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Araştırma Makalesi/Research Article

Variations in Erosion Risk in Western Anatolia (Turkey): Modified Fournier Approach

Ercan Yeşilırmak[1*] **Levent Atatanır**[2]

[1] Department of Biosystems Engineering, Faculty of Agriculture, Aydın Adnan Menderes University, Aydın, Turkey
[2]Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Aydın Adnan Menderes University, Aydın, Turkey
[*] Corresponding author: eyesilirmak@adu.edu.tr

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Abstract

As a result of global warming, more intense rainfall events and hence higher flood and erosion risk are expected to occur more likely. As erosion has been an important environmental problem in Turkey, it would be beneficial to document how it changed during global warming era. The aim of this study is to investigate the temporal evoluation of erosion risk from 1950 to 2018 in western Anatolia (Turkey), by using Modified Fournier Index (MFI). Also, temporal patterns of annual average temperature and annual total rainfall were analysed. The results, firstly, showed that the study area has cooled slightly from 1950 to 1976 and strongly warmed afterwards (–0.24 and 0.48 °C decade^{-1} on average, respectively), which is consistent with the temporal pattern of global average temperature. Neither annual total rainfall nor MFI showed statistically significant tendencies during both periods. Erosion risk during the rapid warming period (average MFI = 116.7) was not different from that in the cooling period (average MFI = 124.7). It follows that, on the contrary to the expectation, erosion risk in the study area stayed unchaged while average temperature increased substantially after mid-1970s.
Key words: Climate Change, Erosion, Flood, Temperature, Extreme Precipitation

Batı Anadolu'da Erozyon Riskindeki Değişimler: Modifiye Fournier Yaklaşımı

Öz

Küresel ısınmanın sonucu olarak, daha şiddetli yağışlar ve buna bağlı olarak taşkın ve erozyon riskinde artış beklenmektedir. Erozyonun Türkiye'nin en önemli çevre sorunlarından biri olması nedeniyle, küresel ısınmayla birlikte erozyon riskinde nasıl bir değişim olduğunun ortaya konması yararlı bilgiler verebilir. Bu çalışmada, 1950 ile 2018 yılları arasında, batı Anadolu'da modifiye Fournier indeksi kullanılarak erozyon riskindeki değişimler incelenmiştir. Ayrıca, çalışma alanındaki yıllık ortalama sıcaklıklar ile yıllık toplam yağışlardaki değişimler de incelenmiştir. Sonuçlar, çalışma alanındaki yıllık ortalama sıcaklıkların, küresel sıcaklık değişimi ile uyumlu olarak, 1950 ile 1976 arasında hafif bir azalış ve ardından 1976 sonrasında ise hızlı bir artış eğiliminde olduğunu (ortalama olarak, sırasıyla, –0.24 and 0.48 °C onyıl^{-1}), hem yıllık toplam yağışlarda hem de MFI değerlerinde her iki dönem içinde de istatistiksel olarak önemli bir değişim eğilimi olmadığını göstermiştir. Hızlı ısınma dönemindeki erozyon riski (ortalama MFI = 116.7), hafif soğuma dönemindekinden (ortalama MFI = 124.7) farklı bulunmamıştır. Batı Anadolu'daki 1970'lerin ortasından itibaren gerçekleşen hızlı sıcaklık artışına rağmen, beklentinin aksine, erozyon riskinde bir değişim olmadığı saptanmıştır.
Anahtar Kelimeler: İklim Değişikliği, Erozyon, Taşkın, Sıcaklık, Ekstrem Yağış

Introduction

Erosion has long been considered as the most important environmental problem in Turkey. Land use, topography, soil type, vegetation and rainfall are the most important factors that cause erosion by water. Turkey has a mean elevation of 1250 m, and more than 64% of its surface area has a slope greater than 12% (Parlak, 2014). About 12% of Turkey is under severe or very severe erosion risk. As a result of intensive measures, annual soil loss due to erosion has dropped from 500 million tons per year in 1970s to 154 million tons in 2017, and is projected to drop to 130 million tons in 2023 (Anonymous, 2020).

