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Use of CORINE Methodology to Assess Soil Erosion Risk in the Semi-Arid Area of Beypazarı, Ankara

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Abstract: Soil erosion is one of the major threats to the conservation of soil and water resources in the semi-arid and arid regions of Turkey. Therefore, there is a need to accurately assess soil erosion and accordingly determine the specific control activities adaptable to these conditions. Using the daily rainfall amounts recorded from 1958 to 2003 from 11 climate stations by the Turkish Meteorological Service in the semi-arid area of Beypazarı, Ankara, Turkey, 5 different procedures of calculating the Modified Fournier Index (MFI) were performed to obtain the effect of rainfall variability and incidence of extreme storms on assessing 'Actual Soil Erosion Risk' (ASER) by CORINE methodology. MFI surface calculated from the averages of i_{th} monthly rainfall amounts and averaged over a number of years ($\overline{MFI}$) caused ASER to underestimate the soil erosion since it was statistically unable to account for the year-to-year variations in the rainfall data. In addition to within-year variations, introducing the year-to-year variations to MFI surface, which was estimated from the monthly rainfall amounts of each individual year and averaged over a number of years ($MFI_{\bar{j}}$) to some extent refined ASER surface. However, ASER surfaces produced by the monthly return frequencies of rainfall events for 10 (MFI_{10}), 20 (MFI_{20}), and 30 (MFI_{30}) years showed significant improvements and agreements with the erosion classes of the conventional soil survey of the study area.

Key Words: Modified Fournier Index, rainfall variability, rainfall frequency, soil erosion risk assessment, CORINE

Beypazarı-Ankara Bölgesinde Yarı Kurak Bir Alanda Toprak Erozyon Riski Değerlendirmesinde CORINE Yönteminin Kullanılması

Özet: Erozyon Türkiye'nin kurak ve yarı kurak alanlarında toprak ve su kaynaklarını tehdit eden başlıca etmenlerden biridir. Bu yüzden, toprak erozyonunun doğru olarak değerlendirilmesi ve aynı doğrultuda, bölge koşullarına uygulanabilir özel koruma önlemlerinin belirlenmesi gereklidir. Bu çalışmada, Beypazarı-Ankara bölgesinde bulunan 11 adet istasyonda, 1958-2003 yılları arasında Meteoroloji Genel Müdürlüğü tarafından ölçülen günlük yağış verileri kullanılmış ve CORINE yöntemi ile "Gerçek Toprak Erozyon Riski" (ASER) değerlendirmesi yapılmıştır.Yağış değişebilirliği ve ekstrem yağışların erozyon risk değerlendirmesi üzerine olan etkisini belirlemek için, beş farklı yöntem ile "Modifiye edilmiş Fournier İndeksi"(MFI) hesaplanmıştır. Uzun yıllar aylık yağış değerlerinin ortalamasından hesaplanan MFI yüzeyleri (MFI), istatistiksel olarak yağış verilerindeki yıllar arasındaki değişimi yansıtmada yetersiz olduğu için, ASER'in düşük tahmin edilmesine neden olmuştur. Yıl içi değişimlere ek olarak, yıllar arasındaki yağış değişimlerinin de MFI hesaplarda kullanılması ($MFI_{\bar{j}}$), belirli oranlarda ASER değerlendirmesini iyileştirmiştir. Ancak, 10, 20 ve 30 yılda gelmesi olası en yüksek aylık yağış verilerinden hesaplanan, sırası ile MFI_{10}, MFI_{20}, MFI_{30}'dan üretilen ASER yüzeylerinde önemli iyileşmeler gözlenmiş ve ASER erozyon sınıfları, çalışma alanının geleneksel toprak etütleri ile belirlenen erozyon sınıfları ile büyük oranda uyum göstermiştir.

Anahtar Sözcükler: Modifiye edilmiş Fournier İndeksi, Yağış Değişebilirliği, Yağış Frekansı, Toprak Erozyon Risk Değerlendirmesi, CORINE

Introduction

Soil erosion study is of significance in order to estimate future soil productivity accurately and of fundamental concern to balance the use of natural resources against the need for the ecosystem protection from the field and regional scale to the national level. Mapping and assessment of erosion on a broad scale allows the determination of the areas where erosion is most severe and provides the basis for remediation of soil erosion.

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Particularly in semi-arid and arid Mediterranean regions, soil erosion is one of the major threats to the conservation of soil and water resources. The substantial signs of the potential risk of soil erosion in these regions are very high climatic unevenness in which extreme events occur and rainy and vegetative seasons hardly concur, the existence of highly vulnerable soils with low organic matter and restricted soil depth, and steep slopes. The fragility of the Mediterranean eco-systems to soil erosion was indicated by Berney et al. (1997). Similar views were also presented in the report of ICONA (1991), and the data of RIVM (2000) reported that southern European countries have more water erosion risk than others, especially with high water erosion risk rates of 58%, 66%, 66%, and 85% in France, Italy, Spain, and Greece, respectively. Soil erosion is as acute as or more severe in Turkey than it is in other Mediterranean countries. Therefore, erosion has attracted considerable attention at the national and regional levels recently and it is crucial to make a more detailed assessment of erosion on local scales (Doğan et al., 2000). However, few studies have been performed about erosive status mapping on regional scales in Turkey. Şahin and Kurum (2002) carried out a case study in Seyhan Köprü Dam Construction, and they calculated the soil erodibility from the lithological nature of the substrate (ICONA, 1982, 1986).

The CORINE Model (Coordination of Information on the Environment) has been applied by countries of the European Community and by some Mediterranean countries for assessing and mapping soil erosion risk. Doğan and Denli (1999) calculated rainfall erosivity from the Fournier Index and Bagnauls-Gaussen Aridity Index (Kirkby, 2001) to determine the erosion risk by the CORINE method at the national level in Turkey (Figure 1a, b, c). Long-term monthly and annual precipitation and temperature data of 247 state meteorological stations all over Turkey were used to calculate the indices, and the observation periods of these stations varied from 28 to 63 years. Similarly, Aslan (1997) investigated spatial and temporal variations in rainfall erosivity analyzing monthly mean and total precipitation observed in different geographical regions in Turkey between 1929 and 1990.

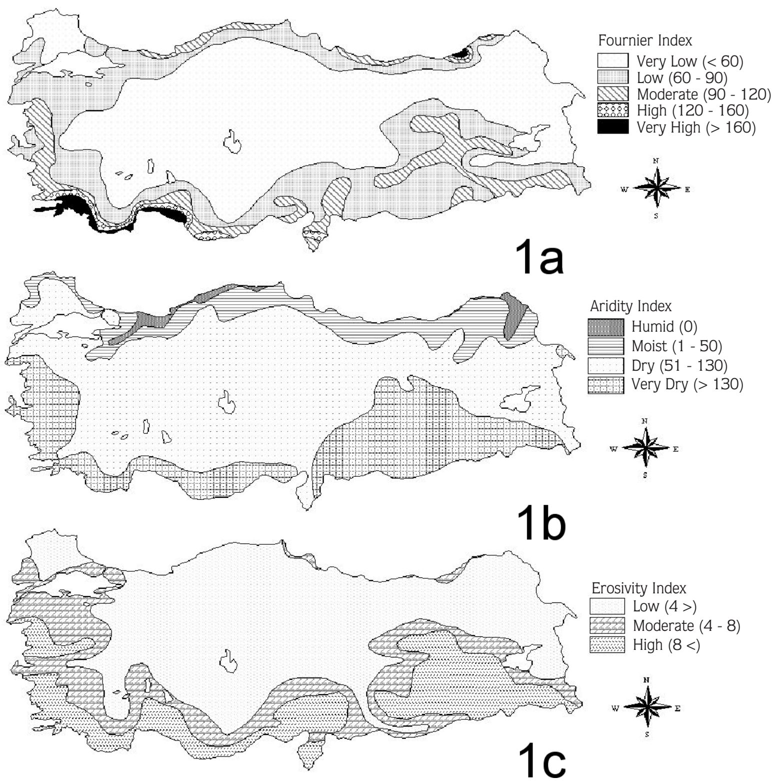

Figure 1. Gaussen – Bagnauls Aridity Index (a), Modified Fourner Index (b), Erosivity Maps (c) of Turkey (adapted from Doğan and Denli, 1999).

