor the following equation 12 is used;

$$R_{30m} = 0.8205 * R_{10m} \qquad (12)$$

Table 3-3 presents the calculation for intensity I_{10}, kinetic energy and rainfall factor R_{10} for the same erosive event. Maximum 30-min intensity occurs between 13:30 and 13:40 with 1.20 mm rainfall in a degree of 7.20mm/h. The total kinetic energy of rainfall event is 1.88 MJ/ha, so the rainfall factor R_{10} of this erosive event is 13.54 MJmmha^{-1} h^{-1} yr$^{-1.}$ Multiplying by the conversion factor in Formula 12, R_{30} can be found as 11.10 MJmmha^{-1} h^{-1} yr^{-1}.In RUSLE, the R factor is computed as a sum of R factors of individual erosive events in a year. Table3-4 lists the sum of all erosive events within each study year for both R_{30} and R_{30con} methods. According to the Figure3-2, there is a strong correlation (R^2=0.98) between R_{30} and R_{30con} factor. So, further calculations are made by using non-converted R_{30} values in Table 3-4. The details of all erosive rainfall events for six stations between 2010 and 2015 are given in Appendix B.

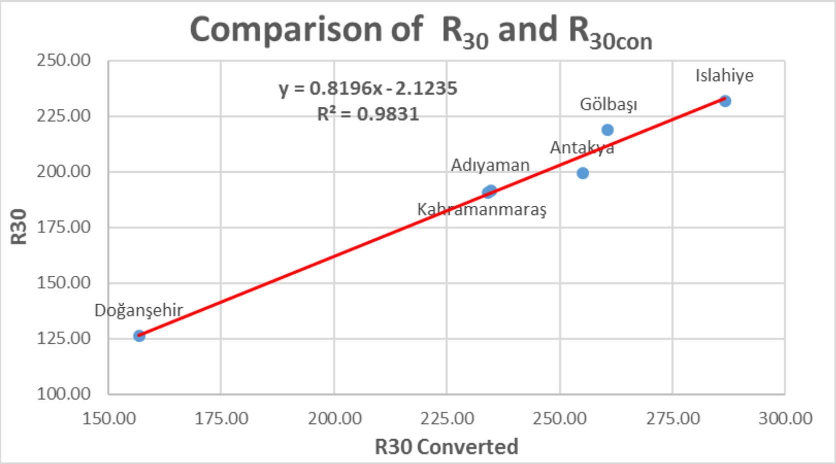


Figure3-2: Comparison of R_{30} and R_{30} converted

Table 3-3: Calculation of I_{10}, KEJ and R_{10}

ISLAHIYE STATION – 31 / 01 /2015					
Time	*V_{10}(mm)*	*Time(in hour)*	*I10*	*e_r*	*KE_j*
00:30	0.4	0.1666667	2.4	0.1	0.04
00:40	0.4	0.1666667	2.4	0.1	0.04
00:50	0	0.1666667	0	0.08	0
01:00	0.2	0.1666667	1.2	0.09	0.02
01:10	0.2	0.1666667	1.2	0.09	0.02
01:20	0.2	0.1666667	1.2	0.09	0.02
01:30	0.8	0.1666667	4.8	0.13	0.1
01:40	0.8	0.1666667	4.8	0.13	0.1
01:50	0	0.1666667	0	0.08	0
02:00	0	0.1666667	0	0.08	0
02:10	0	0.1666667	0	0.08	0
02:20	0	0.1666667	0	0.08	0
02:30	0.2	0.1666667	1.2	0.09	0.02
02:40	0.2	0.1666667	1.2	0.09	0.02
02:50	0	0.1666667	0	0.08	0
03:00	0	0.1666667	0	0.08	0
03:10	0.2	0.1666667	1.2	0.09	0.02
03:20	0.2	0.1666667	1.2	0.09	0.02
03:30	0.6	0.1666667	3.6	0.12	0.07
03:40	0.6	0.1666667	3.6	0.12	0.07
03:50	0	0.1666667	0	0.08	0
04:00	0	0.1666667	0	0.08	0
04:10	0.2	0.1666667	1.2	0.09	0.02
04:20	0	0.1666667	0	0.08	0
04:30	0.6	0.1666667	3.6	0.12	0.07
04:40	0.6	0.1666667	3.6	0.12	0.07
04:50	0.2	0.1666667	1.2	0.09	0.02
05:00	0	0.1666667	0	0.08	0
05:10	0	0.1666667	0	0.08	0
05:20	0.2	0.1666667	1.2	0.09	0.02
05:30	0.4	0.1666667	2.4	0.1	0.04
05:40	0.4	0.1666667	2.4	0.1	0.04
05:50	0.2	0.1666667	1.2	0.09	0.02
06:00	0	0.1666667	0	0.08	0
06:10	0	0.1666667	0	0.08	0
06:20	0	0.1666667	0	0.08	0
06:30	0	0.1666667	0	0.08	0
06:40	0	0.1666667	0	0.08	0
06:50	0	0.1666667	0	0.08	0
07:00	0	0.1666667	0	0.08	0
07:10	0	0.1666667	0	0.08	0
07:20	0	0.1666667	0	0.08	0
07:30	0	0.1666667	0	0.08	0
07:40	0	0.1666667	0	0.08	0
07:50	0	0.1666667	0	0.08	0

ISLAHIYE STATION – 31 / 01 /2015					
Time	*V_{10}(mm)*	*Time(in hour)*	*I10*	*e_r*	*KE_j*
08:00	0	0.1666667	0	0.08	0
08:10	0	0.1666667	0	0.08	0
08:20	0	0.1666667	0	0.08	0
08:30	0	0.1666667	0	0.08	0
08:40	0	0.1666667	0	0.08	0
08:50	0	0.1666667	0	0.08	0
09:00	0	0.1666667	0	0.08	0
09:10	0	0.1666667	0	0.08	0
09:20	0	0.1666667	0	0.08	0
09:30	0.2	0.1666667	1.2	0.09	0.02
09:40	0.2	0.1666667	1.2	0.09	0.02
09:50	0	0.1666667	0	0.08	0
10:00	0	0.1666667	0	0.08	0
10:10	0.2	0.1666667	1.2	0.09	0.02
10:20	0.2	0.1666667	1.2	0.09	0.02
10:30	0.8	0.1666667	4.8	0.13	0.1
10:40	0.8	0.1666667	4.8	0.13	0.1
10:50	0.2	0.1666667	1.2	0.09	0.02
11:00	0.2	0.1666667	1.2	0.09	0.02
11:10	0	0.1666667	0	0.08	0
11:20	0	0.1666667	0	0.08	0
11:30	0.6	0.1666667	3.6	0.12	0.07
11:40	0.6	0.1666667	3.6	0.12	0.07
11:50	0.2	0.1666667	1.2	0.09	0.02
12:00	0.4	0.1666667	2.4	0.1	0.04
12:10	0.2	0.1666667	1.2	0.09	0.02
12:20	0.2	0.1666667	1.2	0.09	0.02
12:50	0.2	0.5	0.4	0.09	0.02
13:00	0	0.1666667	0	0.08	0
13:10	0.2	0.1666667	1.2	0.09	0.02
13:20	0.2	0.1666667	1.2	0.09	0.02
13:30	1.2	0.1666667	7.2	0.14	0.17
13:40	1.2	0.1666667	7.2	0.14	0.17
13:50	0.2	0.1666667	1.2	0.09	0.02
14:00	0.2	0.1666667	1.2	0.09	0.02
14:10	0	0.1666667	0	0.08	0
14:20	0	0.1666667	0	0.08	0
14:30	0.2	0.1666667	1.2	0.09	0.02
14:40	0.2	0.1666667	1.2	0.09	0.02
	$P_{total=16.60}$	**MAX I10=**	**7.2**	**Sum**	**1.88**
			R_{10}=13.54		**R_{30con} =11.10**

Table 3-4: RUSLE Rainfall Factor

		Antakya	*Adıyaman*	*Doğanşehir*	*Islahiye*	*Gölbaşı*	*Kahramanmaraş*
R_{30}	2010	191.33	161.18	82.24	60.61	226.60	199.35
	2011	166.81	108.41	89.16	183.00	186.49	160.64
	2012	308.78	350.02	193.40	541.40	251.23	281.25
	2013	197.25	115.41	101.66	208.27	188.03	140.21
	2014	87.92	203.33	164.50	110.04	213.21	135.61
	2015	244.17	210.70	125.40	287.29	246.78	225.85
	Ave	**199.38**	**191.51**	**126.06**	**231.77**	**218.73**	**190.49**
R_{30C}	2010	219.37	191.08	82.83	62.54	225.42	239.45
	2011	190.68	130.65	127.84	211.63	213.59	196.11
	2012	370.97	416.52	241.25	672.68	311.06	338.09
	2013	264.65	152.90	133.08	283.11	238.65	179.86
	2014	135.80	234.40	202.65	138.97	272.98	189.78
	2015	349.64	283.49	153.02	350.89	302.50	261.68
	Ave	**255.19**	**234.84**	**156.78**	**286.64**	**260.70**	**234.16**

3.1.2. Calculation of Modified Fournier Index

There are a number of studies in Europe such as the Ebro catchment in Spain (Angulo-Martinez et al., 2009), Germany (Fiener et al., 2013) that have determined R factor directly from sub-hourly precipitation data. It is obvious that more detailed precipitation data gives more accurate erosion model. However, there are many studies that prove the Modified Fournier Index is a preferred substitution of RUSLE rainfall factor (Apaydin et al., 2006; Gabriels, 2006). MFI depends on total precipitation in a month (Pi) and total mean annual precipitation. Arnoldus (1980) proved that F index is a good approximation of R to which it is linearly correlated. Then, Colotti (2004) found the following general equation using the modified Fournier index as an erosion estimate;

$$R = a * \mathrm{MFI} + b \tag{13}$$

Where R is the rainfall erosivity factor, MFI is the modified Fournier index, a and b are two regional fitting parameters. There are many equations which are derived to estimate the value of R for a certain location. The main formula of Modified Fournier Index (MFI) using the mean annual and monthly rainfall amount data improved by Arnoldus (1980):

$$MFI_J = \frac{\sum_{i=1}^{12} p_{i,j}^2}{P_j} \tag{14}$$

In Equation 14, $p_{i,j}$ is the mean rainfall amount for month i (mm) in year j, and P is the mean annual rainfall amount (mm). Also, MFI can be calculated for long-term annual, annual or monthly erosivity as Equation 15. Erosivity for a period of N years can be calculated by (Ferro et al., 1999):

$$MFI_{MA} = \sum_{j}^{N} \sum_{i=1}^{12} \frac{p_{i,j}^2}{P_j} \tag{15}$$

where MFI_{MA} is the average of MFI over a period of N years.

Although Wischmeier and Smith (1978) omitted rains of less than 12.7 mm in their erosion index computations, MFI accepts every rainfall event as an erosive event. The only condition for MFI is a recommendation from Arnoldus (1980) that relations obtained using MFI should be applied only to locations which show homogenous climatic attributes. Therefore, in this stage there is no need to filter or order the data. All precipitations are incorporated to calculate MFI. Later for correlated data with secondary parameters, Arnoldus' (1980) criteria will be considered.Based on available rainfall data, MFI were determined for each station both in average and on an individual year basis. Table 3-5 presents the calculation of MFI average for Antakya Station between 1981 and 2015. Also, MFI is calculated for each year to find a correlation with the rainfall factor in that year.

Table 3-5: MFI Calculation of Antakya Meteorological Station

Year	***January***	***February***	***March***	***April***	***May***	***June***	***July***	***August***	***September***	***October***	***November***	***December***	***Total Annual Precipitation***
1981	309.9	149.4	128.2	107.0	91.5	60.9	0.0	0.2	9.3	21.6	122.6	202.5	1203.1
1982	124.3	102.3	114.8	88.1	18.0	4.3	7.6	0.0	5.5	158.0	46.1	102.6	771.6
1983	113.8	189.0	180.2	77.4	87.5	0.3	0.0	2.0	61.9	29.7	353.6	65.8	1161.2
1984	151.0	134.0	192.8	176.3	1.8	7.2	3.6	3.1	0.0	128.5	88.4	80.9	967.6
1985	233.9	292.6	61.8	51.6	4.9	8.0	0.0	0.0	16.6	195.2	48.6	122.6	1035.8
1986	177.8	232.3	52.8	17.1	430.7	39.5	0.0	0.0	0.1	114.3	199.1	223.7	1487.4
1987	400.1	218.7	292.2	63.1	8.8	0.8	1.1	19.0	2.4	90.6	120.9	169.9	1387.6
1988	205.7	193.7	369.6	40.2	209.2	40.8	2.0	0.0	4.9	77.8	186.6	226.8	1557.3
1989	29.1	28.9	86.6	2.0	50.7	0.7	0.0	0.0	20.4	67.0	174.3	140.3	600.0
1990	94.4	208.3	14.9	13.4	26.6	41.6	0.0	0.0	27.1	95.3	34.6	56.9	613.1
1991	131.0	134.8	104.4	118.1	151.9	0.0	5.5	0.0	110.8	60.5	83.0	394.9	1294.9
1992	64.6	187.8	53.9	31.8	174.4	79.8	17.4	0.0	26.4	1.0	95.4	99.8	832.3
1993	67.5	122.5	153.1	34.1	75.7	6.9	0.0	0.0	0.9	3.1	155.3	71.7	690.8
1994	247.0	366.5	48.7	128.1	40.3	9.0	7.8	21.1	0.4	34.3	142.6	173.4	1219.2
1995	275.2	62.2	130.8	78.4	59.6	25.0	16.7	0.0	28.9	42.1	202.6	38.7	960.2
1996	146.8	68.8	308.4	177.5	2.5	0.9	0.0	2.0	24.8	164.4	24.4	244.8	1165.3
1997	81.6	119.2	207.9	274.2	36.7	0.2	3.0	9.1	217.0	144.3	103.1	201.2	1397.5
1998	137.1	90.1	336.7	91.8	169.9	0.0	1.8	0.0	77.4	30.2	147.9	256.4	1339.3
1999	98.1	186.3	123.7	191.8	0.0	4.5	0.0	1.6	24.2	59.6	24.6	143.5	857.9
2000	310.7	185.7	64.5	116.7	2.8	0.0	0.0	4.0	25.8	41.5	29.5	161.7	942.9
2001	88.4	208.4	128.6	54.4	638.5	0.5	0.0	1.9	17.8	53.3	113.1	337.0	1641.9
2002	204.0	92.9	163.8	234.2	11.6	9.0	0.0	15.2	27.5	30.4	69.2	148.3	1006.1
2003	153.8	272.1	233.9	45.4	46.8	10.8	18.9	0.0	8.4	27.1	127.0	248.5	1192.7
2004	371.3	189.7	30.4	70.6	106.4	0.0	0.0	0.0	0.0	12.8	201.5	70.5	1053.2
2005	91.6	111.6	123.1	82.7	37.2	11.2	6.9	0.0	206.6	71.0	114.7	112.5	969.1
2006	180.5	134.0	182.7	39.0	14.9	0.0	0.0	0.0	62.7	98.2	123.4	6.5	841.9
2007	109.4	198.8	130.4	124.2	32.7	4.4	0.0	0.0	31.9	12.1	158.8	211.0	1013.7
2008	126.1	127.9	109.5	27.3	87.1	21.3	0.0	1.6	276.9	75.5	133.7	199.0	1185.9
2009	165.8	272.0	182.8	293.5	51.4	0.0	5.3	0.0	17.3	15.4	170.0	394.0	1567.5
2010	222.3	124.9	62.9	57.2	39.2	62.9	0.0	0.0	5.8	75.0	0.0	257.2	907.4
2011	106.9	154.8	143.5	130.4	65.1	86.3	0.0	0.0	34.7	82.5	58.6	190.9	1053.7
2012	418.1	243.6	105.2	16.5	97.6	1.6	14.1	0.0	0.0	42.5	164.1	341.2	1444.5
2013	55.5	55.2	67.8	20.7	6.4	70.6	0.0	4.6	98.5	184.4	84.1	155.2	803.0
2014	55.5	55.2	67.8	20.7	6.4	70.6	0.0	4.6	98.5	184.4	84.1	155.2	803.0
2015	336.9	314.9	335.9	79.1	24.6	2.0	0.9	5.0	0.2	68.6	27.7	39.6	1235.4
Average	***173.9***	***166.6***	***145.6***	***90.7***	***83.1***	***19.5***	***3.2***	***2.7***	***44.9***	***74.1***	***114.7***	***172.7***	***1091.5***
P^2	***30233.3***	***27737.5***	***21185.2***	***8227.0***	***6909.9***	***379.3***	***10.4***	***7.4***	***2016.3***	***5485.3***	***13147.6***	***29827.3***	
P^2/P	***27.7***	***25.4***	***19.4***	***7.5***	***6.3***	***0.4***	***0.0***	***0.0***	***1.9***	***5.0***	***12.0***	***27.3***	***133.0***

Long-term MFI values for each station are shown in Figure 3-3 and listed in Table 3-6.