Estimation of soil loss due to erosion is crucial in terms of adopting proper land use planning and development strategies (Biswas and Pani, 2015). Among the various estimation methods, the Universal Soil Loss Equation (USLE) or revised USLE (RUSLE) are extensively used approaches. The USLE is given as

$$A = R\,K\,L\,S\,C\,P \tag{1}$$

where A is average annual soil loss (ton ha^{-1} year^{-1}) over the long term period, R is the rainfall–runoff "erosivity" factor, K is the soil "erodibility" factor, L and S are the topographic factors, C is the crop and crop management factor, and P is the soil conservation practice factor (Kinnell, 2010). R factor is considered as the most important component of the USLE (Amara et al., 2020), and determined by calculating the average annual sum of the product of a storm's kinetic energy (E) and its maximum 30-min intensity (I30), known as the EI30 (Garcia-Marin et al., 2017). High-resolution rainfall data are required to calculate R values. However, such data are generally unavailable in required spatial and temporal coverage. Instead, alternative indices were developed and have been extensively used, which make use of daily, monthly or annual rainfall total. The index proposed by Fournier (1960) was shown to have a high correlation with the amount of sediment transported into stream by runoff (Munka et al., 2007). Fournier index (FI) is the squared monthly rainfall divided by annual rainfall total. Modified Fournier Index abbreviated as MFI is the total of all FI values within a year. Numerous researches made use of FI and/or MFI to explore the status and/or time variation of erosion risk, or to estimate R value in USLE/RUSLE models, for example in Rwanda (Muhire et al., 2015), in Spain (De Luis et al., 2010; Hernando and Romana, 2015; Garcia-Marin et al., 2017), in Italy (Di Lena et al., 2013; Capra et al., 2017), in Ethiopia (Meshesha et al., 2015), in Uruguay (Munka et al., 2007), in Portugal (Nunes et al., 2016), in Jordan (Eltaif et al., 2010), in Korea (Lee and Heo, 2011), in the Netherlands (Lukiç et al., 2018), in Turkey (Bayramin et al., 2006; İrvem et al., 2007; Yuksel et al., 2008; Imamoglu and Dengiz, 2017; Oğuz, 2019).

The earth has been experiencing a temperature increase since the late 19th century. With the warming, changes in extreme precipitation events are expected (Cubasch et al., 2013), due to the increase in water holding capacity of air as a result of increased air temperature (Fowler and Hennessy, 1995; Mishra and Singh, 2010), leading to more frequent and severe flood events (Li et al., 2011; Coscarelli and Caloiero 2012) and thereby a higher risk of erosion.

Previous studies have shown that Turkey, particularly western Anatolia, have experienced substantial warming for 30-40 years (Akçakaya et al., 2015). It would be crucial to ascertain how erosion risk has changed over that period; has it become more severe under increased air temperature as expected? The objective of this study is to answer that question using MFI for the period from 1950 to 2018. The results are expected be useful for soil conservation and/or water management strategies and for understanding regional effects of increased temperature.

Materials and Methods

The stations whose climatic data analysed in this study are located in western Anatolia, limited by Marmara Sea in the north, Aegean Sea in the west and Mediterranean Sea in the south (Figure 1). The stations are also listed in Table 1, together with their geographical attributes.

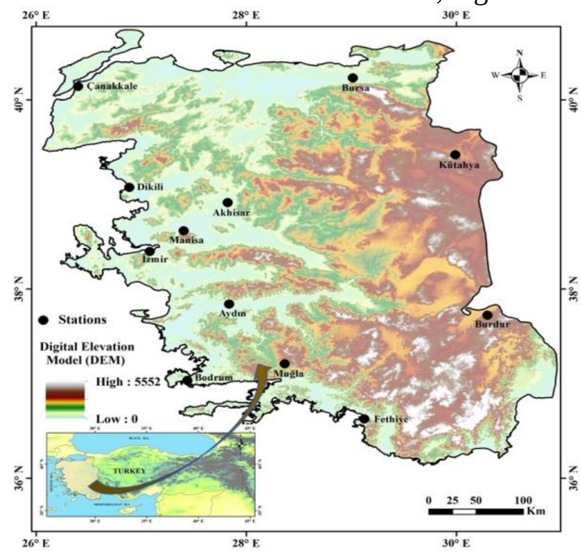

Figure 1. Locations of the stations within western Anatolia.