Higher values of the Fournier Index were observed in the northeastern Black Sea, southern Aegean Sea and Mediterranean Sea regions. The lower values are recorded in Eastern and Central Anatolia. These results are in a good agreement with Figure 1c, climatologically showing a very low index and erosivity values for the terrestrial part of Turkey, Eastern and Central Anatolia. However, it has been long known that the climatic characteristics of these regions together with topographic, soil and land use factors have escalated soil erosion. The pattern of actual erosion favors the fact that the most severe erosion occurs in these regions, giving rise to complete removal of the soil and exposure of bedrock. Essentially, there is a high risk of an irreversible removal of the thin soil although the lowest values of the rainfall erosivity factor calculated by the Fournier Index matches Eastern and Central Anatolia.

Gabriels et al. (2003) reported that calculation of the Modified Fournier Index (MFI) from the long-term monthly and yearly rainfall amounts is statistically unable to account for year-to-year variability in the rainfall data and accordingly underestimates the rainfall erosivity. This is particularly important for regions of Eastern and Central Anatolia where the most severe erosion normally occurs in intense spring and autumn storms, falling upon sparse vegetation cover at the end of winter and summer, respectively. Therefore, knowing the total variability in rainfall data by a component that measures the year-to-year variation and a component that measures the within-year variation provides statistically valid MFI calculations.

The objective of this paper is to show the effect of refining MFI surfaces using knowledge on total variability in rainfall data and incidence of extreme storms on the assessment of soil erosion risk by CORINE methodology in the semi-arid area of Beypazarı, Ankara, Turkey.

Materials and Methods

The study was performed in the Beypazarı area (Figure 2) and contains different land use and land cover units, e.g., agricultural lands, forest and bare lands, and diverse landforms such as alluvial plains, plateaus, steep slopes of hills, and mountainous areas ranging from 480 to 1581 m in elevation. Geographically, the study area is located between 403955 – 414955 m eastern and 4428285 – 4456185 m northern (UTM) coordinates with approximately 290 km^2 coverage.

The overall scheme, flow diagram and steps for generating a soil erosion risk map by the CORINE methodology is described by Kirkby (2001). The methodology requires soil erodibility, erosivity, slope angle and surface cover as essential databases for evaluating actual erosion risk. Soil survey studies were carried out over the study area and a digital soil map with the scale of 1:25,000 was prepared (Figure 3). Information on the surface stoniness and texture classes of each map unit was added to the soil database. Soil texture, depth and stoniness layers were regrouped according to the CORINE methodology using Arc GIS™ and Arc View™ (Figures 5-7, respectively). Distributions of the texture classes of Beypazarı soils were 16.9%, 44.0%, and 39.2% of clayey, clay loams, and loams respectively, and those of the soil depth classes were 37.8%, 32.4%, and 29.8% respectively of > 75 cm, 25 - 75 cm, < 25 cm with 60.5% of soils having more than 10% stoniness. These layers were multiplied and reclassified to obtain the soil erodibility layer (Figure 8), which indicated that 51.4% of the study area had high erodibility and 20.3% had low erodibility values (Table 3).

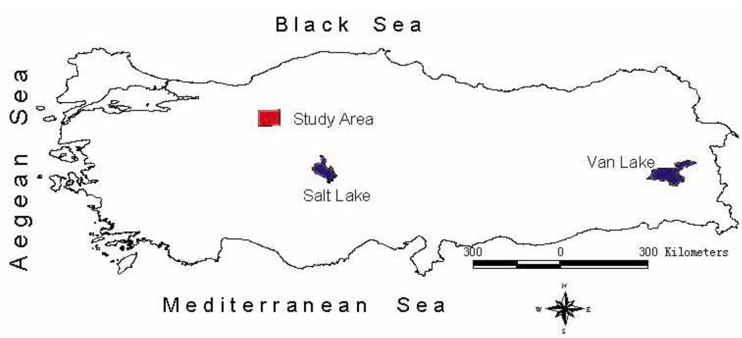

Figure 2. Location of the study area.

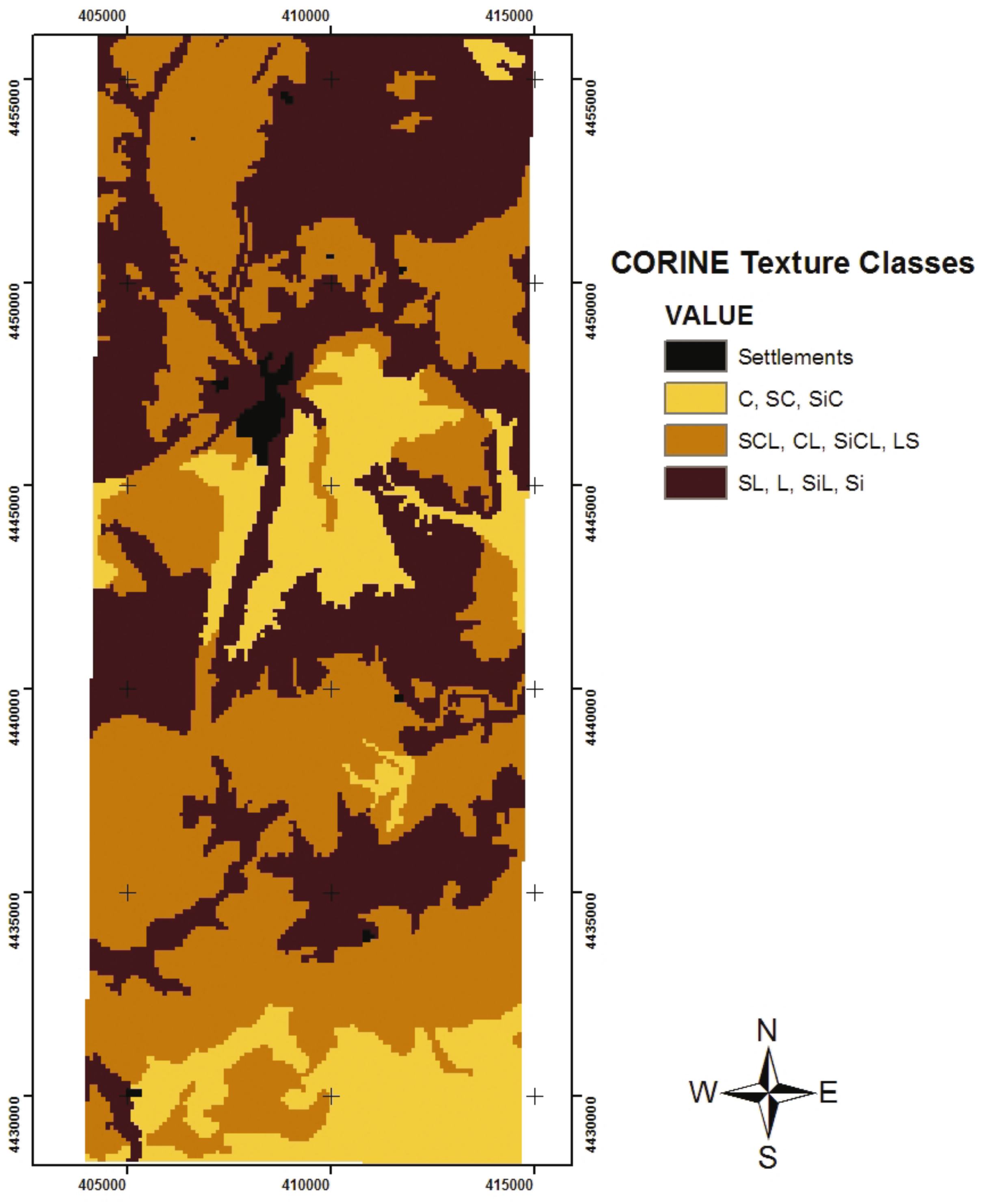

Figure 3. Texture map of surface soils of the study area.