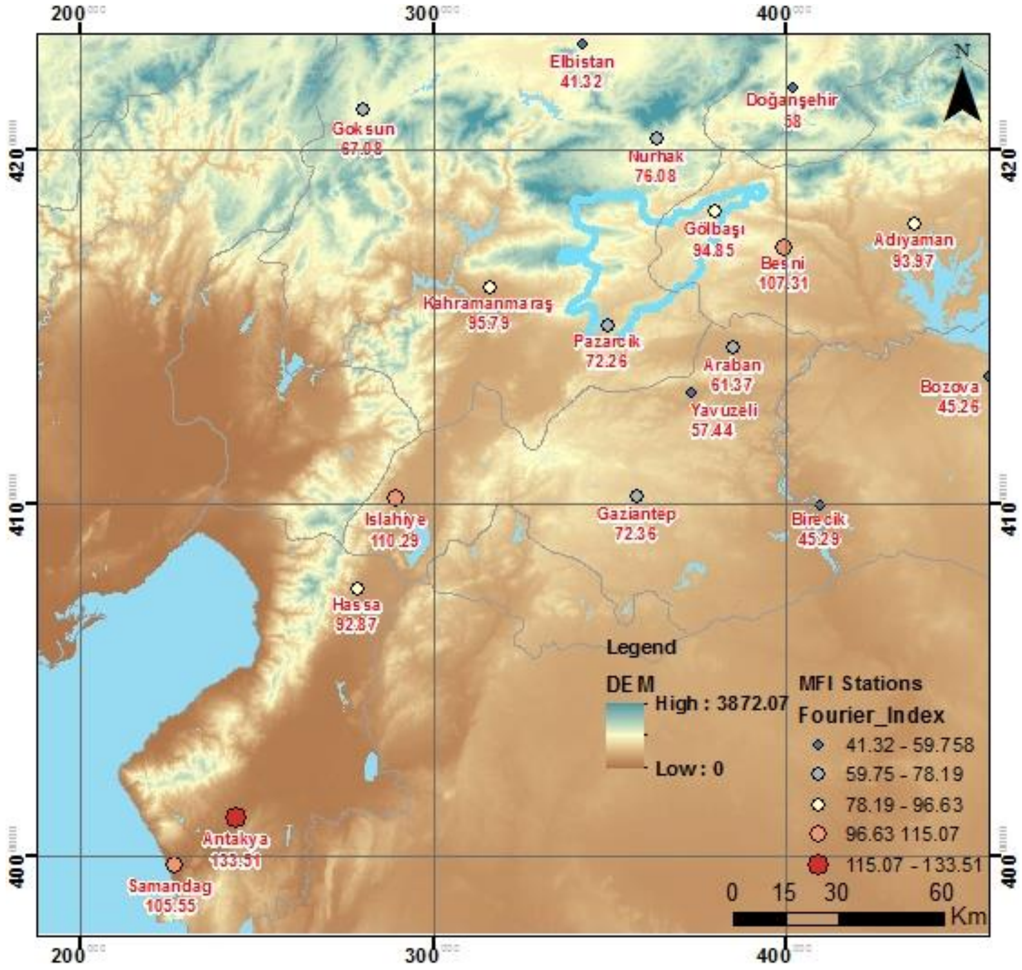


Figure 3-3: Meteorological Stations Average MFI Value

Table 3-6: Average long term MFI Value for Meteorological Stations

Stations	*Fournier Index*	*Stations*	*Fournier Index*
Adıyaman	93.97	Göksun	67.08
Antakya	132.99	Gölbaşı	96.84
Araban	61.37	Hassa	94.01
Besni	110.15	Islahiye	110.65
Birecik	45.29	Kahramanmaraş	95.79
Bozova	45.26	Nurhak	76.89
Doğanşehir	57.90	Pazarcık	72.26
Elbistan	41.32	Samandağ	105.55
Gaziantep	72.36	Yavuzeli	57.44

3.2. Calculated rainfall factor and its correlations

In this study, relations based on MFI and R-factor values for six meteorological stations were used to produce estimation relations. Also secondary parameters such as annual average precipitation, elevation and physiographical factors are used for improvement of results. The results obtained were compared to each other to establish a correlation between low and high temporal data R calculations.

3.2.1. The relationship between Calculated R factor and rainfall data

The R factor value, MFI value and annual average precipitation value in years between 2010 and 2015 are listed in Table 3-7. As established in the literature, there is a relationship between MFI and R for which power function gives the highest coefficient of determination compared to other functions (Figure 3-4). For our study area,

$$Rave = 10.584 * MFI^{0.5869} \qquad R^2 = 0.7792 \qquad (16)$$

Table 3-7: MFI and R values (6 Year Average)

Station Name	R	MFI
Antakya	199.38	193.87
Adıyaman	191.51	138.72
Doğanşehir	126.06	75.08
Islahiye	231.77	166.18
Gölbaşı	218.73	140.38
Kahramanmaraş	190.49	137.59

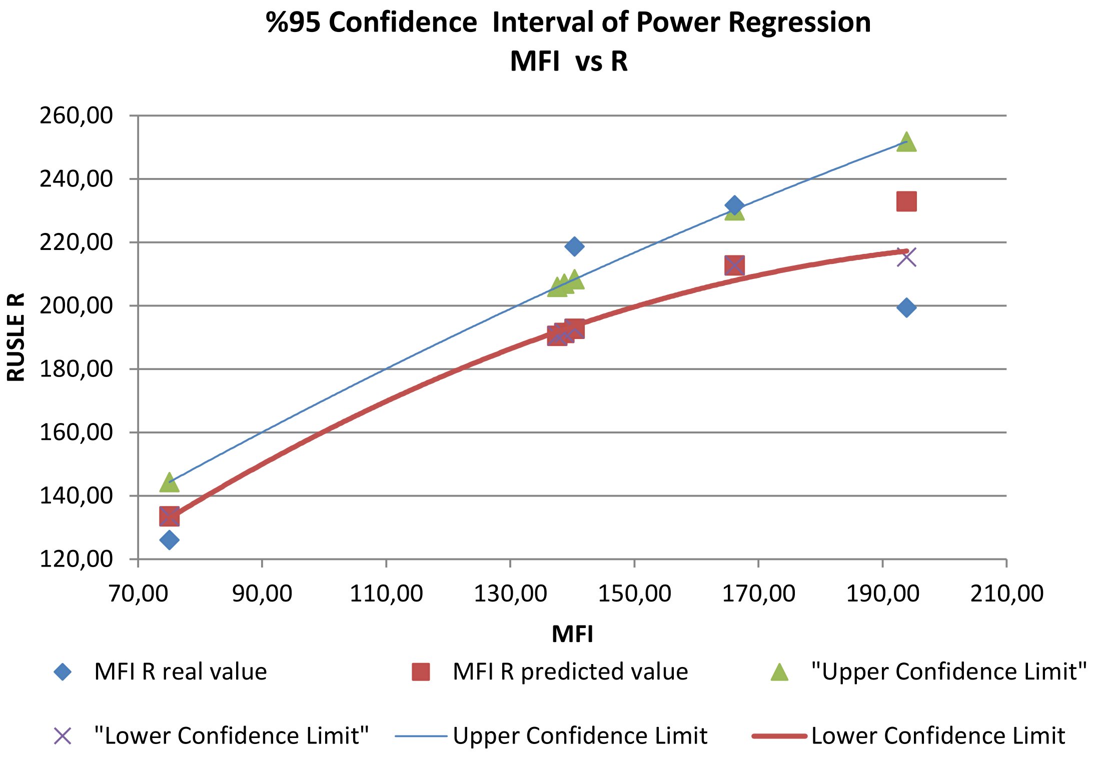


Figure 3-4: Relationship between calculated R and MFI

Although there are some studies that show MFI does not improve R factor estimation (B.Yu, 1996, Lo et al, 1985), comparing MFI versus average annual precipitation (P), in the study area R^2 is significantly improved.

$$R = 3.7357 * P^{0.5927} \qquad R^2 = 0.64 \qquad (17)$$

In the study area, high temporal data is just available in six major meteorological stations. On the other hand, daily data is available for 18 stations surrounding the catchment area. Based on this relationship RUSLE from R value can be calculated everywhere in the study area when high resolution temporal data is not available.

It is notable that when regression analysis is undertaken individually for stations, some data did not show significant correlations with R. For individual stations, when MFI vs R values plotted year by year, coefficient of determination is varying from 0.52 to 0.92 except Doğanşehir Station in Table 3-8. This exception of Doğanşehir occurred due to precipitation occur in specific months not distributed to all year. In 2010, Doğanşehir received 390 mm total precipitation, but this precipitation mainly occurred in January (159.2 mm) and December (86.8 mm). Therefore, these two values enhanced MFI value of 2010, but those rainfall events were not significant in terms of intensity and energy, they did not strongly affect RUSLE rainfall factor. Higher MFI values like those caused by monthly extreme rainfalls represent outliers for the calibration. However, even though these outliers are not important for RUSLE, they are important for erosion due to increase surface flow and risk of landslide.

Monthly erratic changes in rainfall can underestimate or overestimate MFI values. When examining average values for both rainfall factor and Fournier these extreme values act as a negligible factor. For years such as 2010 for Doğanşehir with an extreme monthly value, erosivity should be calculated in terms of events.

High temporal variability and flashy characteristics are main characteristic of Mediterranean rainstorms. From the annual precipitation data, it is known that Antakya is the wettest station compared to other stations, with maximum precipitation volume at nearly 1100 mm between 2010 and 2015. However, its rainfall erosivity value is not the highest.

Rainfall erosivity should be correlated with rainfall intensity, not the total precipitation. The higher the rainfall intensity, the higher the rainfall erosivity value will be. The highest rainfall volume may not be always the highest rainfall factor because it depends on energy and intensity of erosive events. In the literature, there are also studies that show high values of annual precipitation do not necessarily produce higher values of erosivity (Mello et al., 2007).

Table 3-8: Station Basis R and MFI correlation for 2010-2015

		Antakya	*Adıyaman*	*Doğanşehir*	*Islahiye*	*Gölbaşı*	*Kahramanmaraş*
R	2010	191.33	161.18	82.24	60.61	226.6	199.35
	2011	166.81	108.41	89.16	183	186.49	160.64
	2012	308.78	350.02	193.4	541.4	251.23	281.25
	2013	197.25	115.41	101.66	208.27	188.03	140.21
	2014	87.92	203.33	164.5	110.04	213.21	135.61
	2015	244.17	210.7	125.4	287.29	246.78	225.85
MFI	2010	164.81	167.86	95.86	164.82	182.53	172.71
	2011	125.8	91.46	70.69	110.09	108.72	114.93
	2012	277.17	232.63	78.96	331.9	231.18	219.68
	2013	207.26	98.76	56.38	127.11	93.91	82.7
	2014	113.41	103.91	74.7	115.71	100.95	84.11
	2015	274.75	137.68	73.89	147.45	125.01	151.4
Annual Precip.	2010	907.4	619.4	390	802	724.2	829.1
	2011	1053.7	646.2	471.8	783.6	793	768.8
	2012	1444.5	1169.9	496.8	1499.4	1112	1177.91
	2013	1162.7	552.1	372.6	516	594	628.7
	2014	803	737.6	513.4	601.4	757.6	615.5
	2015	1235.4	691.9	453.3	659.8	696.8	761.9
Formula		$y = 0.942x + 16.756$	$y = 1.3961x - 2.1561$	$y = 11.635\ln(x) + 75.958$	$y = 1.7212x - 54.256$	$y = 0.3684x + 167.01$	$y = 6.2269x^{0.6967}$
R^2 Correlation between R &MFI		**0.83**	**0.73**	**0.002**	**0.71**	**0.52**	**0.92**

3.3. The relationship between Calculated R factor and physiographic characteristics

In the previous chapter, the link between average annual precipitation and physio-geographic parameters were investigated. Now that the calculated rainfall factor is available, it is necessary to evaluate the compatibility of physiographic parameters with these factors. When calculated rainfall factors are plotted, both MFI and RUSLE R have shown inverse relationship with elevation. If this reverse equation is used for spatial interpolation of rainfall factor, it will assign lowest values of DEM for highest precipitation. Therefore, it is important to group the stations based on the dominant precipitation factors.

Arnoldus (1980) stated interpolations obtained using MFI should be applied only to locations which show homogenous climatic attributes. Therefore, as explained in Section 2.4, meteorological stations were grouped as Group 1 and Group 2, in other words, the stations for which the precipitation is mainly affected by elevation and those affected by the distance to sea respectively. When the basin stations are plotted, a correlation of coefficient 0.90 was found between computed MFI and elevation (Figure 3-5).

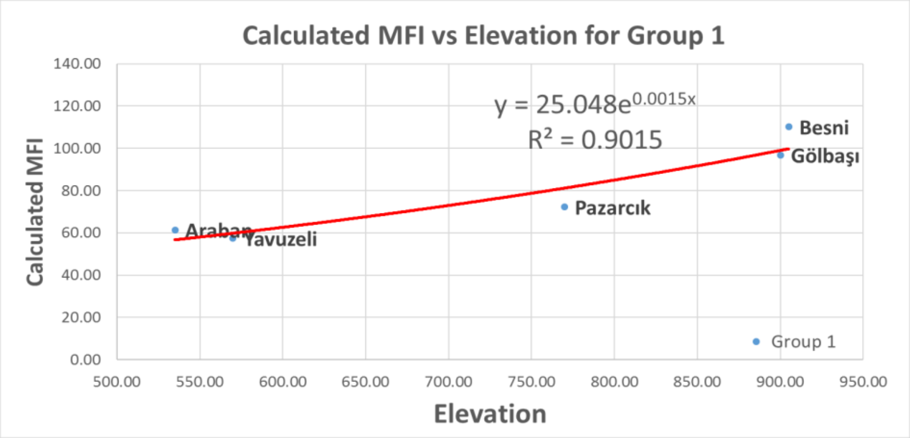


Figure 3-5: Calculated MFI vs Elevation for Group 1 Meteorological Stations

Based on this relationship, using a DEM in catchment area, MFI values will be derivated and compared with calculated values.

With regard to the effect of distance from the sea, Group 2 station's erosive force is not elevation; it`s their proximity to the sea. As show in Figure 3-6, when distance from sea increases, MFI values are decreasing as expected. The decrease in rainfall volume due to the distance to the sea starts when elevation increases and acts like a barrier that does not allow humid air to pass.

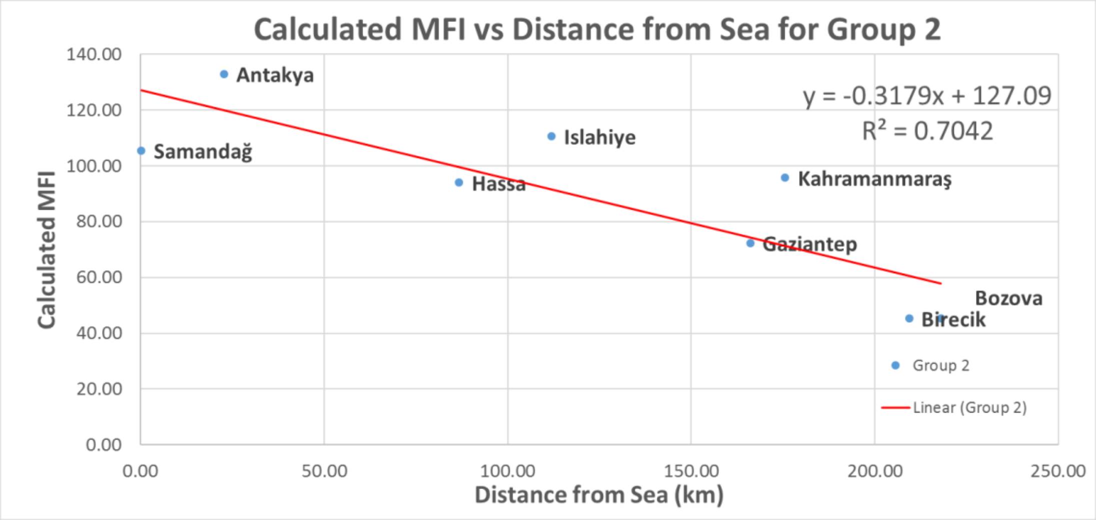


Figure 3-6: Calculated MFI vs Distance from Sea for Group 2 Meteorological Stations

CHAPTER 4

INTERPOLATION OF EROSIVITY FACTOR

As a result of detailed calculations and analysis, two different rainfall factors MFI and R and their correlation with geographical characteristics were determined so far. Afterwards, in order to estimate values for all study area, spatial interpolation methods have been applied.