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Precipitation and temperature data were supplied from The State Meteorological Service of Turkey (MGM) for 12 weather stations in daily basis, which cover the period from 1950 to 2018 with minimum missing data and the longest period of record possible. The percentage of missing days at any station was less than 0.5%. All of them were filled by averaging the values of the neighbouring days (Li et al., 2011). Daily values were summed or averaged to obtain firstly monthly, then seasonal and annual totals or averages. Each rainfall and temperature series were checked for consistency by the double-mass curve method (Zhang et al., 2012). The results revealed that all series were consistent.

Table 1. The list of the stations with their geographical attributes

Station	Latitude (°N)	Longitude (°E)	Elevation (m.a.s.l.)
Akhisar	38.9118	27.8233	92
Aydın	37.8402	27.8379	56
Bodrum	37.0328	27.4398	26
Burdur	37.7220	30.2940	957
Bursa	40.2308	29.0133	100
Çanakkale	40.1410	26.3993	6
Dikili	39.0737	26.8880	3
Fethiye	36.6266	29.1238	3
İzmir	38.3949	27.0819	29
Kütahya	39.4171	29.9891	969
Manisa	38.6153	27.4049	71
Muğla	37.2095	28.3668	646

Modified Fournier Index (MFI), which was originally proposed by Fournier (1960) and then modified by Arnoldus (1980) is calculated for each year as given below

$$MFI = \sum_{i=1}^{12} \frac{P_i^2}{R} \tag{2}$$

where P is the monthly rainfall total and R is the annual rainfall total. Based on index values, rainfall erosivity is classified as very low (0 < MFI < 60), low (60 < MFI < 90), moderate (90 < MFI < 120), high (120 <MFI < 160), and very high (MFI > 160) (Nunes et al., 2016).

Non-parametric Mann-Kendall test was employed to detect statistical significance of trends in each time series at each station by using the Excel template MAKESENS (Salmi et al., 2002). In Mann-Kendall test, the null hypothesis of no trend (H_0) is that the observations x_i are randomly ordered in time. Alternative hypothesis (H_1) states that there exists an upward or downward monotonic trend. The test statistic S is calculated as given below

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \tag{3}$$

where x_j and x_k are the values in year j and k, respectively, and

$$sgn(x_j - x_k) = \begin{cases} 1 \text{ if } x_j - x_k > 0 \\ 0 \text{ if } x_j - x_k = 0 \\ -1 \text{ if } x_j - x_k < 0 \end{cases} \tag{4}$$

If the number of data points is 9 or less, then the absolute value of S is compared directly to the theoretical distribution of S (Gilbert, 1987). The normal approximation test is used, If n is at least 10. The variance of S is estimated using the following equation which considers equal values, if any,

$$VAR(S) = {}^{1}/_{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \tag{5}$$

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where q is the number of tied groups and t_p is the number of data values in the p^{th} group. Then, the test statistic Z is calculated using S and $VAR(S)$ as follows

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases} \quad (6)$$

A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. If there is a statistically significant monotonic trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$ where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In this study, the significance level of $\alpha = 0.05$ was used. The trend rates (β) were determined using Sen's Slope Estimator:

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i-j}\right), \forall j < i \quad (7)$$

The statistical significance of changes in mean values of MFI between subperiods was evaluated using t-test (Munka et al., 2007).

Results

Firstly, temporal patterns of annual mean temperature series for all individual stations and regional mean averaged over all stations were investigated during whole period of 1950-2018. Figure 2 shows the temporal evolution of regional annual average temperature from 1950 to 2018. There was a cooling tendency between 1950 and 1976, with a rate of 0.24 °C decade^{-1} on average. The year 1976 was the coolest year, 15.1 °C on average, over the whole study period of 1950-2018. At individual stations, this cooling is statistically significant at 95% level at only three stations, namely Aydın, Burdur and Fethiye (Table 2). The highest rate of cooling was observed at Fethiye with a rate of –0.92 °C decade^{-1}.