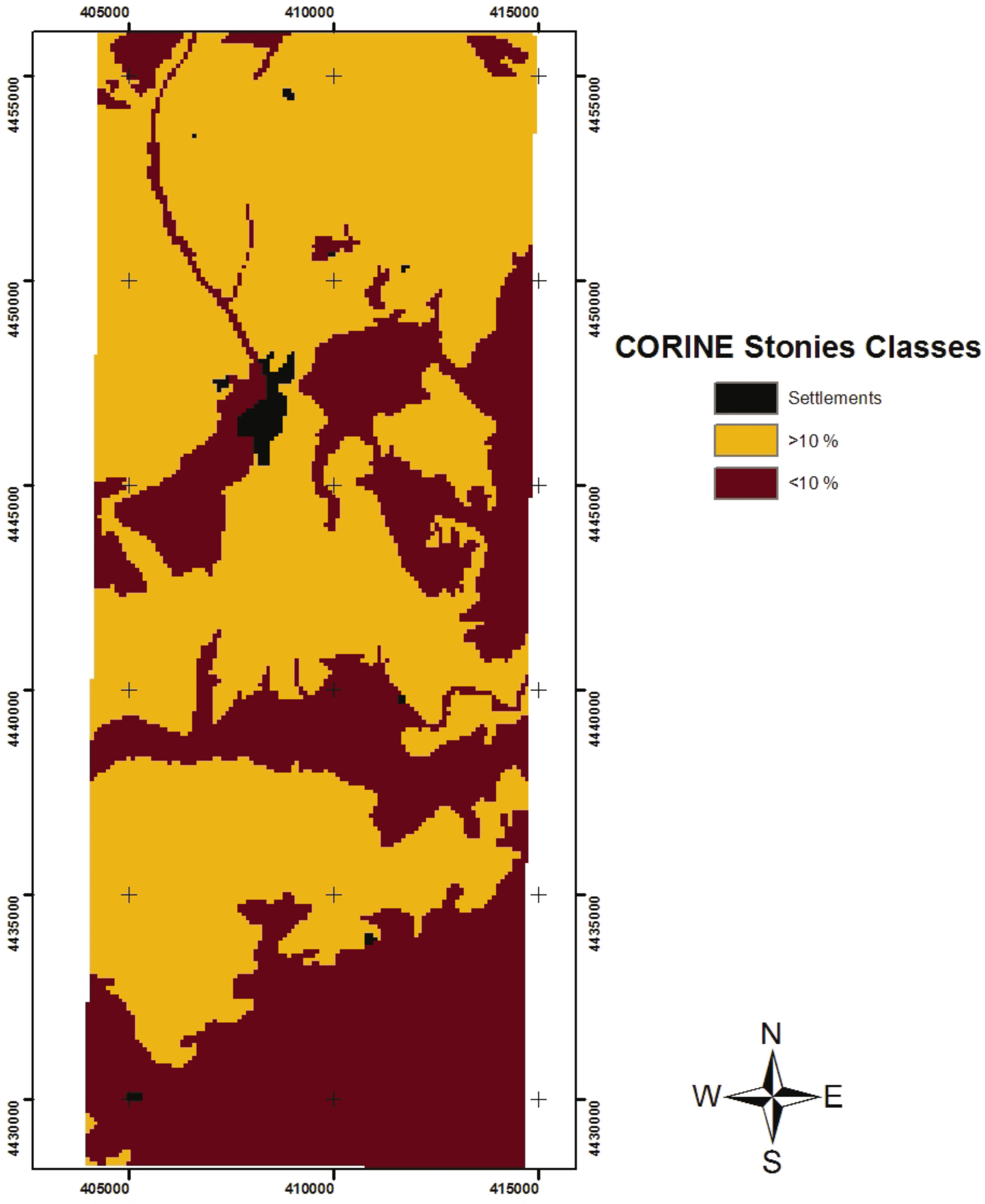

Figure 4. Stoniness map of surface soils of the study area.