The performance of a spatial interpolation method depends not only on the features of the method itself, but also on factors such as data variation and sampling design. Most of the methods performed at an acceptable level for predicting rainfall properties in gentle regimes, but few performed well in complex regimes. Geostatistical methods like ordinary kriging, geometric methods like inverse distance weighting (IDW) and statistical methods such as the linear regression are the most commonly used interpolation methods.

In this study, rainfall factors were associated with physiographic descriptors of land, if not, direct interpolation techniques would be applied to estimate the rainfall factor value spatially in the study area. Therefore, it was also another interest to examine whether using geographical information would improve estimations or not. Accordingly, both direct interpolations and interpolations that combine rainfall data with a secondary variable will be applied to spatially interpolate rainfall factor, and then the statistical comparison of each method will be discussed.

4.1. Direct Interpolations of Calculated Rainfall Factor

Modified Fournier Index value is calculated for 18 stations, whereas RUSLE rainfall factor values are calculated for only 6 stations. Using Inverse Distance Weighted method, firstly the RUSLE rainfall factor values will be interpolated to spatially distribute the rainfall factor in the study area using 6 stations calculated rainfall factor data.

IDW works on the logic that things are close to one another are more alike than those that are further apart. The known values closest to the prediction location have more influence compared to distant locations. IDW gives each measured points a weight that decrease with distance. Weights are inversely proportional to distance and linked with power value. The power parameter controlled significance of known points on the interpolated values based on their distance from the output point. The power is set to the value of 2 in this study. The output raster resolution is set to 25 m. However, it is difficult to create perfect R interpolation map for this study area using this coarse resolution point observations and from these parameters. Therefore, one of the aims of this study was the comparison of these coarser and finer maps and estimate differences. Secondly, inverse distance weight interpolation using 18 stations Modified Fournier Index value is applied.

4.2. Interpolation based on auxiliary data

The IDW was chosen for the rainfall factor map creation because compared to kriging and other interpolation methods it gives more reasonable results due to sample size and density is not enough. The disadvantage to using this method is that it does not consider any effects of topography or other effects based on the location of points to the value at the interpolation location.

In addition to this, in the case that MFI or R was not associated with environmental features, only IDW methods will be applied to get a spatial distribution of values and the result will be very coarse. Therefore, by using relationship between MFI values and digital elevation model for basin stations as in explained Figure 3.3, MFI map was derived from elevation for basin stations (Figure 4.1c). In the resultant map, the ranges for F values were overestimated when compare to the calculated MFI values.

Based on available annual precipitation data, rainfall erosivity values of each station can be estimated using mathematical models that were developed between R and MFI. Therefore, relationship between R and MFI (Equation 16) and using interpolated MFI map in Figure 4-1c, R map was created (Figure 4-1d).

As a result of all these interpolations, 4 rainfall erosivity maps have been created for the catchment area. The range of rainfall erosivity values in those maps is changing due to different calculation methods.

Table 4-1: List of Interpolated Maps

MFI Map 1.	Produced based on interpolation of 18 calculated station MFI values	IDW Interpolation	4.1a
R Map 1.	Produced based on interpolation of 6 calculated stations RUSLE R values	IDW Interpolation	4.1b
MFI Map 2	Produced based on relationship between MFI and elevation in basin stations	Based on equation: $y = 25.048e^{0.0015x}$ $R^2 = 0.9015$	4.1c
R Map 2.	Produced based on relationship between R and MFI	$y = 10.584x^{0.5869}$ $R^2 = 0.7792$ Input Map:4.1c	4.1d

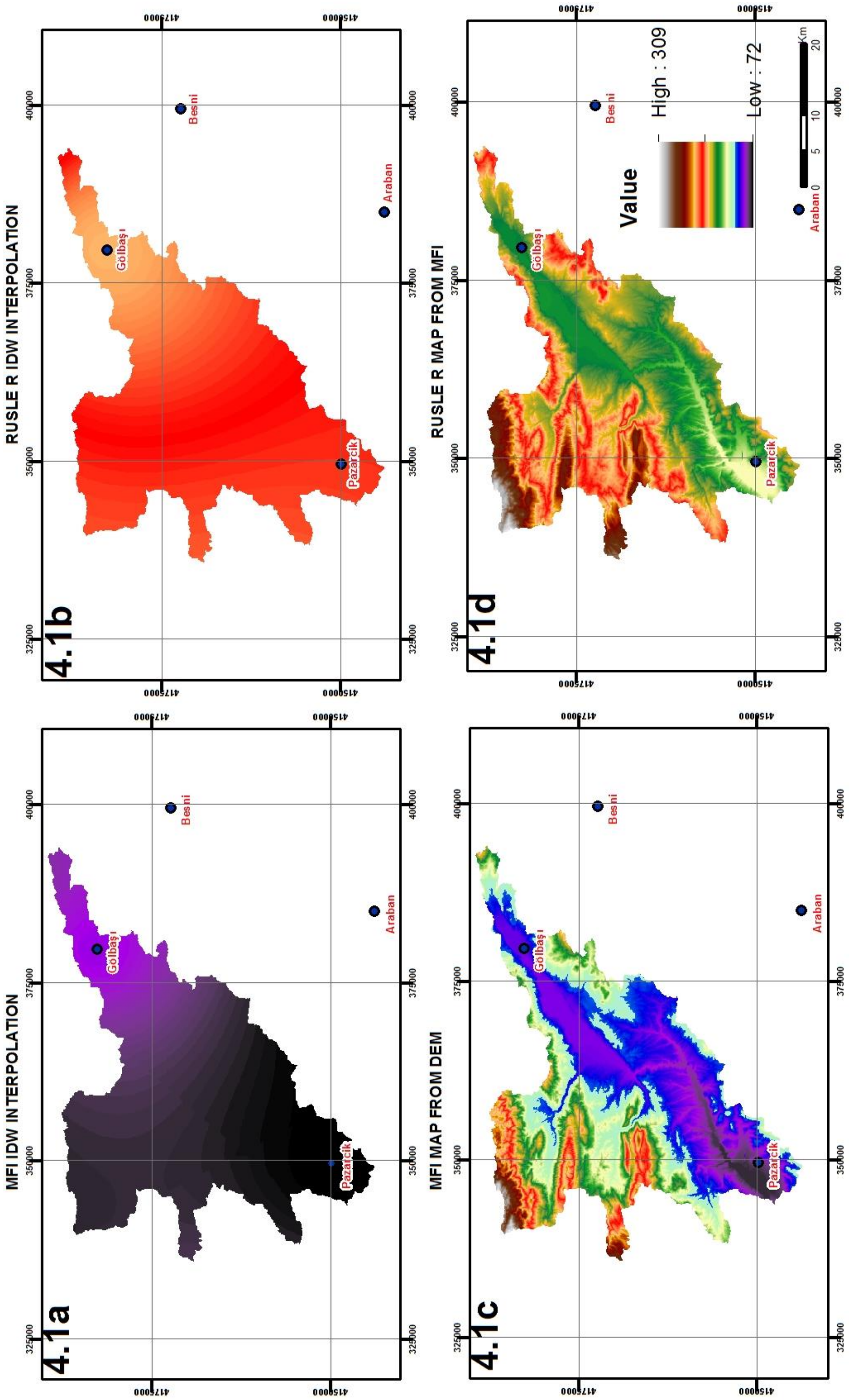


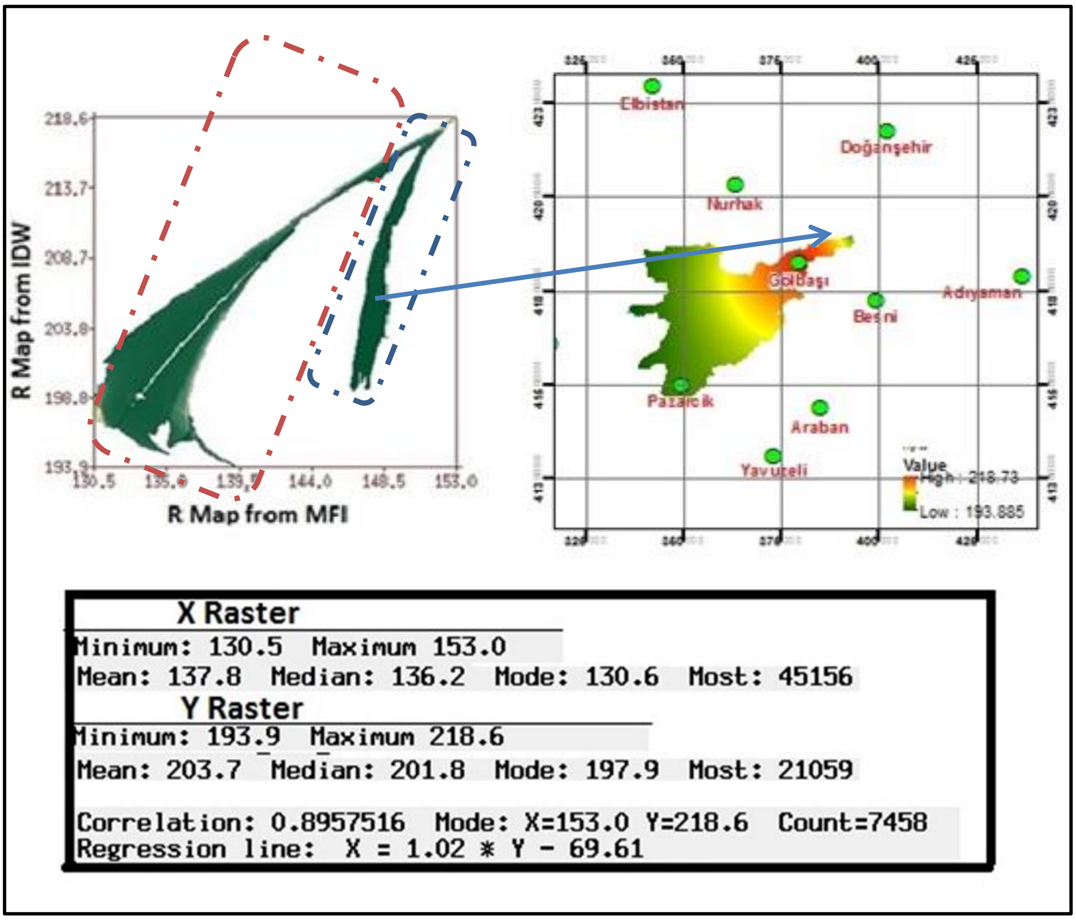
Figure 4-1: RUSLE and MFI Maps, MFI Map (a), R Map (b), MFI Map from Dem (c), RUSLE Map From MFI (d) (See Table 4.1 for details)

4.3. Comparison of spatially interpolated erosivity indices

4.3.1. Raster comparison

These four maps for the catchment area are compared with each other statistically. Figure 4.2 presents scatter plots showing the relationship between the R map from direct interpolation and MFI map from direct interpolation. The x-axis represents estimated R factor values while the y-axis represents MFI values. With the overall coefficient determinant (R^2) value of 0.89, this model indicates a good correlation between two variables. This strong correlation proves that instead of using breakpoint rainfall data, rainfall factor values based on MFI values can be produced by monthly rainfall data. By using this model, the R values of each station would be able to be estimated based on the annual MFI. This method will also simplify the method of calculating R values for future work because the R calculation based on minute interval precipitation data is complex to process and time consuming task.

As seen in Figure 4-2, the linear relationship between the two maps is shown within the red dashed area. However, the blue dashed area falls outside the general trend. The reason behind these different patterns, Gölbaşı and Besni stations with high MFI values will have a higher impact on the specific point on the MFI map. As for R map just Doğanşehir, Adıyaman and Gölbaşı have been examined due to the availability of minute based data and the low R value of Adıyaman and Doğanşehir will have a lower impact on the specific point. Only Gölbaşı station high R value is not enough to require high MFI values. In that specific area, the R map from MFI has shown values around 150, nevertheless R IDW map value is around 200.



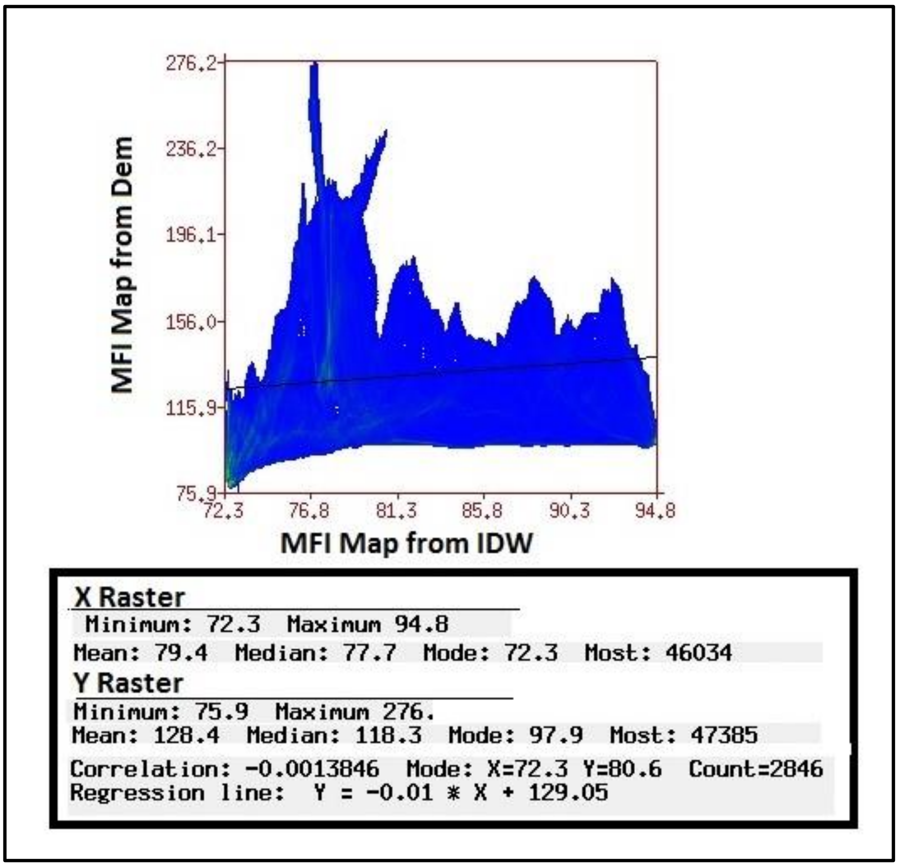
```
      X Raster
Minimum: 130.5  Maximum 153.0
Mean: 137.8  Median: 136.2  Mode: 130.6  Most: 45156
       Y Raster
Minimum: 193.9  Maximum 218.6
Mean: 203.7  Median: 201.8  Mode: 197.9  Most: 21059

Correlation: 0.8957516  Mode: X=153.0 Y=218.6  Count=7458
Regression line:  X = 1.02 * Y - 69.61
```

Figure 4-2: Comparison of Rainfall Factor Maps

When MFI value for inland stations and elevation values are compared by point, there is a strong relationship (R^2=0.716). However, creating an MFI map based on this elevation relationship cannot give the same results because the direct interpolation map based on just meteorological station points, and the DEM map has a different input value in every pixel. In addition to this, station elevations range from 500 m. to 900 m, so there is no control point at higher elevations in catchment area so it will be overestimated.