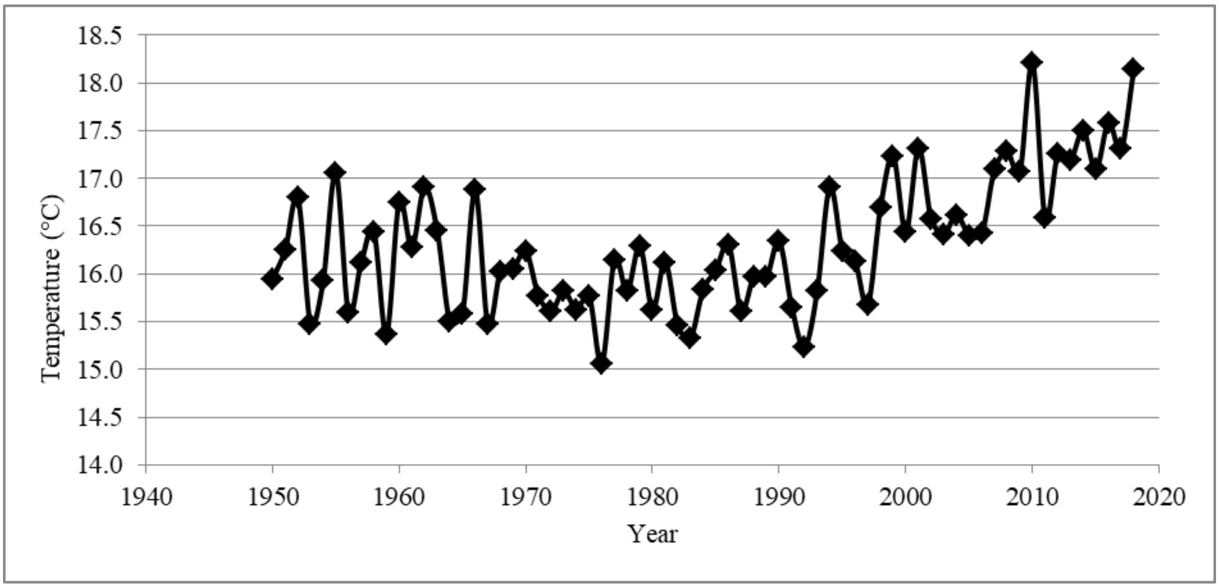

Figure 2. Temporal pattern of regional mean temperature over the study area

After the coolest year 1976, annual average temperature experienced a rapid increase. During this period, all stations had statistically significant increasing trends, ranging from 0.37 °C decade^{-1} at İzmir to 0.77 °C decade^{-1} at Fehiye. Regional annual average trend was 0.48 °C decade^{-1}. When seasonal average temperatures were analysed for trends during the same period, it was found that the

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trend rates were not homogeneous among seasons (Table 2). The rate of increase was the highest in summer and the lowest in winter at all stations, 0.071 °C year^{-1} and 0.029 °C year^{-1}, respectively, in terms of regional averages. In other words, summer has warmed more than winter.

Table 2. Annual and seasonal average temperature trend rates (°C year^{-1}) (Statistically significant trends at 95% shown in bold and red)

Station	Annual		Seasonal (1976-2018)			
	1950-1976	1976-2018	Summer	Fall	Winter	Spring
Akhisar	– 0.022	**0.052**	**0.080**	**0.052**	0.020	**0.057**
Aydın	**– 0.045**	**0.049**	**0.069**	**0.045**	**0.027**	**0.046**
Bodrum	– 0.008	**0.054**	**0.078**	**0.053**	**0.039**	**0.052**
Burdur	**– 0.043**	**0.039**	**0.062**	**0.032**	0.021	**0.046**
Bursa	– 0.025	**0.048**	**0.075**	**0.043**	0.023	**0.051**
Çanakkale	– 0.021	**0.048**	**0.072**	**0.049**	0.030	**0.050**
Dikili	– 0.021	**0.040**	**0.067**	**0.033**	0.029	**0.047**
Fethiye	**– 0.092**	**0.077**	**0.113**	**0.075**	**0.048**	**0.072**
İzmir	– 0.012	**0.037**	**0.050**	**0.033**	0.025	**0.043**
Kütahya	– 0.003	**0.051**	**0.069**	**0.044**	**0.039**	**0.050**
Manisa	– 0.012	**0.042**	**0.059**	**0.041**	0.017	**0.048**
Muğla	– 0.023	**0.041**	**0.059**	**0.031**	**0.027**	**0.042**
Average	– 0.024	0.048	0.071	0.044	0.029	0.050

Annual total rainfall experienced non-significant trends at all stations during both periods of 1950-1976 and 1976-2018, except Bursa between 1976 and 2018 (Table 3). Annual total rainfall increased at Bursa with a rate of 34 mm decade^{-1} during 1976-2018. Regionally, there were slight decrease and increase with the rates of –13 mm decade^{-1} and 14 mm decade^{-1}, respectively.