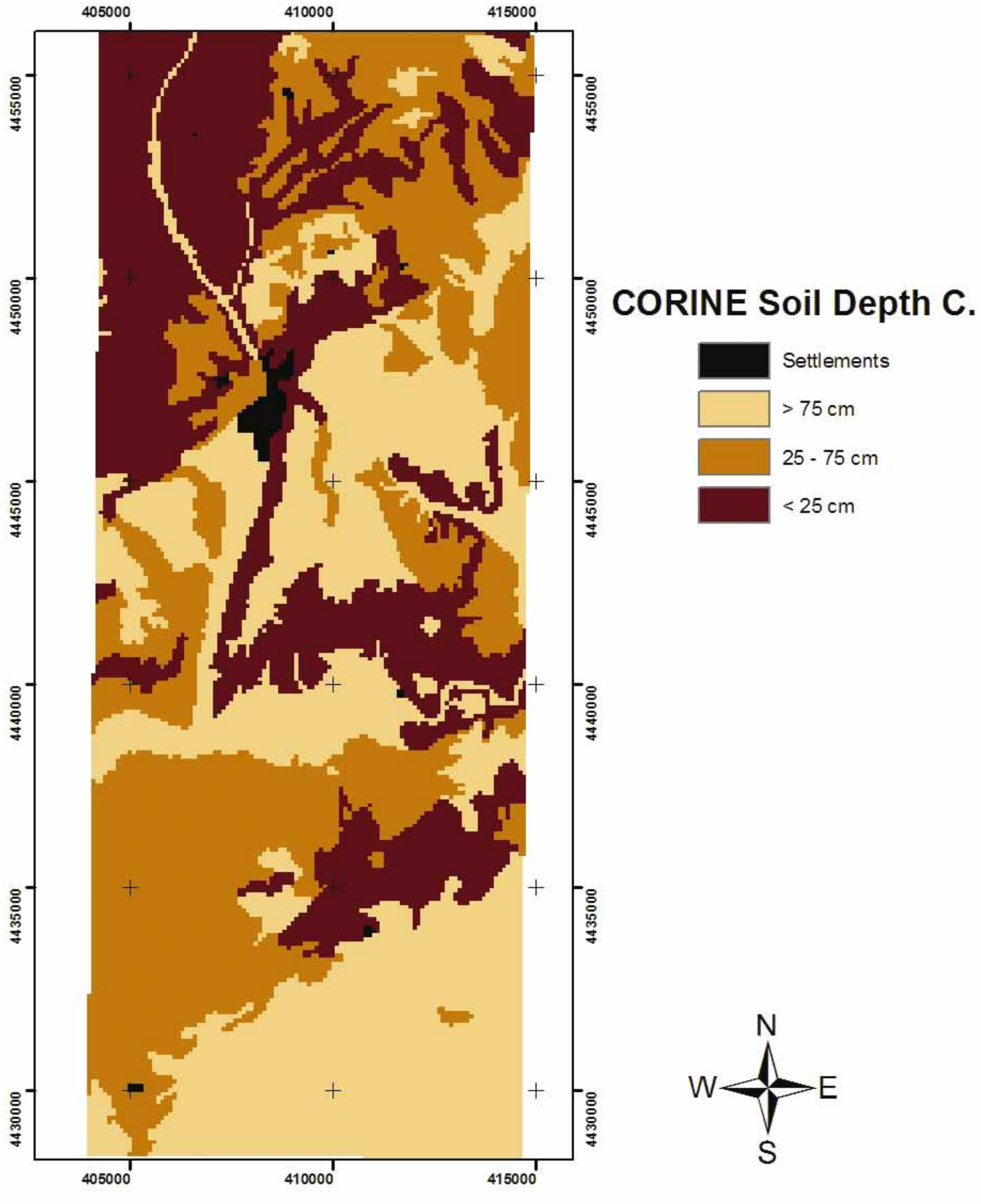

Figure 5. Soil depth map of the study area.

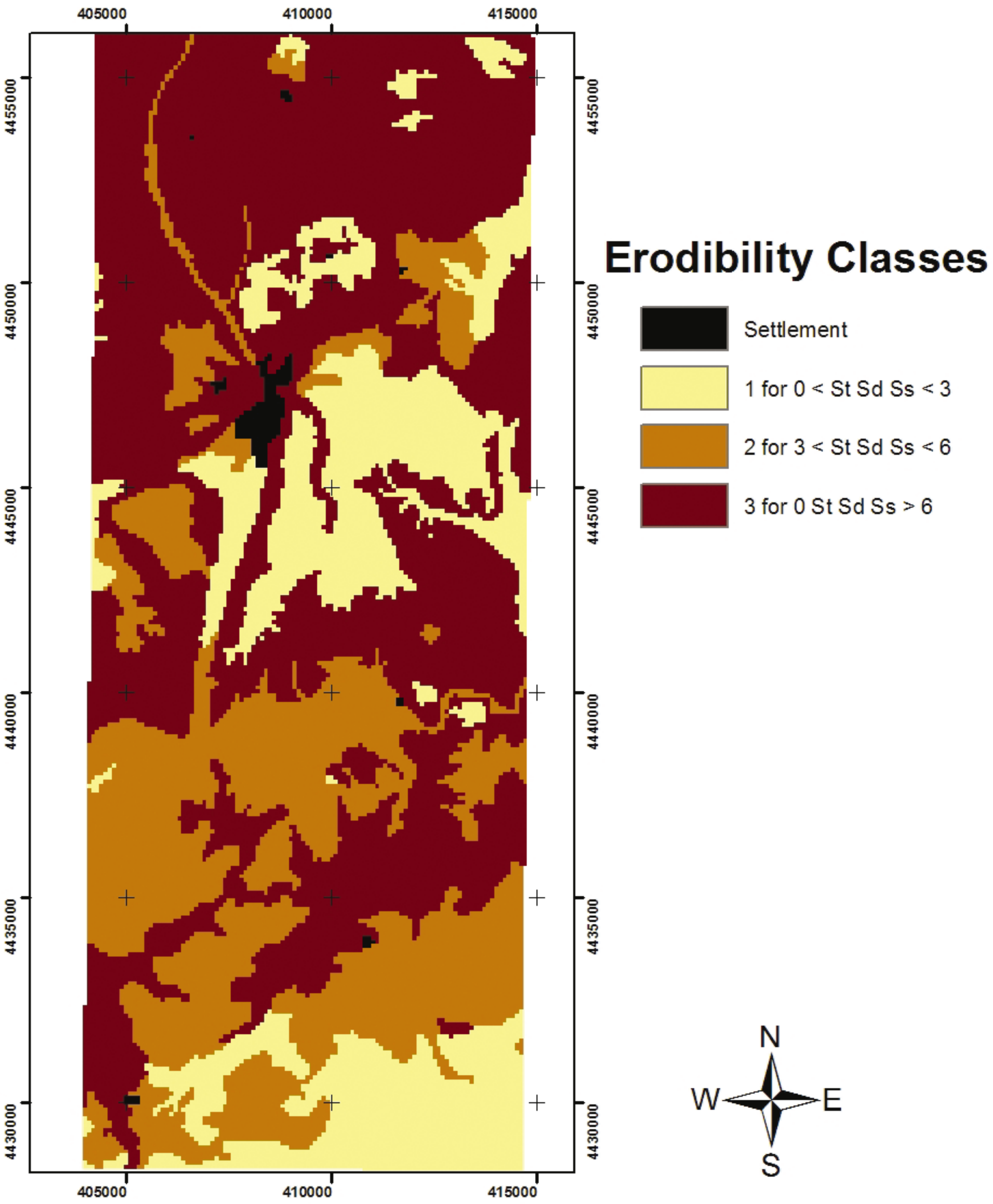

Figure 6. Soil erodibility map of the study area.