Also, as shown in Figure 4-3, when MFI increases due to high elevation values in the y axis, this increase is not displayed in the interpolation map. Therefore, to examine which maps estimate closest value to the observed point, the bootstrapping technique was utilized.



```
X Raster
 Minimum: 72.3  Maximum 94.8
Mean: 79.4  Median: 77.7  Mode: 72.3  Most: 46034
Y Raster
Minimum: 75.9  Maximum 276.
Mean: 128.4  Median: 118.3  Mode: 97.9  Most: 47385
Correlation: -0.0013846  Mode: X=72.3 Y=80.6  Count=2846
Regression line:  Y = -0.01 * X + 129.05
```

Figure 4-3: Comparison of MFI Maps

4.3.2. Bootstrapping

Changes in the rainfall factor can depend on many drivers and a full evaluation of landscape dynamics at different scales. One of the purposes of this study was to investigate whether using an auxiliary geographical factor can improve estimation of rainfall factor.

It is known that basin stations precipitation and rainfall factor is related to their elevation. To investigate whether using elevation improves interpolation of rainfall factor bootstrap methodology was applied. The term “bootstrap” is a reference to the notion of “pulling oneself up by the bootstraps” when the usual methods for ascertaining statistical significance do not apply (Efron and Tibshirani,1993).

The bootstrap method was applied 5 times to test direct interpolation estimates performance over interpolation with DEM. The methodology consists of temporarily removing one rainfall factor value from the data set and “re-estimate” this value from the remaining data using the alternative algorithms. By eliminating each rain gauge one by one, different equations were calculated between elevation and MFI and the value of the removed rain gauge is estimated. Also same procedure, applied without considering DEM, by eliminating each rain gauge one by one, different IDW maps were created and IDW MFI value is determined for each station.

Table 4-2: Comparison of calculated and estimated MFI values from Bootstrapping

	Araban	*Besni*	*Gölbaşı*	*Pazarcık*	*Yavuzeli*	*RMSE*
Calculated MFI Value	61.37	110.15	96.84	72.26	57.44	
Bootstrapping Method MFI Value From IDW	72.32	78.87	85.53	71.59	69.85	***16.61***
Bootstrapping Method MFI Value from DEM	52.33	90.06	101.85	84.75	61.50	***11.68***
IDW MFI “ %	17.84	-28.40	-11.68	-0.93	21.61	
MFI from DEM Error %	-14.73	-18.24	5.17	17.28	7.07	

Table 4-2 shows calculated MFI values and MFI values extracted from bootstrapping method. Larger prediction errors are obtained for the one that ignore elevation. Interpolation with elevation has a lower RMSE compare to IDW method. When estimations compared by error percentage red showings in Table 4.2, MFI value extracted from DEM estimates better than direct IDW.

For Besni station calculated MFI value is 110.15, while MFI value using DEM is 90.06 and MFI value using just IDW is 90.06. Only for Pazarcık, the error is larger compare to IDW value. The reason behind Pazarcık estimation is better with IDW, can be its very close to elevation//distance from sea boundary. Due to Pazarcık closer to Kahramanmaraş, compare to other station it will give better estimates with IDW.

As a result, bootstrapping method reviewed those two ways and it is concluded that secondary information like elevation increase prediction performances.

4.4. Comparison of erosivity indexes in Kartalkaya Catchment Area with previous studies

R-factor values estimated in this study were compared to the earlier studies performed in the study area.Tanyaş et al., (2015) calculated RUSLE parameters and transported sediment amount by using SEDD model in Kartalkaya Dam. After the calculation of annual transported material within each sub-basin, results were compared with the two different bathymetry maps of Kartalkaya Dam obtained from General Directorate of State Hydraulic Works (DSI).

In mentioned study, rainfall factor was estimated using maximum EI_{30} values of for each 12 meteorological stations in the near vicinity of the study area taken from Kaya (2008). Using inverse distance method, R factor map for the study area is produced. Source data of study is the daily rainfall data regularly recorded in 252 meteorological stations spreading all over Turkey. Maximum ExI_{30} values for each meteorological station of Turkey are calculated between years 1993 and 2004. The name and R-values of meteorological stations used in the interpolation is listed in Table 4-3 and Figure 4-4 shows the map of meteorological station used in the mentioned study.

Table 4-3: Maximum EI_{30} values (adapted from Kaya, 2008)

Stations	Max. ExI30 values
Adıyaman	349.96
Afşin	503.29
Birecik	276.42
Bozova	312.25
Doğanşehir	288.14
Elbistan	860.02

Stations	Max. ExI30 values
Kilis	924.29
Osmaniye	915.61
Gaziantep	536.86
Göksun	924.3
Gölbaşı	222.18
Kahramanmaraş	816.61

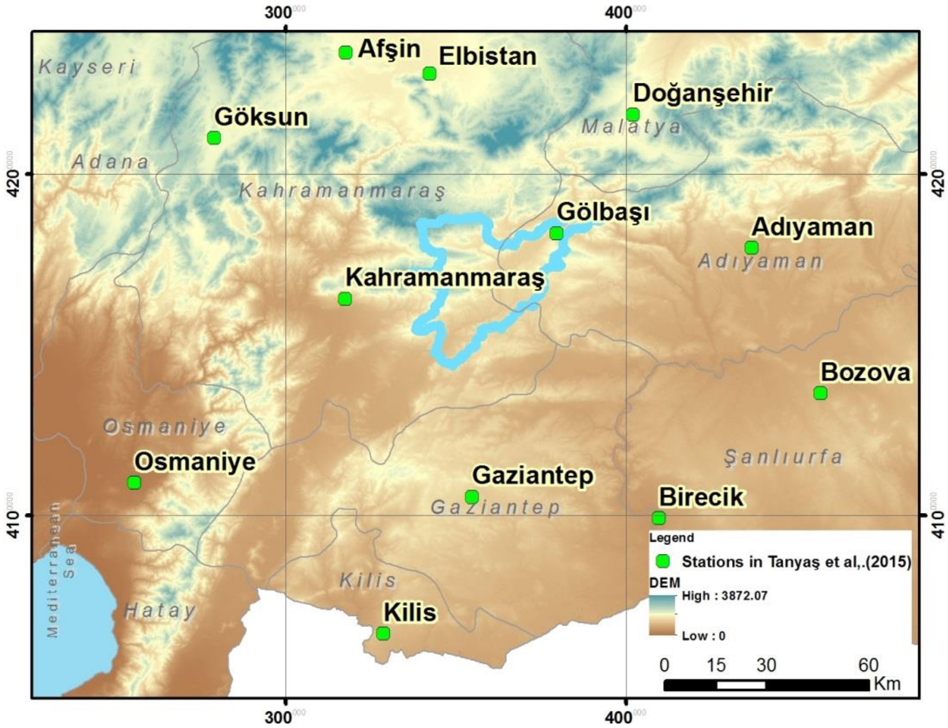
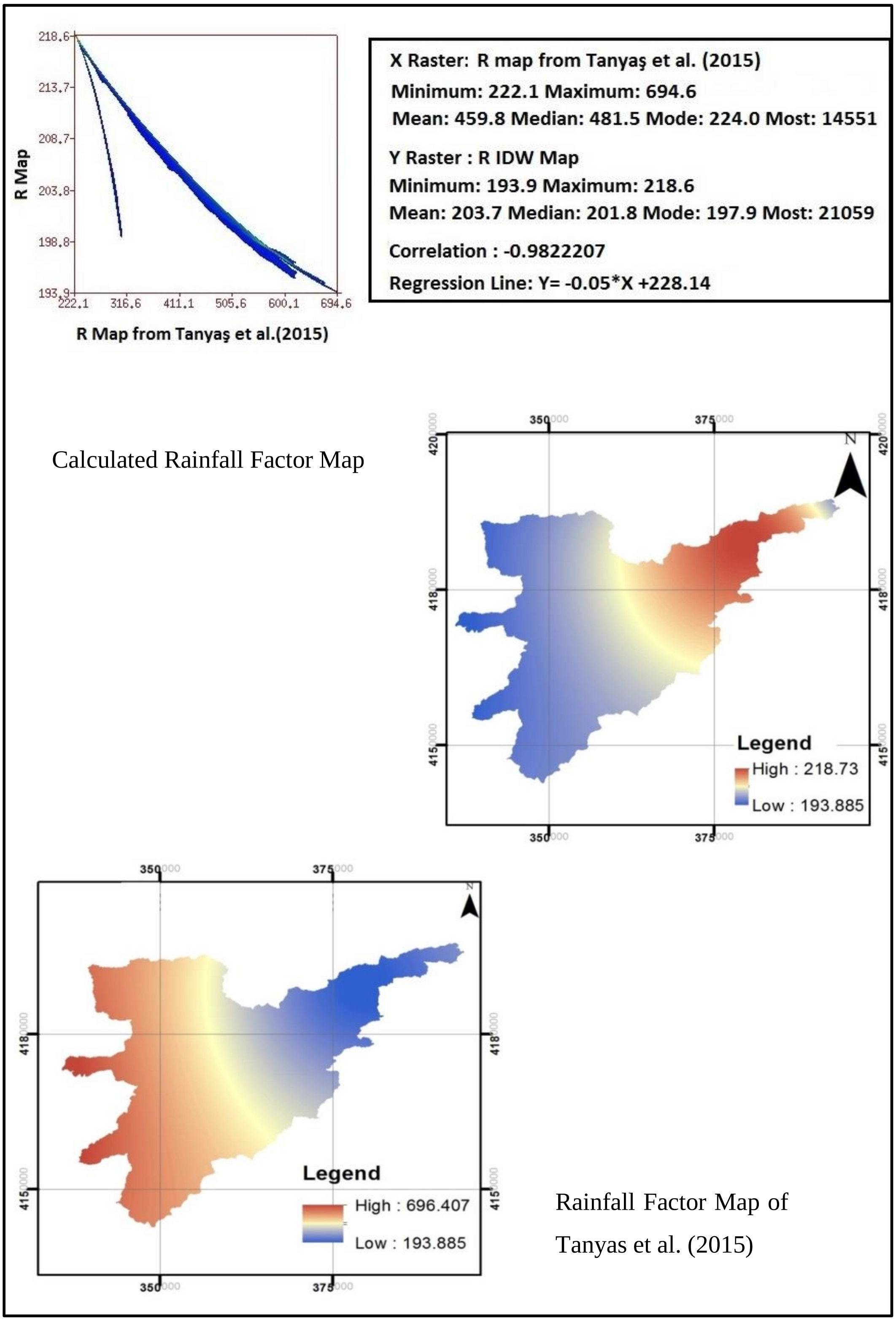


Figure 4-4: Location of meteorological stations in the study of Tanyaş et al. (2015)

As in shown in Figure 4-5, comparison of interpolated maps showed that there is an inverse relationship (R^2=-0.98) between results of the two studies as expected. Tanyaş et al., (2015) just used available meteorological station`s maximum EI_{30} value around catchment area and interpolated them using IDW without considering geographical parameters of study area.

Rainfall factor map from Tanyaş et al., (2015) shows highest value at both south and west part due to stations affect that area like Osmaniye, Kilis and Kahramanmaraş have highest value of R. However, it is proven that due to elevation also rises through catchment area, those high values cannot reach inside the catchment area so they should not be included in rainfall factor interpolation for study area.



X Raster: R map from Tanyaş et al. (2015)
Minimum: 222.1 Maximum: 694.6
Mean: 459.8 Median: 481.5 Mode: 224.0 Most: 14551
Y Raster : R IDW Map
Minimum: 193.9 Maximum: 218.6
Mean: 203.7 Median: 201.8 Mode: 197.9 Most: 21059
Correlation : -0.9822207
Regression Line: Y= -0.05*X +228.14

Figure 4-5: R-factor maps relation based on calculated R-values and R-values from study of Tanyaş et al., (2015)

CHAPTER 5

CONCLUSION

5.1. Conclusion and Discussion

In Turkey, rainfall erosivity measurements are restricted to a few locations which results in difficulty in modelling soil erosion. Also, high temporal data availability of precipitation records is very limited. Therefore, the studies that have been developed estimate rainfall factor using more readily available precipitation data or estimate the relationship between rainfall and local geographic variables of study area. This study aims to estimate the rainfall erosivity index in Kartalkaya Dam using different temporal precipitation data and correlate rainfall factor with local geographic information of the study area to obtain a better result over direct interpolation.

The study area is chosen widely because there are only a few meteorological stations which has minute interval data around the catchment area. In addition to this, observing physiographic attributes of land associated with rainfall factor are analyzed more easily. For that reason, this study uses monthly precipitation data of 18 rainfall stations and minute interval precipitation data of 6 rainfall stations around Kartalkaya Dam Region have been examined in order to obtain rainfall factor in the study area. The reason behind these calculations is to develop a relationship between the two datasets and simplify estimating the rainfall factor with available datasets.

First of all, datasets are checked to eliminate irrelevant and erratic records. To understand the data, annual and monthly rainfall graphs are plotted and wet / dry seasons and years are determined. The number of days which has an erosive event calculated for all stations. In this way, general rainfall trends of each station have been investigated.

When elevation is plotted annual average rainfall or calculated rainfall factors of rain gauges, it is established that there is no correlation between total annual precipitation values and elevation of the stations. In fact, changes in elevation varied inversely with rainfall factor. It has been estimated that low elevations do not necessarily produce low values of rainfall factor.

Since the opposite relationship had been expected by the literature, a classification was made to group stations into homogenous climate zones and stations were grouped by geographical locations. From the pattern of rainfall changes, it is estimated that rainfall decreases away from the sea due to the evaporated air blowing up hills and cooling while it ascending. When rain moves into inside of higher elevation it loses its moisture content so less rainfall occurred in inland areas. Therefore, stations have a lower elevation but closer to sea get more precipitation and highest precipitation values are caused by distance from sea.

For stations like Antakya and Samandağ close to coastline, the Mediterranean Sea is the main source of moist air masses causing the abundant precipitation until the catchment area. The valley which covers higher elevation on both sides but has lower elevation itself carries precipitation until Kahramanmaraş Region. After Kahramanmaraş meteorological station, elevation increases through the catchment area and sea affect loses its power. Due to distance from sea is increasing; the effect of moist air masses is decreasing towards the catchment area.For many areas, just one environmental variable such as elevation is not representative of rainfall. Evaluating geographic parameters through years of rainfall data has been shown to be more precise in calculating rainfall erosivity index. Therefore, the study area is grouped into two regions based on main erosive agent named as Group 1 and Group 2.

Then, MFI value which based on monthly precipitation data (MFI) and R value which based on minute precipitation data (RUSLE) has been determined. As a result of those calculations, it has been established that there is a significant relationship between R and MFI can be expressed in a potential form. Therefore, it is proven that even there is no high temporal precipitation data available in this area, rainfall factor can be calculated just using monthly rainfall volume by MFI formula. The relationship between MFI and R can be used to estimate the rainfall factor values based on monthly precipitation values. Furthermore, this relationship (R^2=0.78) is stronger than correlation between annual total precipitation and rainfall factor (R^2=0.64).

In addition to developing relationship between two different precision rainfall datasets, geographic and locational features of the study area have been considered to assess the impact of the spatial distribution in rainfall factor. After calculating a consequential relationship between MFI, R and physiographical information, interpolated maps obtained using these variables are compared. These comparisons are valuable for understanding how different direct interpolation and interpolation with geographical variables affect rainfall factor value.

MFI and R has a relationship (R^2=0.78) in point based. The spatial distribution of MFI and R maps show more powerful and significant correlation (R^2=0.89) which also proves that they can be used as substitution for each other. Therefore, it is now proven that monthly rainfall data can be used for rainfall factor calculation when there is no minute data available. Then, another MFI map also created as derivation of DEM based on inland stations relationship with elevation. Comparison of this two raster point by point do not show significant results due to DEM varied in every cell value although interpolations maps just based on point locations. Also, due to there being no control station at higher elevations like 1200 meter, DEM based maps would likely to overestimate MFI values. However, alongside of overestimation, DEM based MFI estimates are closer to the calculated value of stations calculated MFI value over IDW estimates. Therefore, the comparison of two rasters are made by the bootstrapping method. One observation station is to temporarily be removed from a group and direct IDW and DEM based IDW raster which are to be created using remaining stations. Comparison of both calculations is shown using geographical variable improve estimation rather than direct interpolation.

This study addresses relationships between RUSLE rainfall factor and MFI which can be used in future studies that have limited rainfall data but have both similar climatic conditions. This connection cannot be extrapolated to a generalized form of rainfall factor formula without understanding local geographical information of the study area.