There has been an apparent seasonality in rainfall distribution among seasons (Table 3). A significant portion of total annual rainfall drops during winter. Winter rainfall contribution is as high as 59.0 % at Bodrum. Its regional average is 48.6%. Summer is the season in which the lowest amount of rainfall occurs. Summer rainfall contribution reaches the highest percentage (13.2%) at Kütahya. It is less than 1% at Bodrum and Fethiye. In terms of regional average, about 5.1% total annual rainfall falls in summer.

Table 3. Trends in annual total rainfall (statistically significant trends at 95% shown in bold and red) and the percentage of seasonal rainfall within annual rainfall

Station	Annual Total Rainfall Trend (mm year^{-1})		Rainfall Percentage (%)			
	1950-1976	1976-2018	Summer	Fall	Winter	Spring
Akhisar	– 1.9	– 0.6	4.0	22.1	47.9	26.0
Aydın	– 5.2	1.4	3.1	21.8	50.1	25.0
Bodrum	– 5.9	1.5	0.7	22.6	59.0	17.7
Burdur	– 2.7	0.4	11.7	20.2	36.5	31.6
Bursa	3.1	**3.4**	9.4	26.5	38.3	25.8
Çanakkale	– 2.9	2.4	6.5	26.9	43.6	23.0
Dikili	– 2.6	0.7	2.3	23.6	51.9	22.2
Fethiye	– 5.1	1.3	0.8	23.4	58.1	17.7
İzmir	1.4	0.6	2.0	22.3	53.6	22.1
Kütahya	3.7	1.3	13.2	20.3	36.8	29.7
Manisa	3.4	– 0.5	4.1	21.4	50.5	24.0
Muğla	1.1	1.2	3.6	19.3	56.8	20.3
Average	– 1.3	1.4	5.1	22.5	48.6	23.8

Average MFI values at individual stations during the periods 1950-1976 and 1976-2018, and the corresponding MFI classes are shown in Table 4. During the first period, MFI changed from 59.4

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(Burdur) to 228.9 (Muğla). While six stations had either “high” or “very high” risk of erosion, three stations had either “low” or “very low”. Only three stations had “moderate” erosity. During the next period (1976–2018), MFI ranged from 60.2 (Burdur) to 205.3 (Muğla). In terms of erosion risk, five stations had “high” or “very high”, and only two stations “low” erosion risk. Muğla and Fethiye located in South-western part of the sudy area are caharacterized as the locations with highest ersosion risk during both periods.

Table 4 shows also the changes in average MFI from the period 1950-1976 to the period 1976-2018, together with corresponding risk classes, not only at individual stations but also in regional average. There were an overall slight decrease (5.2%) in regionally averaged MFI, from 124.7 (high) to 116.7 (moderate).

Table 4. Average values, classes, and chages in MFI during two periods (statistically significant changes at 95% in average MFI shown in bold and red

Station	1950 - 1976		1976 – 2018		Change in MFI	
	Average	Class	Average	Class	Absolute	Relative (%)
Akhisar	103.0	Moderate	95.3	Moderate	–7.7	–7.5
Aydın	107.8	Moderate	110.0	Moderate	2.2	2.0
Bodrum	148.2	High	138.2	High	–10.0	–6.7
Burdur	59.4	Very low	60.2	Low	0.8	1.3
Bursa	89.4	Low	93.0	Moderate	3.6	4.0
Çanakkale	105.4	Moderate	98.3	Moderate	–7.1	–6.7
Dikili	133.2	High	105.4	Moderate	**–27.8**	–20.9
Fethiye	186.2	Very high	167.1	Very high	–19.1	–10.3
İzmir	127.8	High	131.3	High	3.5	2.7
Kütahya	76.0	Low	72.6	Low	–3.4	–4.5
Manisa	130.7	High	123.7	High	–7.0	–5.4
Muğla	228.9	Very high	205.3	Very high	–23.6	–10.3
Average	124.7	High	116.7	Moderate	–8.0	–5.2

At individual stations, while eight stations had lower MFI during next period than perivous one, four stations had higher MFI. Increases seems to be minuscule compared to decreases. While increases ranged from 1.3% to 4%, decreases varied from 5.4% to 20.9%, which maked regionally averaged MFI decreasing. The only statistically significant change was observed at Dikili where MFI decreased from 133.2 (high) to 105.4 (moderate), corresponding to 20.9% decline. The classes stayed unchanged at nine stations. But, it shifted from “very low” to “low”, from “low” to “moderate” and from “high” to “moderate” at other three stations (Table 4).