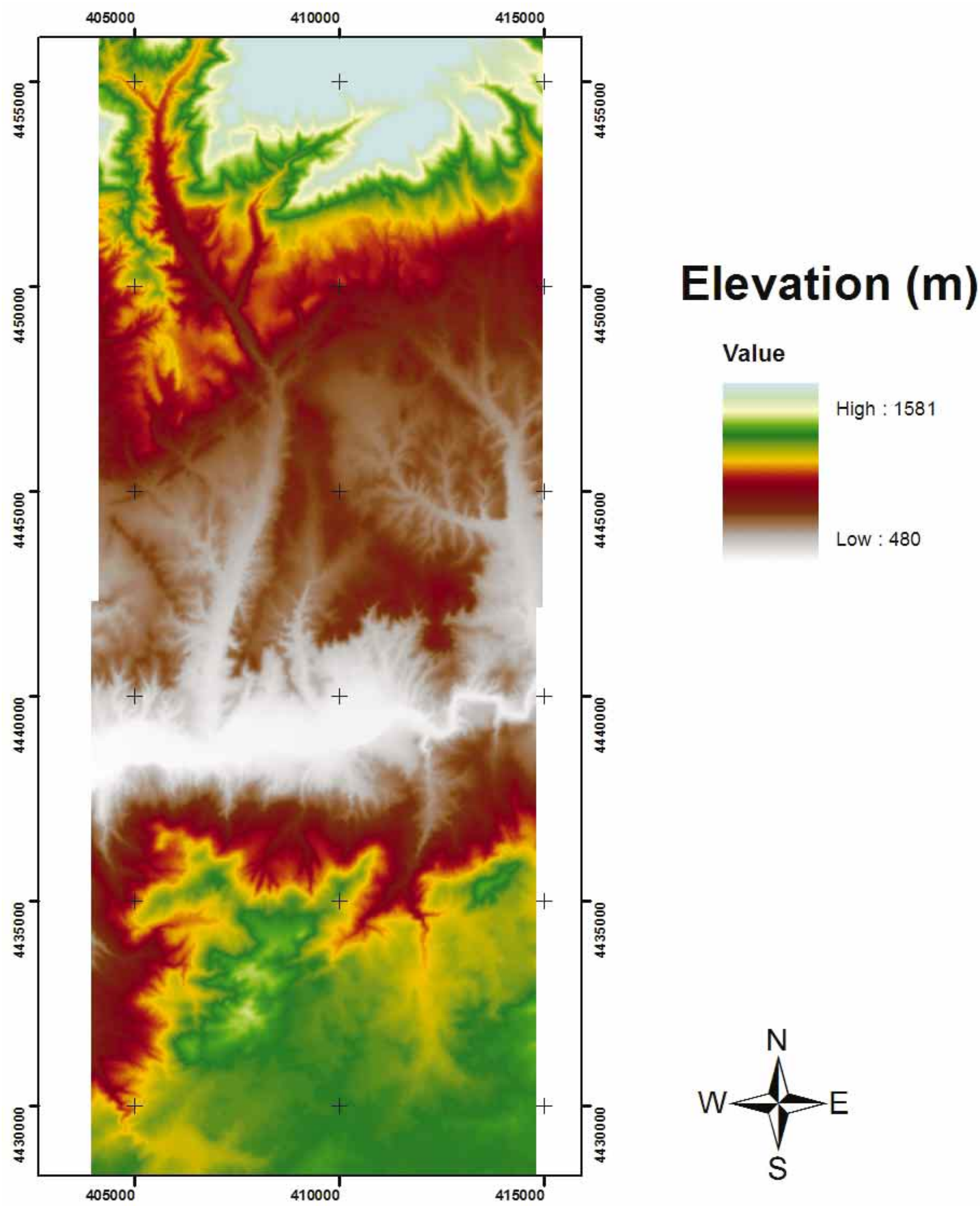

Figure 7. Digital Elevation Model (DEM) of the study area.

The primary data set of climate included monthly rainfall and temperature values recorded from 1958 to 2003 from 11 climate stations in the region by the Turkish State Meteorological Service (TSMS). For the precipitation and temperature surfaces, procedures from the ANUSPLIN package (Hutchinson, 1991) were used to fit the thin plate spline functions, which were tri-variate functions of longitude, latitude, and elevation in kilometers. Thin plate smoothing splines can in fact be viewed as a generalization of standard multi-variate linear regression. The degree of smoothness, or inversely the degree of complexity, of the fitted function is usually determined automatically from the data by minimizing a measure of predictive error of the fitted surface given by the generalized cross validation (Craven and Wahba, 1979).

The DEM available for the study area is a map converted from a 1/250,000 scale digital topographic map with a resolution of 0.01° extending from latitude 38° 04’ N to 36° 06’ N and longitude 31° 36’ E to 34° 32’ E (Figure 9). These small-scale regional DEM data were used to generate climatic surfaces and then all of the climatic maps were re-projected to the Universal Transverse Mercator (UTM) coordinates with a 100 m resolution and masked for the study area to integrate with other digital data sources.

The surfaces of the Modified Fournier Index (Arnoldus, 1977) were calculated both from the averages of i_{th} monthly rainfall amounts and averaged over a number of years (*b*) $\overline{MFI}$ and from the monthly rainfall amounts of each individual year and averaged over a number of years (MFI_j), respectively by Eq. [1] and Eq. [2]. Figure 10 shows a general illustration of rainfall data with the totals and averages for MFI surfaces used in evaluation of the erosivity.

$$\overline{MFI} = \frac{\sum_{i=1}^{12} (\overline{P_{\bullet\bullet}})}{\overline{P_{\bullet\bullet}}} \qquad [1]$$

$$\overline{MFI_j} = \frac{\sum_{i=1}^{12} (P_{ij})^2}{\overline{P_{\bullet j}}} \Rightarrow MFI_{\bar{j}} = \frac{1}{b}\sum_{j=1}^{b} MFI_j \qquad [2]$$

$$P_{\bullet j} = \sum_{i=1}^{12} P_{ij} \qquad [3]$$

$$\overline{P_{\bullet j}} = \frac{P_{\bullet j}}{a} \qquad [4]$$

where is total of monthly rainfalls for j_{th} year; $\overline{P_{\bullet j}}$ is the average of the total of monthly rainfalls for j_{th} year; *j* is number of years and *j* = 1, 2, ..., b; and *i* is number of months within a year and *i* = 1, 2, ..., a = 12.

$$P_{\bullet j} = \sum_{i=1}^{b} P_{ij} \qquad [5]$$

$$\overline{P_{\bullet j}} = \frac{P_{\bullet j}}{b} \qquad [6]$$

where is total of the rainfalls of i_{th} month over the number of years and $\overline{P_{i\bullet}}$ is the average of the total of the rainfalls of i_{th} month over the number of years. Likewise, the grand total and the grand average of all the observations ($P_{\bullet\bullet}$ and $\overline{P_{\bullet\bullet}}$, respectively) can be calculated by:

$$P_{\bullet\bullet} = \sum_{i=1}^{a}\sum_{j=1}^{b} P_{ij} = \sum_{i=1}^{a} P_{i\bullet} = \sum_{j=1}^{b} P_{\bullet j} \qquad [7]$$

$$\overline{P_{\bullet\bullet}} = \frac{P_{\bullet\bullet}}{N} \qquad [8]$$

where N = ab.

Additionally, an analysis was conducted on return frequencies of extreme rainfall events. Monthly return frequencies of 10, 20, and 30 years were analyzed by means of a frequency analysis (Raes et al., 1996). The precipitation – frequency relations represented all the events above a given magnitude for monthly rainfall values for the 45-year period of records from 1958 to 2003 for 11 climate stations in the region by TSMS. Bagnauls-Gaussen Aridity Index (AI) values were calculated from long-year monthly average temperatures and these varied between 80 and 92. Calculations showed that all of the values were within the limit of class 3 for CORINE.

Slope angles were calculated using 3 arc-second DEM data and reclassified (Figure 12). Along with the soil erodibility and erosivity map of the study area, the slope

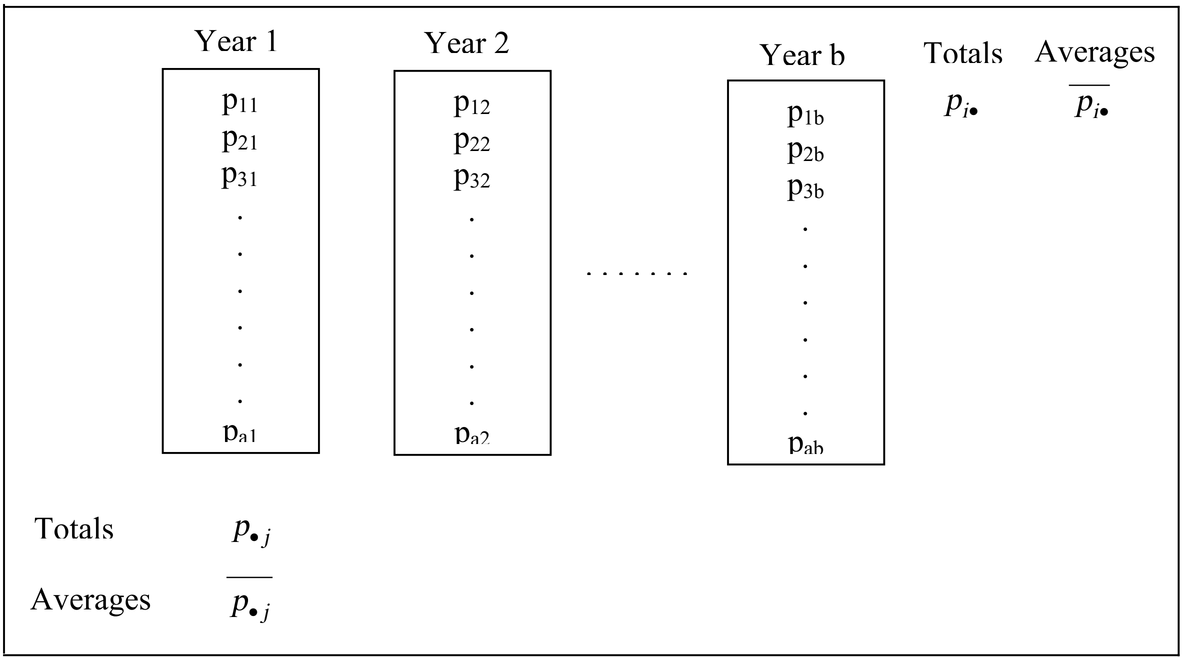

Figure 8. Monthly and annual rainfall totals and averages for MFI surfaces.