There are so many environmental variables such as elevation; climate and temperature that can affect rainfall trends in an area. Estimation of relationship between rainfall and elevation should be utilized in watershed areas that have limited meteorological stations to understand hydro climatological processes in the field. Using elevation as an auxiliary variable can improve estimations however studies must be conducted considering local geographical parameters. To summarize, when precipitation data is limited, R values can be calculated with available monthly data and extrapolated using geographical information. The creation of rainfall erosivity maps is more accurate when related on geographical information of study area.

5.2. Future Work

The seasonal or monthly R-factor values can be associated with average precipitations or local climatic factors such as isothermality. In addition to them, different interpolation techniques such as cokriging and kriging with multiple external drift could be applied if more data is available. Further research should investigate whether other environmental descriptors, such as aspect or temperature may be linked by rainfall factor interpolation.

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APPENDIX A

AVERAGE MONTHLY PRECIPITATION VALUE FOR STATIONS

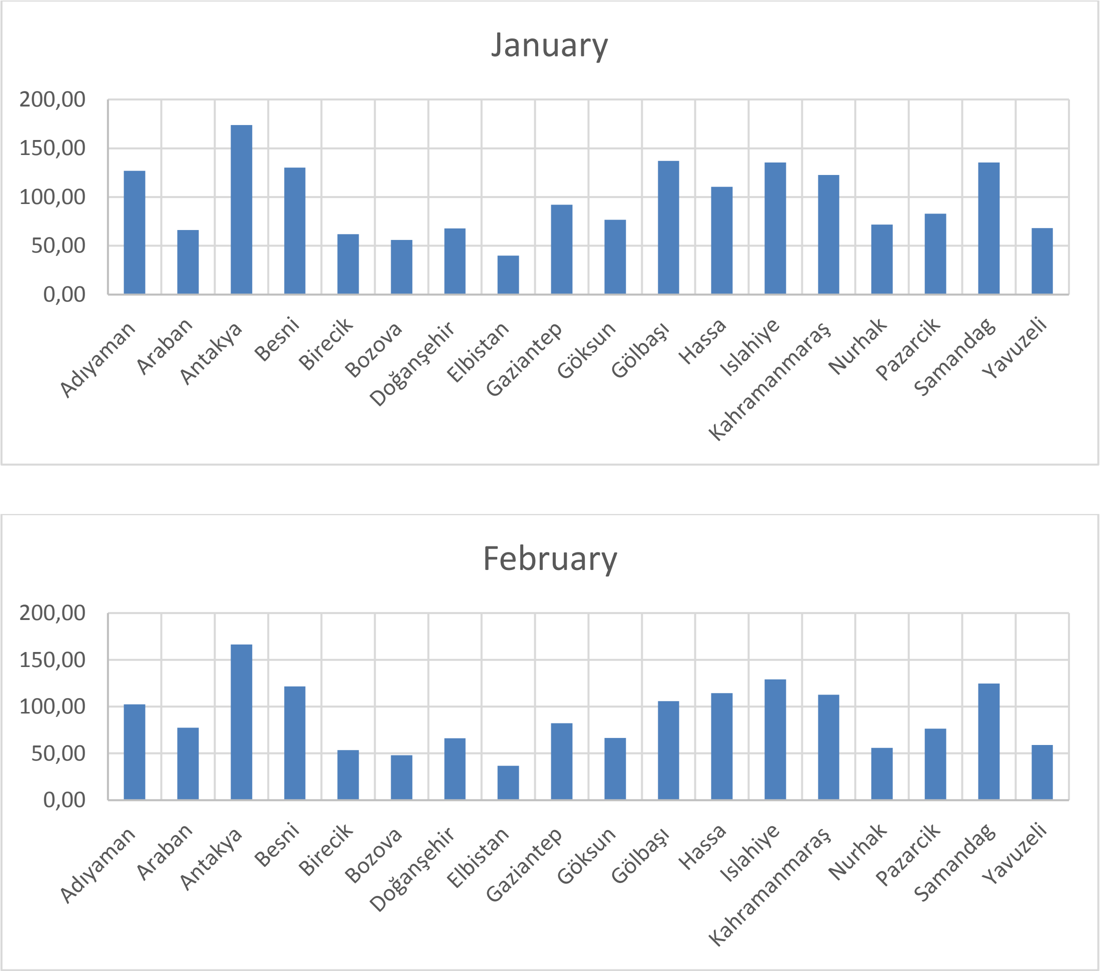
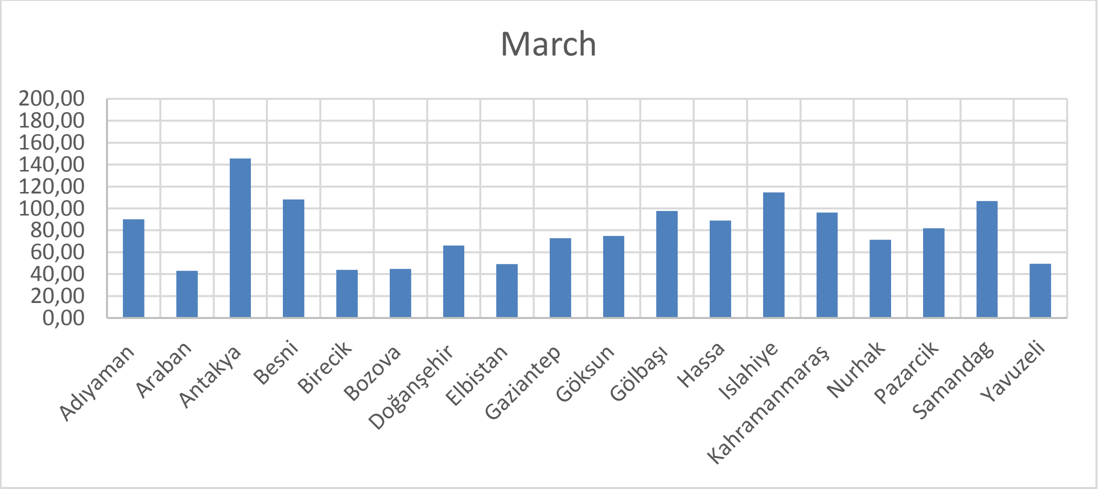


Figure A.1: January and February Average Precipitations for Meteorological Stations



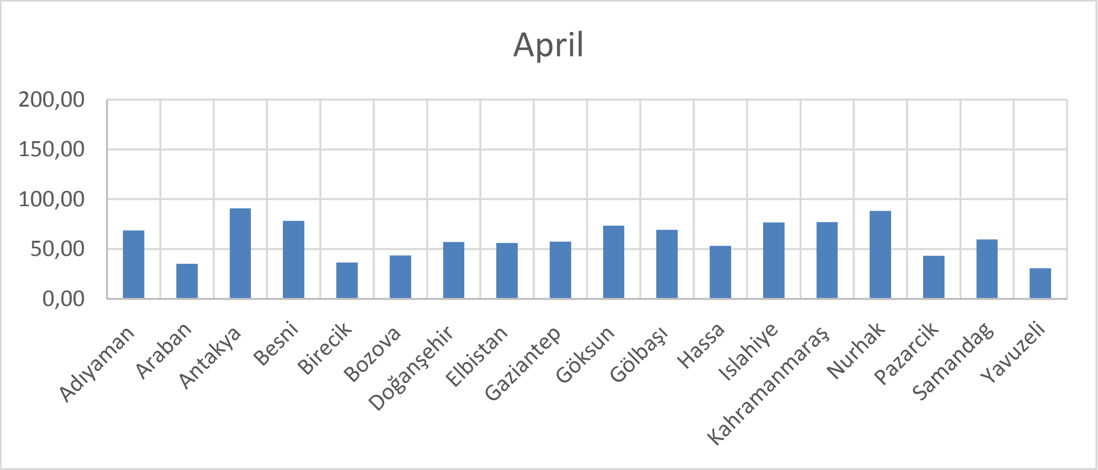
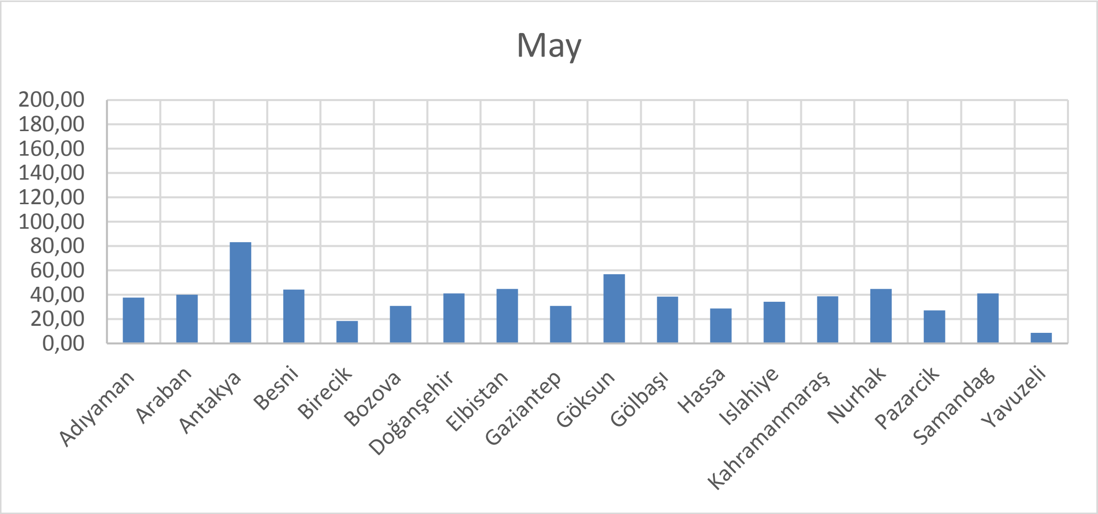


Figure A.2: March and April Average Precipitations for Meteorological Stations



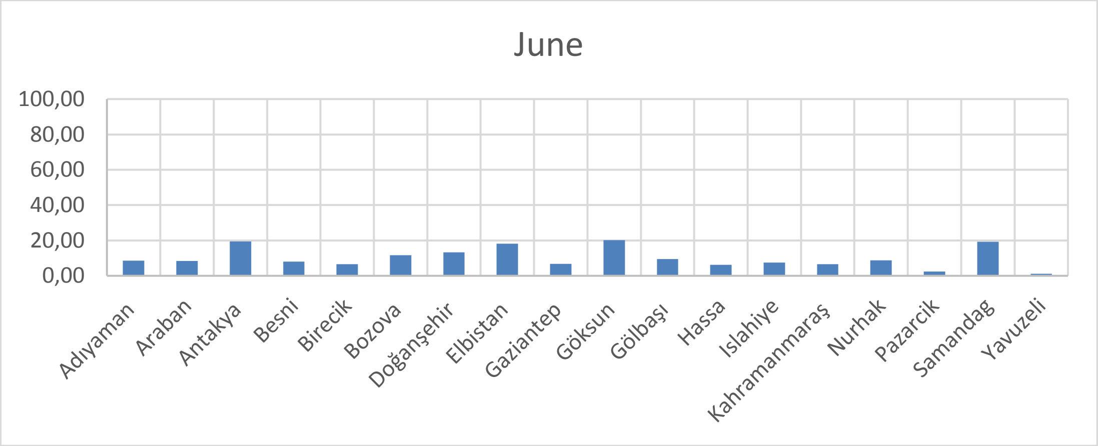
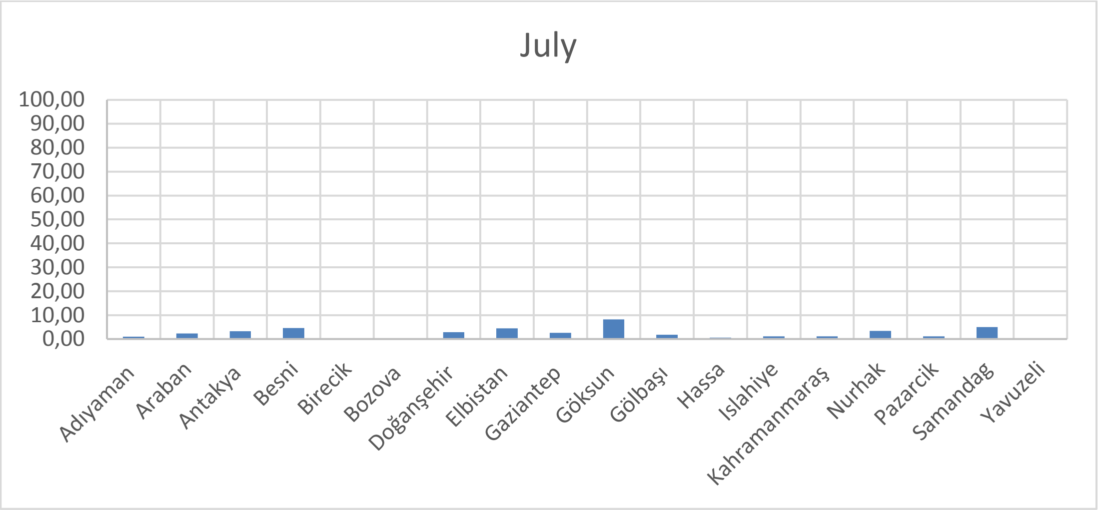


Figure A.3: May and June Average Precipitations for Meteorological Stations



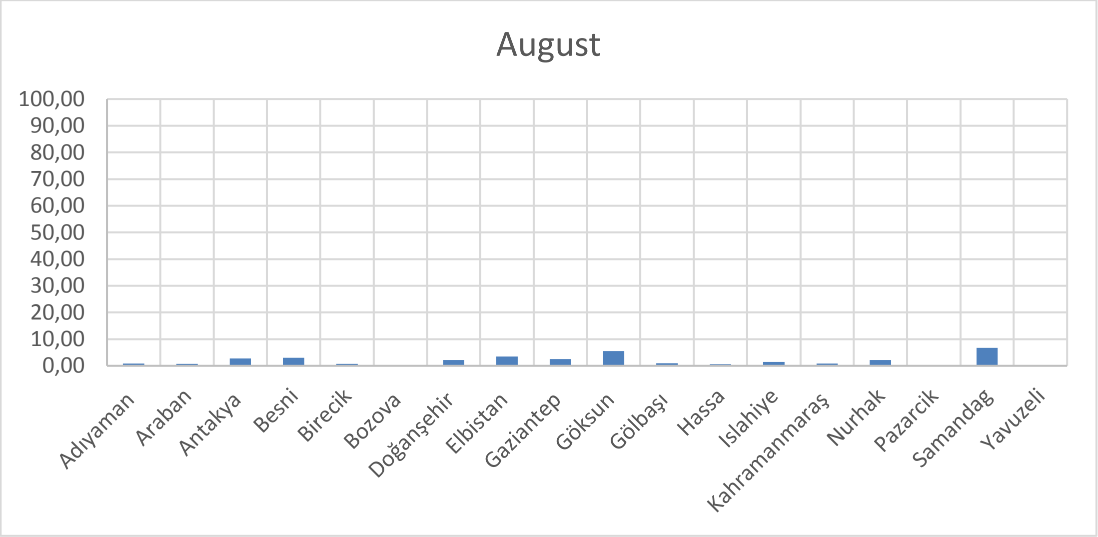
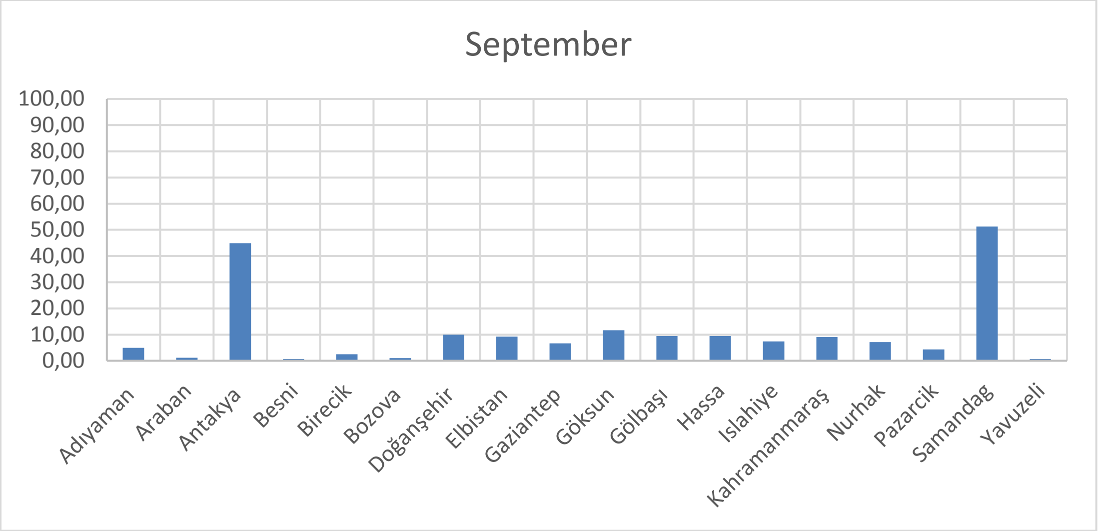