Temporal trends of MFI values during the periods 1950-1976 and 1976-2018 are presented in Table 5. In terms of regional averages, there were slight decreasing tendency between 1950 and 1976 and slight increasing tendency from 1976 to 2018. At individuval stations, the only statistically significant trend occurred at Bursa with a rate of 0.396 $year^{-1}$, equivalent to 17.0 increase in MFI value during 1976-2018. Other stations showed non-significant trends during both periods.

Table 6 displays the association between some geographic variables (latitude, longitude and elevation) and spatial and temporal variations of MFI and rainfall. Latitude has an inverse statistically significant correlation with MFI during both periods ($r = –0.59$ and $r = –0.61$, respectively). Latitude has also negative but non-significant correlation with annual rainfall. However, latitude has a positive (non-signficant) influence on spatial and temporal variations of MFI and rainfall during both periods, with r values ranging from 0.31 to 0.53. On the other hand, neither longitude nor elevation has an influence on MFI and rainfal in spatial and temporal domains.

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Table 5. MFI trend rates during two periods (statistically significant trends at 95% shown in bold and red)

Station	MFI Trend (year^{-1})	
	1950-1976	1976-2018
Akhisar	–0.841	–0.184
Aydın	–1.195	0.233
Bodrum	–2.402	0.351
Burdur	–0.671	0.041
Bursa	–0.252	**0.396**
Çanakkale	–0.936	0.509
Dikili	–0.867	0.174
Fethiye	–1.868	–0.056
İzmir	0.133	0.069
Kütahya	0.237	–0.065
Manisa	–0.009	–0.234
Muğla	–0.296	–0.253
Average	–0.747	0.082

Table 6. Correlations between mean values and trends of MFI and rainfall and some geographical attributes (statistically significant correlations at 95% shown in bold and red)

	Mean values				Trends			
	MFI		Annual Rainfall		MFI		Annual Rainfall	
	1950-1976	1976-2018	1950-1976	1976-2018	1950-1976	1976-2018	1950-1976	1976-2018
Latitude	**–0.59**	**–0.61**	–0.45	–0.42	0.53	0.38	0.51	0.31
Longitude	–0.26	–0.25	–014	–0.11	0.16	–0.31	0.20	0.08
Elevation	–0.24	–0.26	–0.13	–0.10	0.41	–0.37	0.34	–0.09

Discussion

One of the expected consequences of global warming is the more intense rainfall events and hence a higher risk of erosion. Observations showed that global average temperature increase has not been temporally homogeneous. Whole period of increase since late 19th centruy includes cooling and warming subperiods. Global average temperature showed a small negative trend from 1940s to 1970s (Kosaka and Xie, 2016). This cooling is estimated to be –0.04 °C decade^{-1} from 1941 to 1971 (Meehl, 2015). The results of this study showed that western Anatolia also experienced a slight cooling tendency from 1950 to 1976 at a rate of –0.24 °C decade^{-1} in terms of regional average, with most of stations exhibiting non significant decreasing trend. Over the same period, annual total rainfall and MFI at individual stations also had slighltly (statistically nonsignificant) decreasing trends. It follows that the results are in comply with the expectation that the slight cooling was accompanied by unchanged erosion risk.

The next period (1976-2018) is completely different from previous one (1950-1976) in terms of temperature evolution. During 1976-2018, annual average temperature increased substantially; all stations experienced strong temperature increase. However, MFI did not follow the same pattern. Instead, it stayed unchanged, even slightly decreased, which suggests that erosion risk slightly diminished or remained stable over the study area. This is not what is expected in that increased temperature may leads to more intense rainfall events due to increased water vapour holding capacity of air, and, in turn, may cause more severe erosion. One of the explanations for the contradiction would be the asymetrical temperature increases among seasons in the study area. While summer season has the strongest temperature increase, it receives the smallest portion of annual total rainfall. Conversely, winter receives the highest portion but experiences the lowest temperature increase. It should be also noted that extreme precipitation events in western Anatolia, also in Turkey and eastern Mediterranean, are controlled by various ocean-atmosphere teleconnection patterns such as North Atalantic Oscillation (NAO), Arctic Oscillation (AO), El Nino Southern Oscillation (ENSO) and East Atlantic/Western Russian (EA/WR) pattern (Krichak et al., 2014; Duzenli et al., 2018).