layer was used to generate maps of potential erosion risk (PSER). Since 5 different erosivity surfaces were calculated, we had 5 PSER and 5 actual soil erosion risk (ASER) surfaces after generating the land cover surface of the study area (Kirkby, 2001).

A Normalized Difference Vegetation Index (NDVI) (Tucker et al., 1985) was performed with Landsat TM image of 9th September 1998 to create the layer of vegetation cover. NDVI was grouped as fully protected and not fully protected based on ground truth information with the global positioning system (Figure 13).

Results and Discussion

Figure 3 shows that there were 7 subgroups described in the area, which were in the Entisol (70%) and Inceptisol (30%). Entisols were dominant among the mineral soil materials and did not have distinct pedogenic horizons because of insufficient time for horizons to form as in recent deposits and occurred on slopes where the rate of erosion exceeded the rate of pedogenic horizon formation. Lithic Xerorthents had the largest coverage area with 42.9% in the study area. The unique properties of Inceptisols were a combination of water availability to plants for more than half of the year and more pedogenic horizons of alteration and concentration with little accumulation of translocated materials. Table 1 summarizes the soil subgroup distribution, showing percent coverage in the study area.

During soil survey studies, using conventional methods outlined in the manual by the Soil Survey Staff (1993), the erosion status of each map units was also established and loaded into the soil database. Approximately 60% of the soils of the study area had very high erosion risk and only 20% of the soils did not have serious erosion problems (Figure 4 and Table 2). This erosion map was mainly for comparing the pattern of actual erosion determined in the area with soil erosion risk maps generated with CORINE.

MFI surfaces calculated by Eq. [1] and [2] and from monthly return frequencies of rainfall events for 10, 20, and 30 years are shown in Figure 14 a, b, c, d, and e, respectively. There were clearly significant differences in MFI surfaces obtained using the 5 different procedures. Of all surfaces, $\overline{MFI}$ resulted in the lowest values, showing low risk class 1 (MFI < 60) for the whole region. Note that Figure 14a indicates such intervals of MFI that it eases mapping and it does not mean various MFI classes

Table 1. Soil erodibility classes obtained from soil texture, depth and stoniness layers of the soil map.

Soil erodibility classes	Area (ha)	Distribution (%)
1	5964	20.3
2	8299	28.3
3	15088	51.4
	Σ 27351	Σ 100.0

Table 3. Erosion status of the study area determined using conventional methods during soil survey studies.

Erosion classes	Description	Area (ha)	Distribution (%)
1	Non - Low	6014	20.5
2	Moderate	5990	20.4
3	High	17347	59.1
		Σ 29351	Σ 100.0

Table 2. Soil subgroup distribution showing percent coverage in the study area.

Soil Subgroup	% Cover
Water surface (Sarıyer Dam)	0.67
Settlements	0.07
Gypsic Haploxerepts	2.0
Fluventic Haploxerept	3.4
Typic Xerofluvents	5.5
Typic Calcixerepts	6.2
Typic Haploxerepts	18.5
Typic Xerorthents	20.8
Lithic Xerorthents	42.9

exist in the region by $\overline{MFI}$ other than class 1. Given monthly and annual rainfall totals and averages for $\overline{MFI}$ surfaces (Figure 9) and Eq. [1], it is obvious that $\overline{MFI}$ neglects the year-to-year variations and accounts only for within-year variations in rainfall data set. For that reason, it led to a serious underestimation in evaluating soil erosion risk.

The above findings also suggested that the MFI values calculated by Eq. [1] to determine the erosion risk by the CORINE method at the national level in Turkey (Figure 1c) (Doğan and Denli, 1999) should be so improved that it could statistically represent year-to-year variability as well as within-year variation in the rainfall data.

Table 4 gives the percent increases (PI) in MFI values when the surface of Eq. [2] () and those from monthly return frequencies of rainfall events for 10 (MFI_{10}), 20 (MFI_{20}), and 30 (MFI_{30}) years were compared with the surface of Eq. [1] ($\overline{MFI}$). On average, there was a 40% increase in MFI values when calculated by Eq. [2] rather than by Eq. [1]. This was because $MFI_{\bar{j}}$ statistically accounted for both within-year variations and year-to-year variations. However, this refinement caused only 8% of values to change from class 1 to class 2, which had MFI values between 60 and 90 (Figure 14b) (Table 5).

Since events of unusual storm conditions with high runoff and soil erosion potential are very important for soil erosion research, knowledge of the temporal distribution of heavy rainstorms is also necessary for evaluating the amount of runoff and soil loss (Boardman, 1988; Poesen et al., 1996; Klik and Truman, 2003). Table 4 shows PI(s) in the surfaces when Eq. [1] was compared with the surfaces from monthly return frequencies of rainfall events for 10, 20, and 30 years. PI(s) were 88%, 113%, and 129% for MFI_{10}, MFI_{20}, and MFI_{30}, respectively, and these suggested significant refinements in MFI surfaces. Percent distribution of higher erosivity classes of CORINE (R) increased as interval of monthly return frequencies increased (Table 5). In the 3 frequency surfaces, there was no class 1 and percent distributions of class 2 were 99.9%, 92.7%, and 66.4% in the surfaces of MFI_{10}, MFI_{20}, and MFI_{30}, respectively. Although percent distributions of class 3 in MFI_{10} and MFI_{20} (0.1% and 7.3%, respectively) were insignificant, it was remarkably high in MFI_{30} (33.6%). Clearly, the spatial coverage of moderate and high risk of erosivity classes increased when the occurrence of unusual storm conditions was considered by the frequency analysis. This result can seriously affect assessment of erosion and accordingly implementation of erosion control, for which the surfaces of MFI_{10}, MFI_{20}, and MFI_{30} imposed more protective measures.

Maps of 'Potential Soil Erosion Risk' (PSER) and 'Actual Soil Erosion Risk' (ASER) of the study area generated by the surfaces of, $\overline{MFI}$, MFI_{10}, MFI_{20}, and MFI_{30} are shown in Figures 15 and 16, respectively. Additionally, percent distributions of PSER and ASER classes of the corresponding surfaces are given in Table 6.