Figure A.4: July and August Average Precipitations for Meteorological Stations



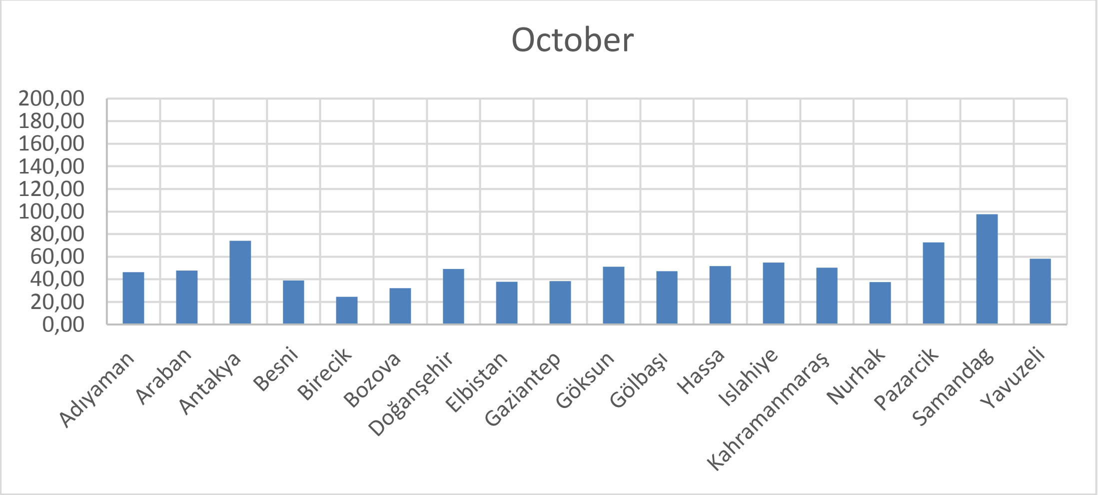
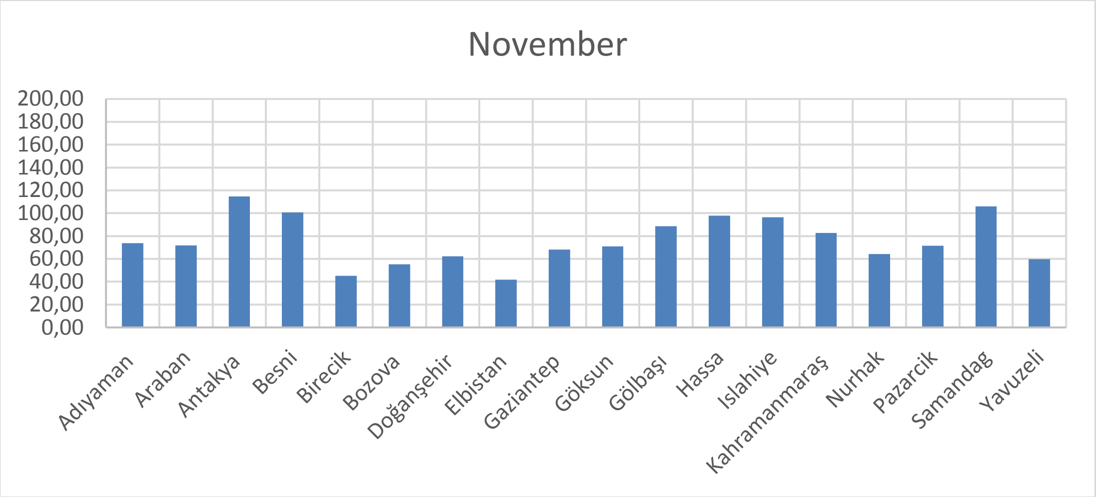


Figure A.5: September and October Average Precipitations for Meteorological Stations



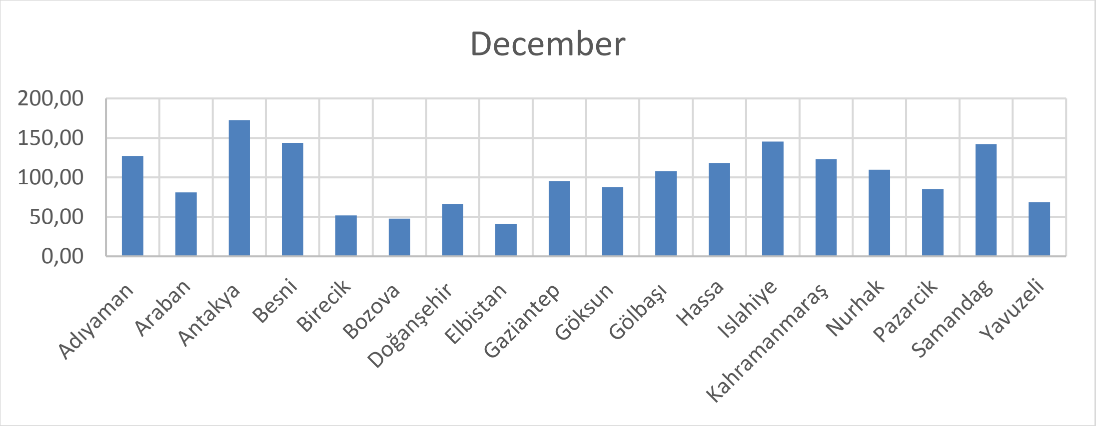
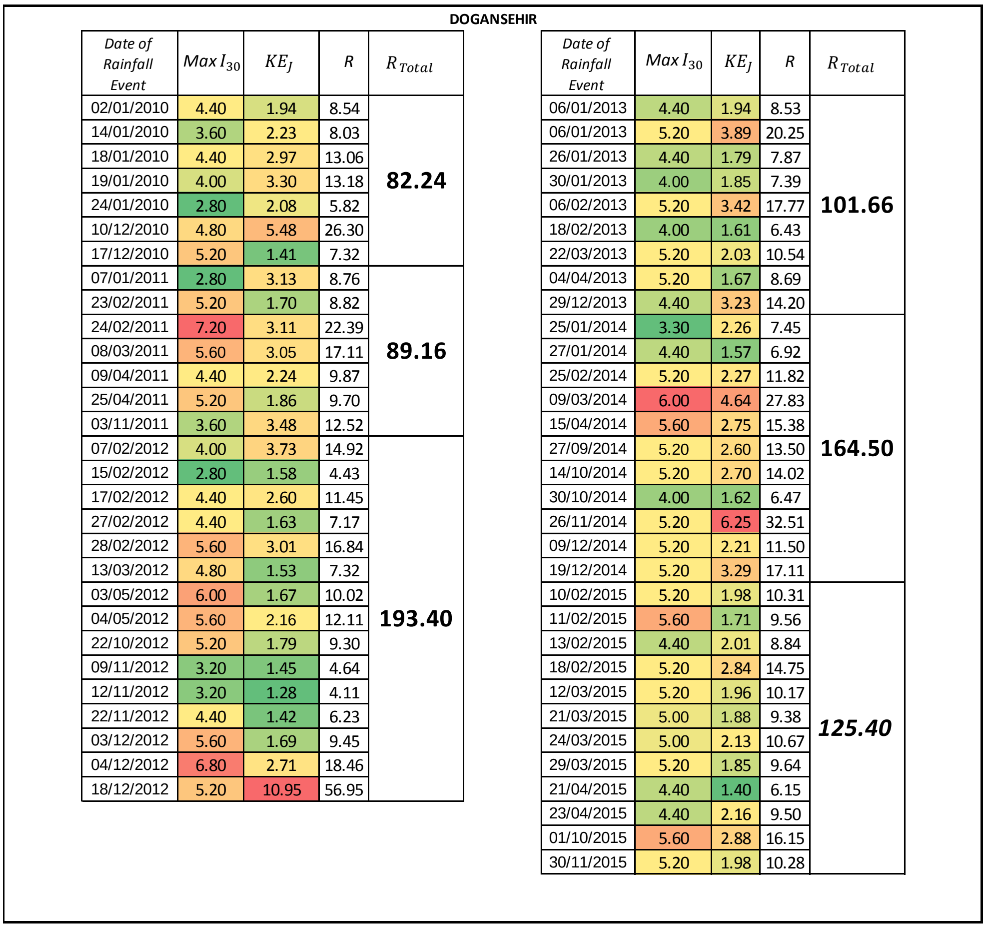


Figure A.6: November and December Average Precipitations for Meteorological Stations

APPENDIX B

EROSIVE RAINFALL EVENTS DETAILS FOR SIX STATIONS BETWEEN 2010 AND 2015

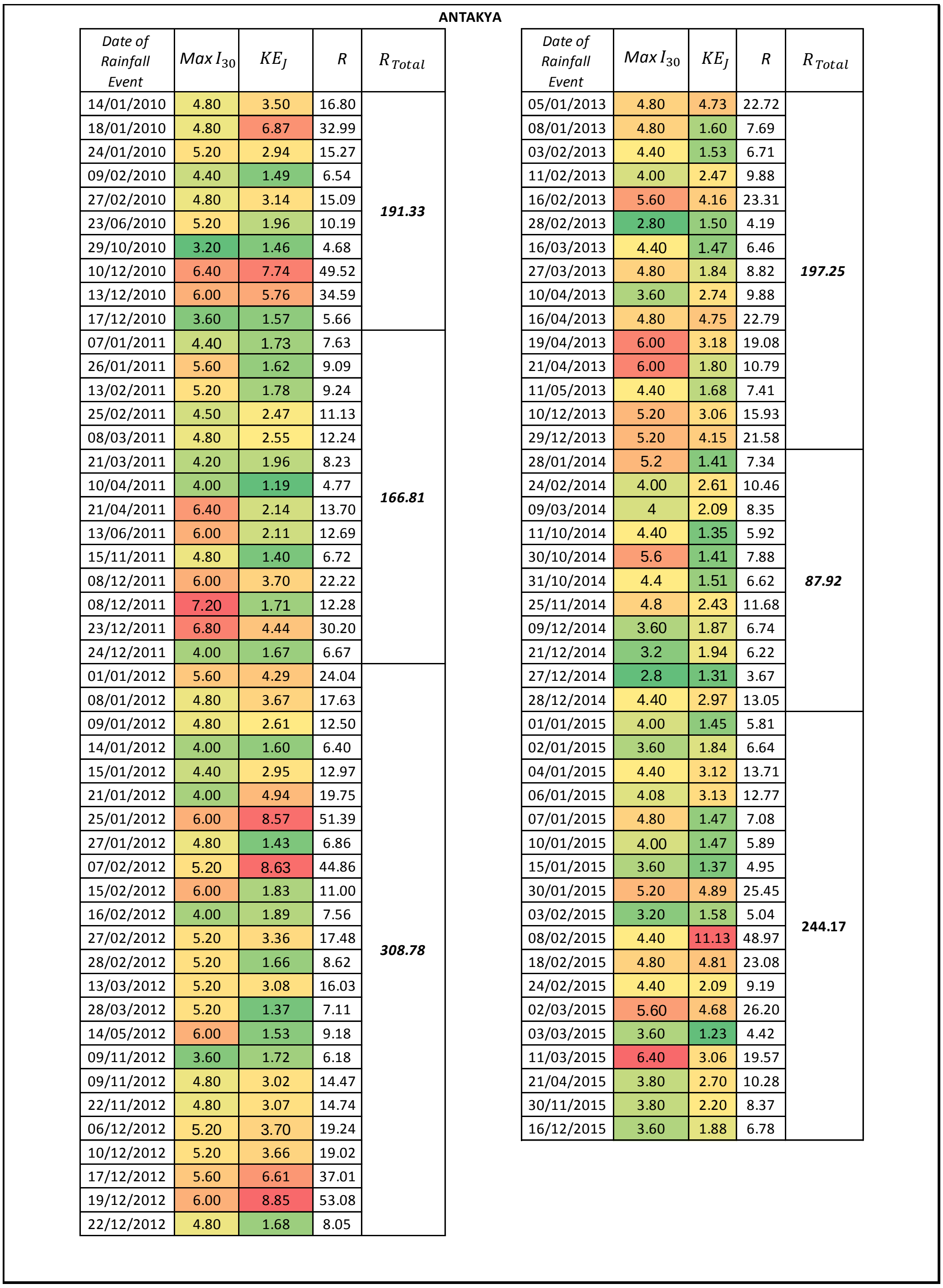


DOGANSEHIR

Date of Rainfall Event	Max I_{30}	KE_J	*R*	R_{Total}
02/01/2010	4.40	1.94	8.54	**82.24**
14/01/2010	3.60	2.23	8.03	
18/01/2010	4.40	2.97	13.06	
19/01/2010	4.00	3.30	13.18	
24/01/2010	2.80	2.08	5.82	
10/12/2010	4.80	5.48	26.30	
17/12/2010	5.20	1.41	7.32	
07/01/2011	2.80	3.13	8.76	**89.16**
23/02/2011	5.20	1.70	8.82	
24/02/2011	7.20	3.11	22.39	
08/03/2011	5.60	3.05	17.11	
09/04/2011	4.40	2.24	9.87	
25/04/2011	5.20	1.86	9.70	
03/11/2011	3.60	3.48	12.52	
07/02/2012	4.00	3.73	14.92	**193.40**
15/02/2012	2.80	1.58	4.43	
17/02/2012	4.40	2.60	11.45	
27/02/2012	4.40	1.63	7.17	
28/02/2012	5.60	3.01	16.84	
13/03/2012	4.80	1.53	7.32	
03/05/2012	6.00	1.67	10.02	
04/05/2012	5.60	2.16	12.11	
22/10/2012	5.20	1.79	9.30	
09/11/2012	3.20	1.45	4.64	
12/11/2012	3.20	1.28	4.11	
22/11/2012	4.40	1.42	6.23	
03/12/2012	5.60	1.69	9.45	
04/12/2012	6.80	2.71	18.46	
18/12/2012	5.20	10.95	56.95	

Date of Rainfall Event	Max I_{30}	KE_J	*R*	R_{Total}
06/01/2013	4.40	1.94	8.53	**101.66**
06/01/2013	5.20	3.89	20.25	
26/01/2013	4.40	1.79	7.87	
30/01/2013	4.00	1.85	7.39	
06/02/2013	5.20	3.42	17.77	
18/02/2013	4.00	1.61	6.43	
22/03/2013	5.20	2.03	10.54	
04/04/2013	5.20	1.67	8.69	
29/12/2013	4.40	3.23	14.20	
25/01/2014	3.30	2.26	7.45	**164.50**
27/01/2014	4.40	1.57	6.92	
25/02/2014	5.20	2.27	11.82	
09/03/2014	6.00	4.64	27.83	
15/04/2014	5.60	2.75	15.38	
27/09/2014	5.20	2.60	13.50	
14/10/2014	5.20	2.70	14.02	
30/10/2014	4.00	1.62	6.47	
26/11/2014	5.20	6.25	32.51	
09/12/2014	5.20	2.21	11.50	
19/12/2014	5.20	3.29	17.11	
10/02/2015	5.20	1.98	10.31	***125.40***
11/02/2015	5.60	1.71	9.56	
13/02/2015	4.40	2.01	8.84	
18/02/2015	5.20	2.84	14.75	
12/03/2015	5.20	1.96	10.17	
21/03/2015	5.00	1.88	9.38	
24/03/2015	5.00	2.13	10.67	
29/03/2015	5.20	1.85	9.64	
21/04/2015	4.40	1.40	6.15	
23/04/2015	4.40	2.16	9.50	
01/10/2015	5.60	2.88	16.15	
30/11/2015	5.20	1.98	10.28	