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Significant correlations between latitude and MFI during both periods suggest that the stations with higher latitudes have lower risk of erosion than those with lower latitudes. Similarly, weaker (and, also non-significant) inverse correlations between latitude and rainfall imply a similar pattern, i.e., a decreasing rainfall from the South to the North. This can be attributed to the weaking of moisture-rich air masses from Mediterranean sea toward North. Elevation is a likely factor on rainfall and erosion risk, and improves the estimates of erosion risk mapping when incorparated into various interpolation techniques such as spline (e.g., Apaydın et al., 2006), kriging (e.g., Sanchez-Moreno et al., 2014). Various studies reported strong agreements between erosion and elevation or other geographical variables such as latitude and longitude (e.g., Jiang et al., 2012; Zhou et al., 2014; Ochoa-Cueva et al., 2015; İkiel et al., 2020). No such a relationship was found between elevation and erosion risk in this study, possibly due to the limited number of stations. As the objective in this study was to analyse the erosion risk, quantified by MFI, particularly in temporal domain under so-called global warming, the main criterion was to select the stations with temperature and rainfall series as long as possible in such a way that they should cover the globally observed slight cooling period within the third quarter of 20th century. Among the numerous stations, the selection process, including consistency, resulted in only twelve stations in the study area, which may not be sufficient to validate/invalidate that relationship.

A number of previous studies are in good agreement with the results of this study. For example, Abbasnia and Toros (2020), Ağbaş (2019), Yeşilırmak and Atatanır (2016), Sensoy et al. (2013) detected no statistically significant changes in extreme precipitation events in western Anatolia, which suggest no change in erosion risk. As less data requirement and easily applicability have made MFI an extensively used tool to evaluate temporal evolution of erosion risk throught the World. Some of them are as follows: no overall trend over eastern Africa during 1981-2016 (Fenta et al., 2017) and in Portugal during 1950-2008 (Nunes et al., 2016), both increasing and decreasing trends in Mediterranean Iberian Peninsula during 1951-2000 (De Luis et al., 2010) and in the Netherlands during 1957-2016 (Lukiç et al., 2018), mostly increasing trends in Bangladesh during 1981-2010 (Alam and Sarker, 2014), mostly decreasing trends in the Abruzzo Region of Italy during 1951-2009 (Di Lena et al., 2013). According to these results, there have been no coherency on the direction and strength of trends. This can be attributed to the spatial inhomogeneity of global warming, regional or local geographical factors, data period used, internal atmospheric variability etc., which need further research.

Conclusions

This study shows that western Anatolia (Turkey) has not undergone a significant tendency in erosion risk, quantified by MFI, during rapid warming period from 1976 to 2018. In other words, warmed air temperature has not been accompanied by higher erosion risk during that period. This does not comply with the expectation that warmer air leads to higher erosion, by creating more intense rainfall events. Besides, erosion risk during rapid warming period was not significantly different from that of slight cooling period. It seems that warmed air does not necessarily lead to a higher erosion risk. Some other factors such as atmospheric circulation patterns, local/regional geography etc. may involve, which should be taken into account in soil coservation and water management strategies.

Land use, topography, soil type, vegetation and rainfall are influential on erosion by water. It should be stressed that this study focused solely on rainfall, to answer the question how the effect of rainfall on erosion risk changed as a result of warmed air temperature since more intense rainfall events and hence higher risk of erosion are expected due to global warming. All other factors that cause erosion were assumed to have stayed unchanged. However, they may have been altered, and actual soil loss may have changed particularly due to the changes in land use and vegatation, even diminished as a result of preventive measures.

The simple and straightforward approach used in this study is generally considered as very useful tool particularly for regions and times in which high temporal resolution rainfall records are unavailable. Growing number of automated weather stations within last one or two decades in Turkey provide high resolution rainfall records, and enable more sophisticated tools/approaches to be used more extensively for more accurate estimations of status and trends of soil loss.

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