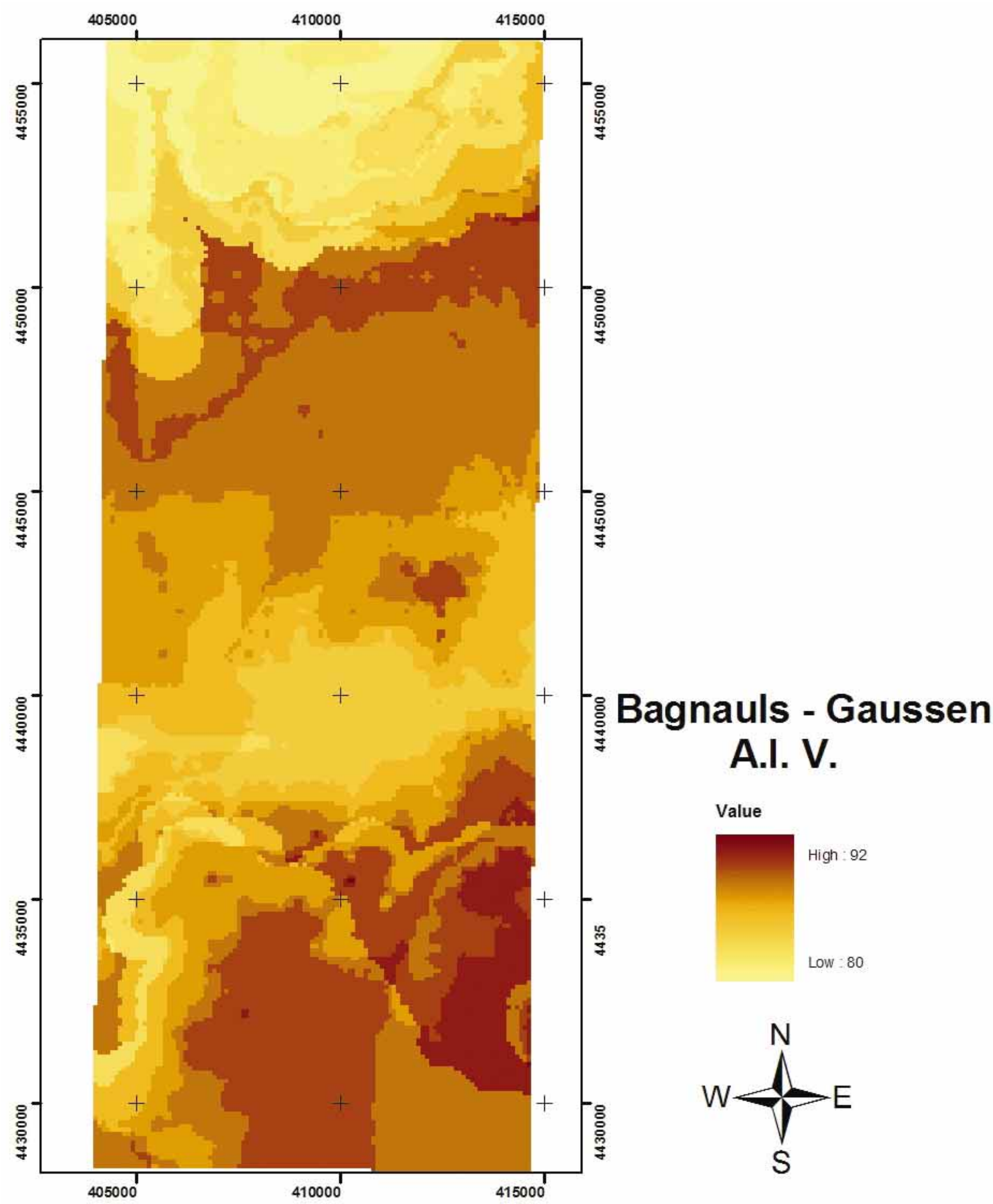

Figure 9. Bagnouls Aridity Index map of the study area.

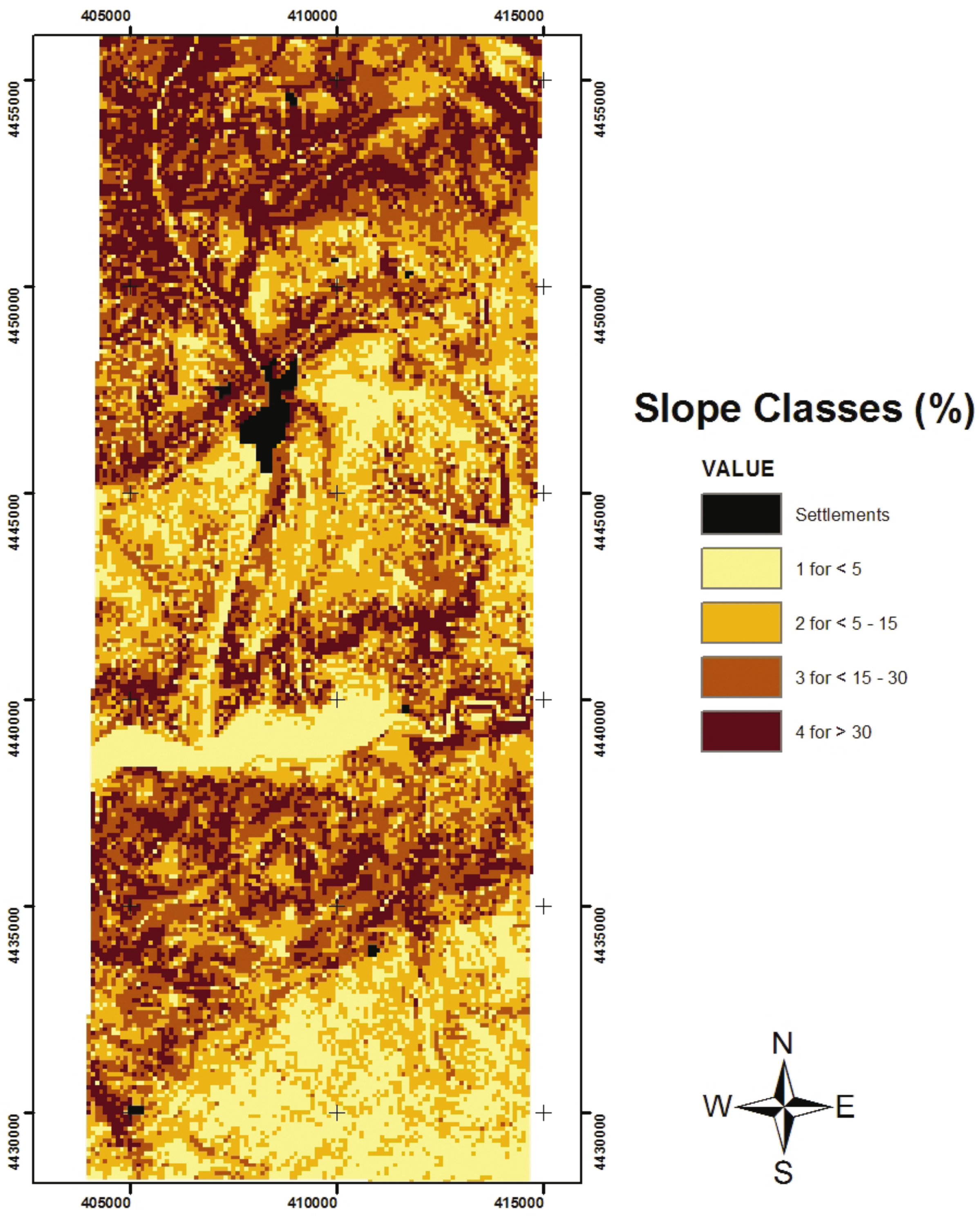

Figure 10. Slope map of the study area calculated by 3 arc-second DEM.