Figure B.1: Doğanşehir Station Erosive Rainfall Events Details occurred between 2010 and 2015

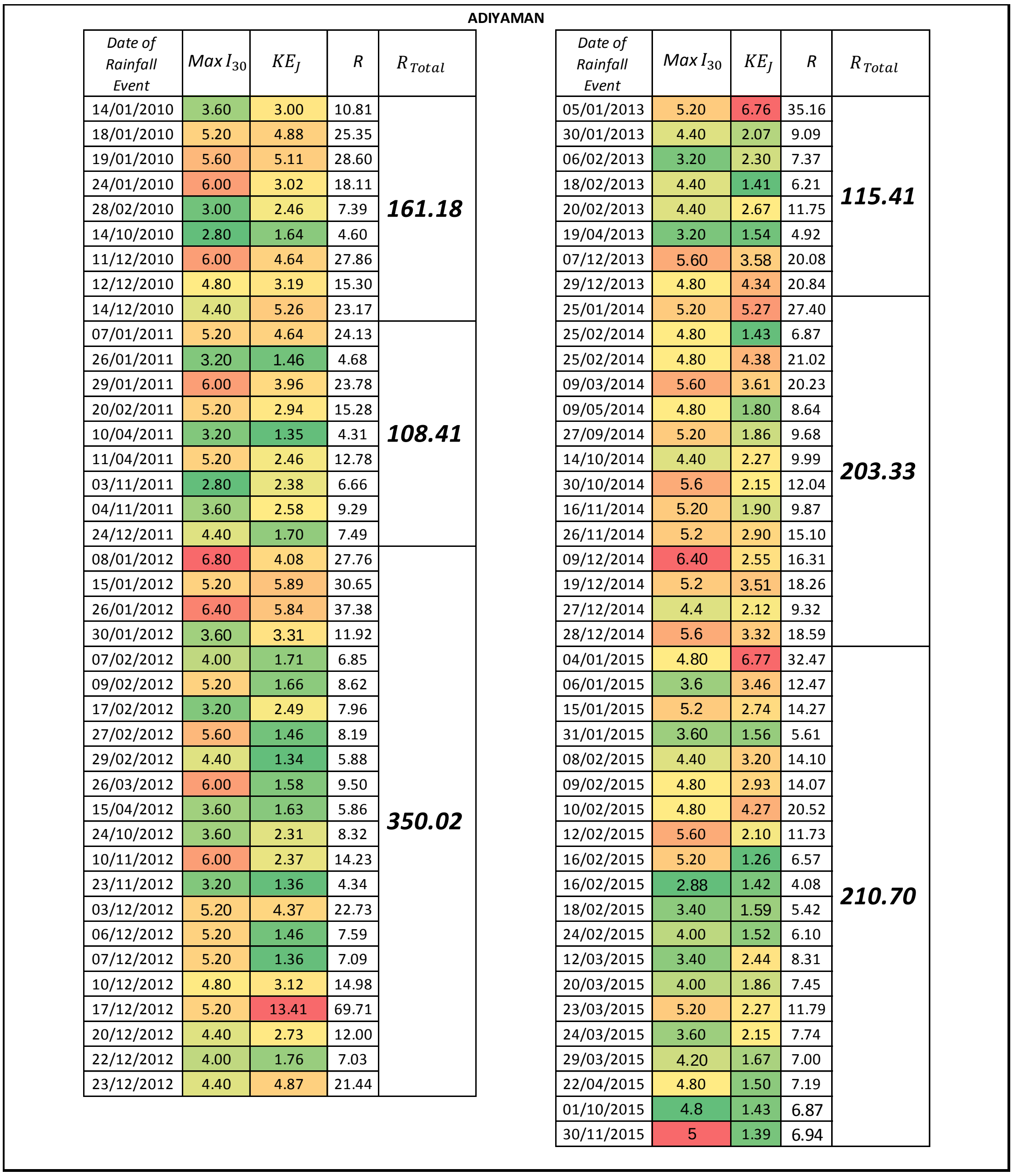


ANTAKYA

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
14/01/2010	4.80	3.50	16.80	191.33
18/01/2010	4.80	6.87	32.99	
24/01/2010	5.20	2.94	15.27	
09/02/2010	4.40	1.49	6.54	
27/02/2010	4.80	3.14	15.09	
23/06/2010	5.20	1.96	10.19	
29/10/2010	3.20	1.46	4.68	
10/12/2010	6.40	7.74	49.52	
13/12/2010	6.00	5.76	34.59	
17/12/2010	3.60	1.57	5.66	
07/01/2011	4.40	1.73	7.63	166.81
26/01/2011	5.60	1.62	9.09	
13/02/2011	5.20	1.78	9.24	
25/02/2011	4.50	2.47	11.13	
08/03/2011	4.80	2.55	12.24	
21/03/2011	4.20	1.96	8.23	
10/04/2011	4.00	1.19	4.77	
21/04/2011	6.40	2.14	13.70	
13/06/2011	6.00	2.11	12.69	
15/11/2011	4.80	1.40	6.72	
08/12/2011	6.00	3.70	22.22	
08/12/2011	7.20	1.71	12.28	
23/12/2011	6.80	4.44	30.20	
24/12/2011	4.00	1.67	6.67	
01/01/2012	5.60	4.29	24.04	308.78
08/01/2012	4.80	3.67	17.63	
09/01/2012	4.80	2.61	12.50	
14/01/2012	4.00	1.60	6.40	
15/01/2012	4.40	2.95	12.97	
21/01/2012	4.00	4.94	19.75	
25/01/2012	6.00	8.57	51.39	
27/01/2012	4.80	1.43	6.86	
07/02/2012	5.20	8.63	44.86	
15/02/2012	6.00	1.83	11.00	
16/02/2012	4.00	1.89	7.56	
27/02/2012	5.20	3.36	17.48	
28/02/2012	5.20	1.66	8.62	
13/03/2012	5.20	3.08	16.03	
28/03/2012	5.20	1.37	7.11	
14/05/2012	6.00	1.53	9.18	
09/11/2012	3.60	1.72	6.18	
09/11/2012	4.80	3.02	14.47	
22/11/2012	4.80	3.07	14.74	
06/12/2012	5.20	3.70	19.24	
10/12/2012	5.20	3.66	19.02	
17/12/2012	5.60	6.61	37.01	
19/12/2012	6.00	8.85	53.08	
22/12/2012	4.80	1.68	8.05	

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
05/01/2013	4.80	4.73	22.72	197.25
08/01/2013	4.80	1.60	7.69	
03/02/2013	4.40	1.53	6.71	
11/02/2013	4.00	2.47	9.88	
16/02/2013	5.60	4.16	23.31	
28/02/2013	2.80	1.50	4.19	
16/03/2013	4.40	1.47	6.46	
27/03/2013	4.80	1.84	8.82	
10/04/2013	3.60	2.74	9.88	
16/04/2013	4.80	4.75	22.79	
19/04/2013	6.00	3.18	19.08	
21/04/2013	6.00	1.80	10.79	
11/05/2013	4.40	1.68	7.41	
10/12/2013	5.20	3.06	15.93	
29/12/2013	5.20	4.15	21.58	
28/01/2014	5.2	1.41	7.34	87.92
24/02/2014	4.00	2.61	10.46	
09/03/2014	4	2.09	8.35	
11/10/2014	4.40	1.35	5.92	
30/10/2014	5.6	1.41	7.88	
31/10/2014	4.4	1.51	6.62	
25/11/2014	4.8	2.43	11.68	
09/12/2014	3.60	1.87	6.74	
21/12/2014	3.2	1.94	6.22	
27/12/2014	2.8	1.31	3.67	
28/12/2014	4.40	2.97	13.05	
01/01/2015	4.00	1.45	5.81	244.17
02/01/2015	3.60	1.84	6.64	
04/01/2015	4.40	3.12	13.71	
06/01/2015	4.08	3.13	12.77	
07/01/2015	4.80	1.47	7.08	
10/01/2015	4.00	1.47	5.89	
15/01/2015	3.60	1.37	4.95	
30/01/2015	5.20	4.89	25.45	
03/02/2015	3.20	1.58	5.04	
08/02/2015	4.40	11.13	48.97	
18/02/2015	4.80	4.81	23.08	
24/02/2015	4.40	2.09	9.19	
02/03/2015	5.60	4.68	26.20	
03/03/2015	3.60	1.23	4.42	
11/03/2015	6.40	3.06	19.57	
21/04/2015	3.80	2.70	10.28	
30/11/2015	3.80	2.20	8.37	
16/12/2015	3.60	1.88	6.78	

Figure B.2: Antakya Station Erosive Rainfall Events Details occurred between 2010 and 2015



ADIYAMAN

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
14/01/2010	3.60	3.00	10.81	**161.18**
18/01/2010	5.20	4.88	25.35	
19/01/2010	5.60	5.11	28.60	
24/01/2010	6.00	3.02	18.11	
28/02/2010	3.00	2.46	7.39	
14/10/2010	2.80	1.64	4.60	
11/12/2010	6.00	4.64	27.86	
12/12/2010	4.80	3.19	15.30	
14/12/2010	4.40	5.26	23.17	
07/01/2011	5.20	4.64	24.13	**108.41**
26/01/2011	3.20	1.46	4.68	
29/01/2011	6.00	3.96	23.78	
20/02/2011	5.20	2.94	15.28	
10/04/2011	3.20	1.35	4.31	
11/04/2011	5.20	2.46	12.78	
03/11/2011	2.80	2.38	6.66	
04/11/2011	3.60	2.58	9.29	
24/12/2011	4.40	1.70	7.49	
08/01/2012	6.80	4.08	27.76	**350.02**
15/01/2012	5.20	5.89	30.65	
26/01/2012	6.40	5.84	37.38	
30/01/2012	3.60	3.31	11.92	
07/02/2012	4.00	1.71	6.85	
09/02/2012	5.20	1.66	8.62	
17/02/2012	3.20	2.49	7.96	
27/02/2012	5.60	1.46	8.19	
29/02/2012	4.40	1.34	5.88	
26/03/2012	6.00	1.58	9.50	
15/04/2012	3.60	1.63	5.86	
24/10/2012	3.60	2.31	8.32	
10/11/2012	6.00	2.37	14.23	
23/11/2012	3.20	1.36	4.34	
03/12/2012	5.20	4.37	22.73	
06/12/2012	5.20	1.46	7.59	
07/12/2012	5.20	1.36	7.09	
10/12/2012	4.80	3.12	14.98	
17/12/2012	5.20	13.41	69.71	
20/12/2012	4.40	2.73	12.00	
22/12/2012	4.00	1.76	7.03	
23/12/2012	4.40	4.87	21.44	

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
05/01/2013	5.20	6.76	35.16	**115.41**
30/01/2013	4.40	2.07	9.09	
06/02/2013	3.20	2.30	7.37	
18/02/2013	4.40	1.41	6.21	
20/02/2013	4.40	2.67	11.75	
19/04/2013	3.20	1.54	4.92	
07/12/2013	5.60	3.58	20.08	
29/12/2013	4.80	4.34	20.84	
25/01/2014	5.20	5.27	27.40	**203.33**
25/02/2014	4.80	1.43	6.87	
25/02/2014	4.80	4.38	21.02	
09/03/2014	5.60	3.61	20.23	
09/05/2014	4.80	1.80	8.64	
27/09/2014	5.20	1.86	9.68	
14/10/2014	4.40	2.27	9.99	
30/10/2014	5.6	2.15	12.04	
16/11/2014	5.20	1.90	9.87	
26/11/2014	5.2	2.90	15.10	
09/12/2014	6.40	2.55	16.31	
19/12/2014	5.2	3.51	18.26	
27/12/2014	4.4	2.12	9.32	
28/12/2014	5.6	3.32	18.59	
04/01/2015	4.80	6.77	32.47	**210.70**
06/01/2015	3.6	3.46	12.47	
15/01/2015	5.2	2.74	14.27	
31/01/2015	3.60	1.56	5.61	
08/02/2015	4.40	3.20	14.10	
09/02/2015	4.80	2.93	14.07	
10/02/2015	4.80	4.27	20.52	
12/02/2015	5.60	2.10	11.73	
16/02/2015	5.20	1.26	6.57	
16/02/2015	2.88	1.42	4.08	
18/02/2015	3.40	1.59	5.42	
24/02/2015	4.00	1.52	6.10	
12/03/2015	3.40	2.44	8.31	
20/03/2015	4.00	1.86	7.45	
23/03/2015	5.20	2.27	11.79	
24/03/2015	3.60	2.15	7.74	
29/03/2015	4.20	1.67	7.00	
22/04/2015	4.80	1.50	7.19	
01/10/2015	4.8	1.43	6.87	
30/11/2015	5	1.39	6.94	

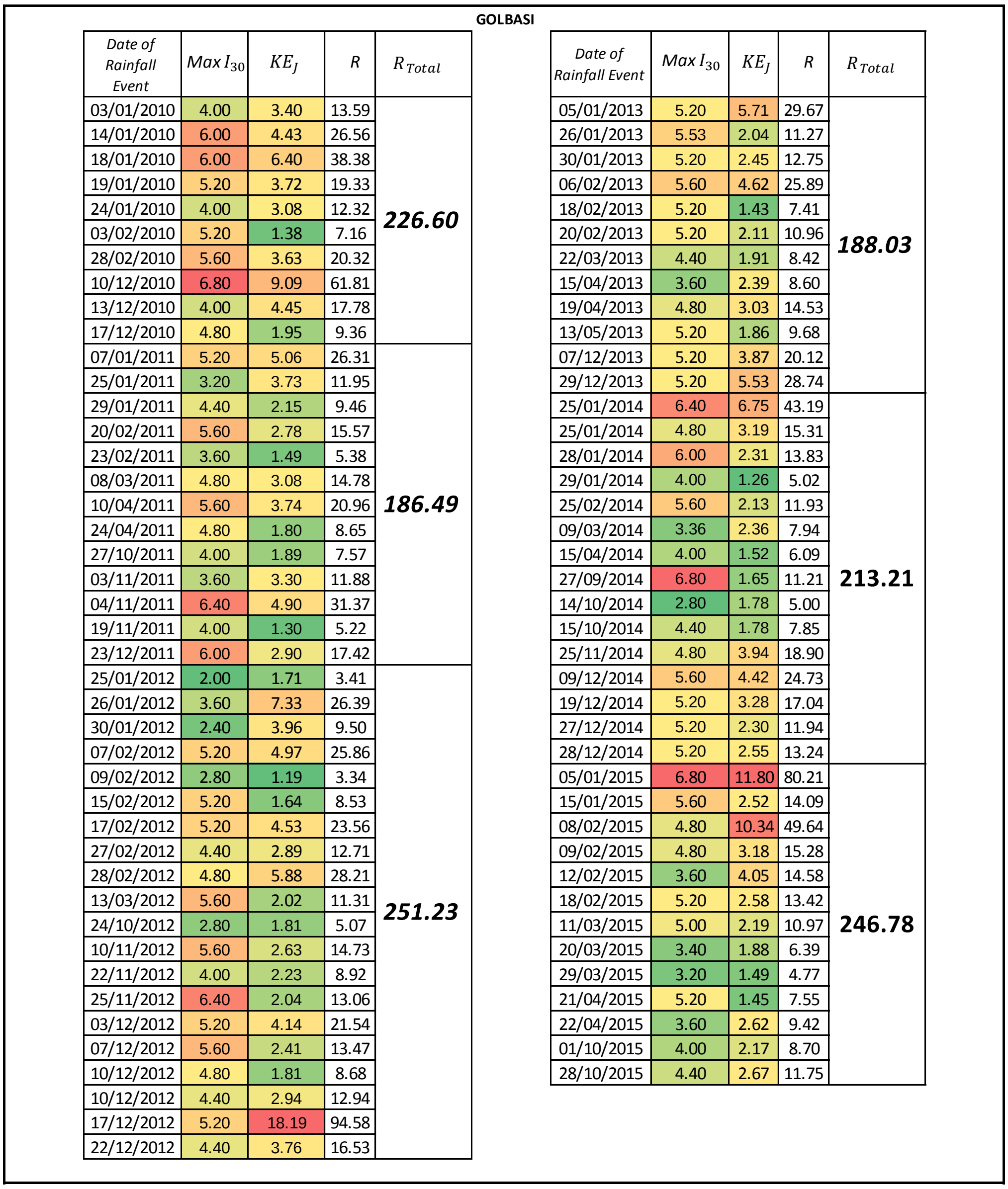
Figure B.3: Adıyaman Station Erosive Rainfall Events Details occurred between 2010 and 2015

ISLAHIYE

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
08/10/2010	4.80	1.80	8.64	60.61
11/12/2010	6.40	4.12	26.37	
14/12/2010	4.80	3.84	18.43	
17/12/2010	4.40	1.63	7.17	
09/03/2011	3.60	3.74	13.45	183.00
09/04/2011	5.40	9.07	48.97	
09/04/2011	6.80	2.61	17.78	
24/04/2011	3.60	2.10	7.57	
12/05/2011	3.60	2.10	7.57	
04/11/2011	4.40	2.57	11.31	
05/11/2011	6.00	3.83	22.98	
08/12/2011	5.20	2.87	14.94	
23/12/2011	5.60	4.93	27.63	
24/12/2011	6.00	1.80	10.79	
01/01/2012	5.20	3.18	16.51	541.40
07/01/2012	5.20	12.26	63.73	
08/01/2012	5.60	5.75	32.19	
09/01/2012	4.80	3.13	15.03	
13/01/2012	6.00	1.64	9.87	
14/01/2012	4.00	8.17	32.66	
21/01/2012	3.20	1.62	5.20	
24/01/2012	5.20	3.42	17.76	
26/01/2012	5.60	7.07	39.59	
15/02/2012	4.80	1.65	7.94	
16/02/2012	5.20	6.97	36.26	
27/02/2012	5.20	3.24	16.87	
28/02/2012	4.40	2.89	12.73	
29/02/2012	4.80	2.67	12.81	
13/03/2012	6.00	1.54	9.26	
14/03/2012	4.00	2.12	8.49	
18/04/2012	4.80	1.94	9.29	
08/11/2012	4.80	8.06	38.69	
22/11/2012	4.80	1.32	6.35	
03/12/2012	4.40	4.44	19.51	
07/12/2012	4.40	3.53	15.52	
10/12/2012	5.20	4.34	22.56	
17/12/2012	5.60	3.94	22.06	
18/12/2012	5.60	10.39	58.17	
22/12/2012	4.80	2.57	12.34	

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
06/01/2013	5.60	3.46	19.38	208.27
23/01/2013	4.00	1.34	5.36	
26/01/2013	5.60	1.87	10.45	
30/01/2013	3.20	1.51	4.82	
02/02/2013	4.80	1.75	8.41	
06/02/2013	3.60	3.25	11.72	
11/02/2013	6.00	3.13	18.79	
15/02/2013	4.80	4.10	19.70	
16/02/2013	4.40	4.61	20.31	
20/02/2013	5.20	3.40	17.66	
28/02/2013	5.20	1.90	9.90	
04/03/2013	4.00	2.80	11.20	
17/03/2013	4.80	2.73	13.10	
27/03/2013	3.60	1.51	5.43	
09/04/2013	4.80	2.36	11.34	
18/04/2013	4.40	2.37	10.43	
18/10/2013	4.00	2.57	10.30	
27/09/2014	4.80	2.84	13.65	110.04
25/11/2014	5.60	4.09	22.92	
08/12/2014	4.80	5.32	25.55	
21/12/2014	4.40	2.55	11.21	
27/12/2014	5.20	2.61	13.58	
28/12/2014	5.60	4.13	23.13	
04/01/2015	4.80	4.52	21.67	287.29
31/01/2015	5.2	1.77	9.18	
03/02/2015	4.40	2.13	9.38	
08/02/2015	5.6	17.35	97.14	
18/02/2015	5.60	5.00	28.03	
24/02/2015	5.2	2.59	13.46	
28/02/2015	5.6	2.57	14.39	
01/03/2015	4.8	1.59	7.65	
11/03/2015	4.00	3.77	15.07	
19/03/2015	5.6	6.49	36.36	
22/04/2015	4	1.44	5.75	
29/11/2015	5.60	1.77	9.89	
17/12/2015	4.80	4.02	19.32	

Figure B.4: Islahiye Station Erosive Rainfall Events Details occurred between 2010 and 2015

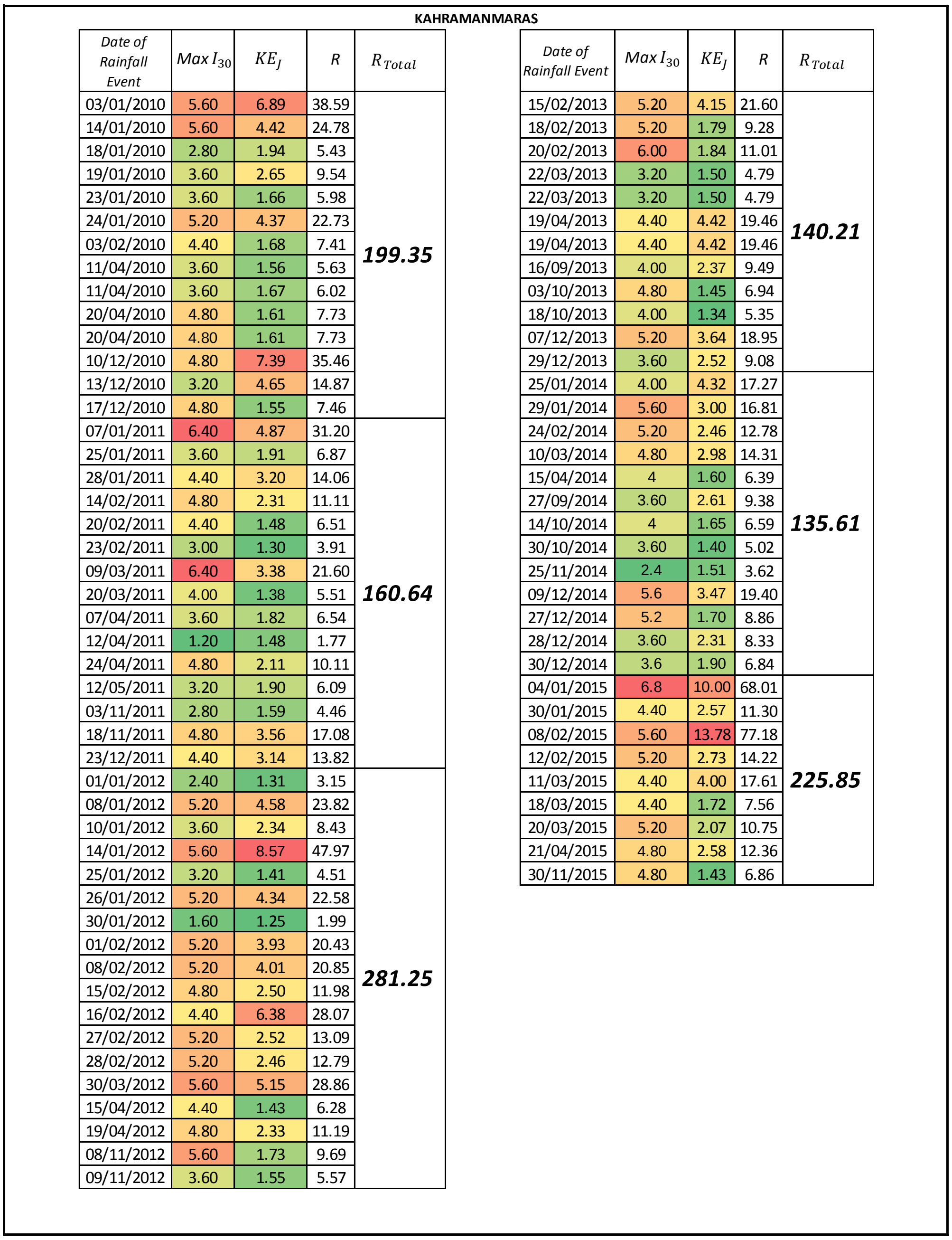


GOLBASI

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
03/01/2010	4.00	3.40	13.59	***226.60***
14/01/2010	6.00	4.43	26.56	
18/01/2010	6.00	6.40	38.38	
19/01/2010	5.20	3.72	19.33	
24/01/2010	4.00	3.08	12.32	
03/02/2010	5.20	1.38	7.16	
28/02/2010	5.60	3.63	20.32	
10/12/2010	6.80	9.09	61.81	
13/12/2010	4.00	4.45	17.78	
17/12/2010	4.80	1.95	9.36	
07/01/2011	5.20	5.06	26.31	***186.49***
25/01/2011	3.20	3.73	11.95	
29/01/2011	4.40	2.15	9.46	
20/02/2011	5.60	2.78	15.57	
23/02/2011	3.60	1.49	5.38	
08/03/2011	4.80	3.08	14.78	
10/04/2011	5.60	3.74	20.96	
24/04/2011	4.80	1.80	8.65	
27/10/2011	4.00	1.89	7.57	
03/11/2011	3.60	3.30	11.88	
04/11/2011	6.40	4.90	31.37	
19/11/2011	4.00	1.30	5.22	
23/12/2011	6.00	2.90	17.42	
25/01/2012	2.00	1.71	3.41	***251.23***
26/01/2012	3.60	7.33	26.39	
30/01/2012	2.40	3.96	9.50	
07/02/2012	5.20	4.97	25.86	
09/02/2012	2.80	1.19	3.34	
15/02/2012	5.20	1.64	8.53	
17/02/2012	5.20	4.53	23.56	
27/02/2012	4.40	2.89	12.71	
28/02/2012	4.80	5.88	28.21	
13/03/2012	5.60	2.02	11.31	
24/10/2012	2.80	1.81	5.07	
10/11/2012	5.60	2.63	14.73	
22/11/2012	4.00	2.23	8.92	
25/11/2012	6.40	2.04	13.06	
03/12/2012	5.20	4.14	21.54	
07/12/2012	5.60	2.41	13.47	
10/12/2012	4.80	1.81	8.68	
10/12/2012	4.40	2.94	12.94	
17/12/2012	5.20	18.19	94.58	
22/12/2012	4.40	3.76	16.53	

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
05/01/2013	5.20	5.71	29.67	***188.03***
26/01/2013	5.53	2.04	11.27	
30/01/2013	5.20	2.45	12.75	
06/02/2013	5.60	4.62	25.89	
18/02/2013	5.20	1.43	7.41	
20/02/2013	5.20	2.11	10.96	
22/03/2013	4.40	1.91	8.42	
15/04/2013	3.60	2.39	8.60	
19/04/2013	4.80	3.03	14.53	
13/05/2013	5.20	1.86	9.68	
07/12/2013	5.20	3.87	20.12	
29/12/2013	5.20	5.53	28.74	
25/01/2014	6.40	6.75	43.19	**213.21**
25/01/2014	4.80	3.19	15.31	
28/01/2014	6.00	2.31	13.83	
29/01/2014	4.00	1.26	5.02	
25/02/2014	5.60	2.13	11.93	
09/03/2014	3.36	2.36	7.94	
15/04/2014	4.00	1.52	6.09	
27/09/2014	6.80	1.65	11.21	
14/10/2014	2.80	1.78	5.00	
15/10/2014	4.40	1.78	7.85	
25/11/2014	4.80	3.94	18.90	
09/12/2014	5.60	4.42	24.73	
19/12/2014	5.20	3.28	17.04	
27/12/2014	5.20	2.30	11.94	
28/12/2014	5.20	2.55	13.24	
05/01/2015	6.80	11.80	80.21	**246.78**
15/01/2015	5.60	2.52	14.09	
08/02/2015	4.80	10.34	49.64	
09/02/2015	4.80	3.18	15.28	
12/02/2015	3.60	4.05	14.58	
18/02/2015	5.20	2.58	13.42	
11/03/2015	5.00	2.19	10.97	
20/03/2015	3.40	1.88	6.39	
29/03/2015	3.20	1.49	4.77	
21/04/2015	5.20	1.45	7.55	
22/04/2015	3.60	2.62	9.42	
01/10/2015	4.00	2.17	8.70	
28/10/2015	4.40	2.67	11.75	

Figure B.5: Gölbaşı Station Erosive Rainfall Events Details occurred between 2010 and 2015



KAHRAMANMARAS

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
03/01/2010	5.60	6.89	38.59	199.35
14/01/2010	5.60	4.42	24.78	
18/01/2010	2.80	1.94	5.43	
19/01/2010	3.60	2.65	9.54	
23/01/2010	3.60	1.66	5.98	
24/01/2010	5.20	4.37	22.73	
03/02/2010	4.40	1.68	7.41	
11/04/2010	3.60	1.56	5.63	
11/04/2010	3.60	1.67	6.02	
20/04/2010	4.80	1.61	7.73	
20/04/2010	4.80	1.61	7.73	
10/12/2010	4.80	7.39	35.46	
13/12/2010	3.20	4.65	14.87	
17/12/2010	4.80	1.55	7.46	
07/01/2011	6.40	4.87	31.20	160.64
25/01/2011	3.60	1.91	6.87	
28/01/2011	4.40	3.20	14.06	
14/02/2011	4.80	2.31	11.11	
20/02/2011	4.40	1.48	6.51	
23/02/2011	3.00	1.30	3.91	
09/03/2011	6.40	3.38	21.60	
20/03/2011	4.00	1.38	5.51	
07/04/2011	3.60	1.82	6.54	
12/04/2011	1.20	1.48	1.77	
24/04/2011	4.80	2.11	10.11	
12/05/2011	3.20	1.90	6.09	
03/11/2011	2.80	1.59	4.46	
18/11/2011	4.80	3.56	17.08	
23/12/2011	4.40	3.14	13.82	
01/01/2012	2.40	1.31	3.15	281.25
08/01/2012	5.20	4.58	23.82	
10/01/2012	3.60	2.34	8.43	
14/01/2012	5.60	8.57	47.97	
25/01/2012	3.20	1.41	4.51	
26/01/2012	5.20	4.34	22.58	
30/01/2012	1.60	1.25	1.99	
01/02/2012	5.20	3.93	20.43	
08/02/2012	5.20	4.01	20.85	
15/02/2012	4.80	2.50	11.98	
16/02/2012	4.40	6.38	28.07	
27/02/2012	5.20	2.52	13.09	
28/02/2012	5.20	2.46	12.79	
30/03/2012	5.60	5.15	28.86	
15/04/2012	4.40	1.43	6.28	
19/04/2012	4.80	2.33	11.19	
08/11/2012	5.60	1.73	9.69	
09/11/2012	3.60	1.55	5.57	

Date of Rainfall Event	Max I_{30}	KE_J	R	R_{Total}
15/02/2013	5.20	4.15	21.60	140.21
18/02/2013	5.20	1.79	9.28	
20/02/2013	6.00	1.84	11.01	
22/03/2013	3.20	1.50	4.79	
22/03/2013	3.20	1.50	4.79	
19/04/2013	4.40	4.42	19.46	
19/04/2013	4.40	4.42	19.46	
16/09/2013	4.00	2.37	9.49	
03/10/2013	4.80	1.45	6.94	
18/10/2013	4.00	1.34	5.35	
07/12/2013	5.20	3.64	18.95	
29/12/2013	3.60	2.52	9.08	
25/01/2014	4.00	4.32	17.27	135.61
29/01/2014	5.60	3.00	16.81	
24/02/2014	5.20	2.46	12.78	
10/03/2014	4.80	2.98	14.31	
15/04/2014	4	1.60	6.39	
27/09/2014	3.60	2.61	9.38	
14/10/2014	4	1.65	6.59	
30/10/2014	3.60	1.40	5.02	
25/11/2014	2.4	1.51	3.62	
09/12/2014	5.6	3.47	19.40	
27/12/2014	5.2	1.70	8.86	
28/12/2014	3.60	2.31	8.33	
30/12/2014	3.6	1.90	6.84	
04/01/2015	6.8	10.00	68.01	225.85
30/01/2015	4.40	2.57	11.30	
08/02/2015	5.60	13.78	77.18	
12/02/2015	5.20	2.73	14.22	
11/03/2015	4.40	4.00	17.61	
18/03/2015	4.40	1.72	7.56	
20/03/2015	5.20	2.07	10.75	
21/04/2015	4.80	2.58	12.36	
30/11/2015	4.80	1.43	6.86	

Figure B.6: Kahramanmaraş Station Erosive Rainfall Events Details occurred between 2010 and 2015