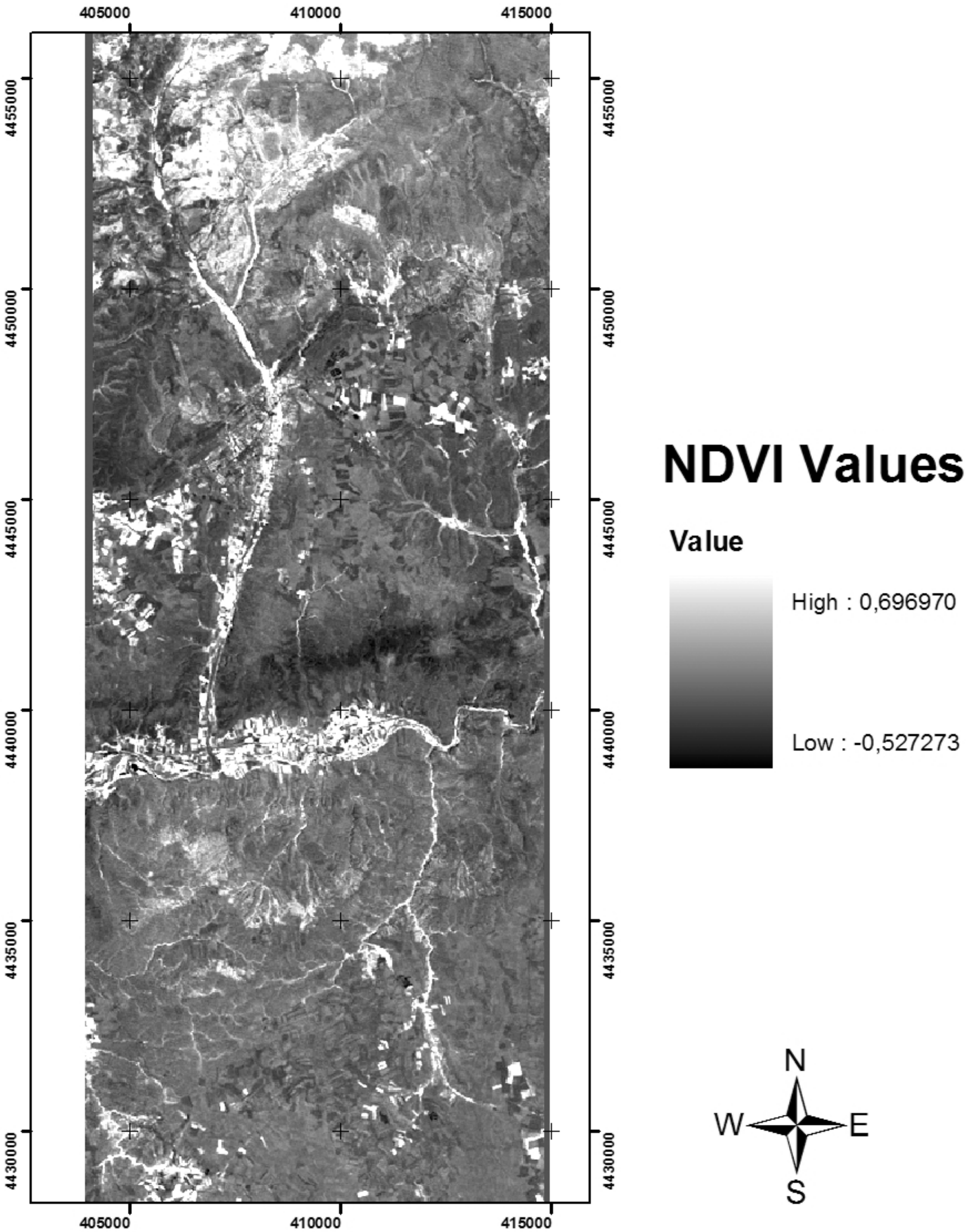

Figure 11. Map of Normalized Difference Vegetation Index (NDVI) of the study area.

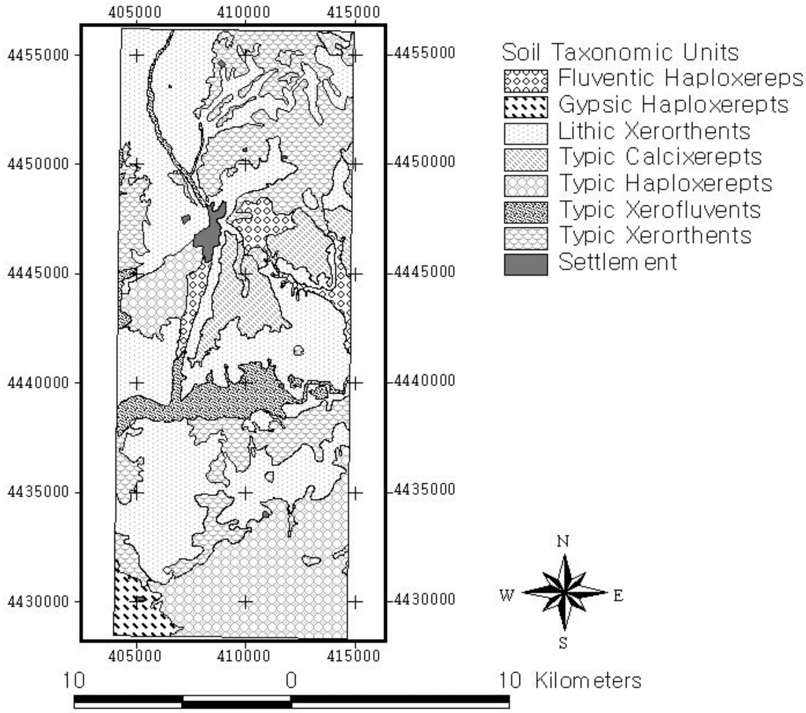

Figure 12. Soil map of the study area.

Table 4. Values of minimum, maximum, mean and standard deviation of MFI surfaces calculated by 5 different procedures and percent increases in the surfaces when Eq. [1] was compared with Eq. [2] and those from monthly return frequencies of rainfall events for 10, 20, and 30 years.

MFI Surfaces	MFI Values				Percent Increases			
	Min	Max	Mean	SD	Min	Max	Mean	SD
$\overline{MFI}$	34	46	38	2.15	-	-	-	-
$MFI_{\bar{j}}$	50	85	53	4.36	25	93	40	7.0
MFI_{10}	65	90	72	4.32	75	105	88	4.1
MFI_{20}	73	102	81	4.98	100	131	113	4.8
MFI_{30}	79	110	87	5.37	115	150	129	5.1

Table 5. Percent distribution of MFI classes determined by 5 different procedures.

Erosivity Classes of CORINE (R)	$\overline{MFI}$	$MFI_{\bar{j}}$	MFI_{10}	MFI_{20}	MFI_{30}
1	100	91.8			
2		8.2	99.9	92.7	66.4
3			0.1	7.3	33.6

Table 6. Percent distributions of PSER and ASER classes determined by 5 different procedures.

	PSER Classes of CORINE				
Classes	$\overline{MFI}$	$MFI_{\bar{j}}$	MFI_{10}	MFI_{20}	MFI_{30}
1	41.4	41.2	26.7	26.3	20.9
2	42.4	38.0	14.7	15.1	17.4
3	16.2	20.8	58.6	58.6	61.7
	ASER Classes of CORINE				
Classes	$\overline{MFI}$	$MFI_{\bar{j}}$	MFI_{10}	MFI_{20}	MFI_{30}
1	43.1	42.3	27.4	27.0	21.6
2	42.0	38.7	16.9	17.3	19.6
3	14.9	19.0	55.7	55.7	58.8

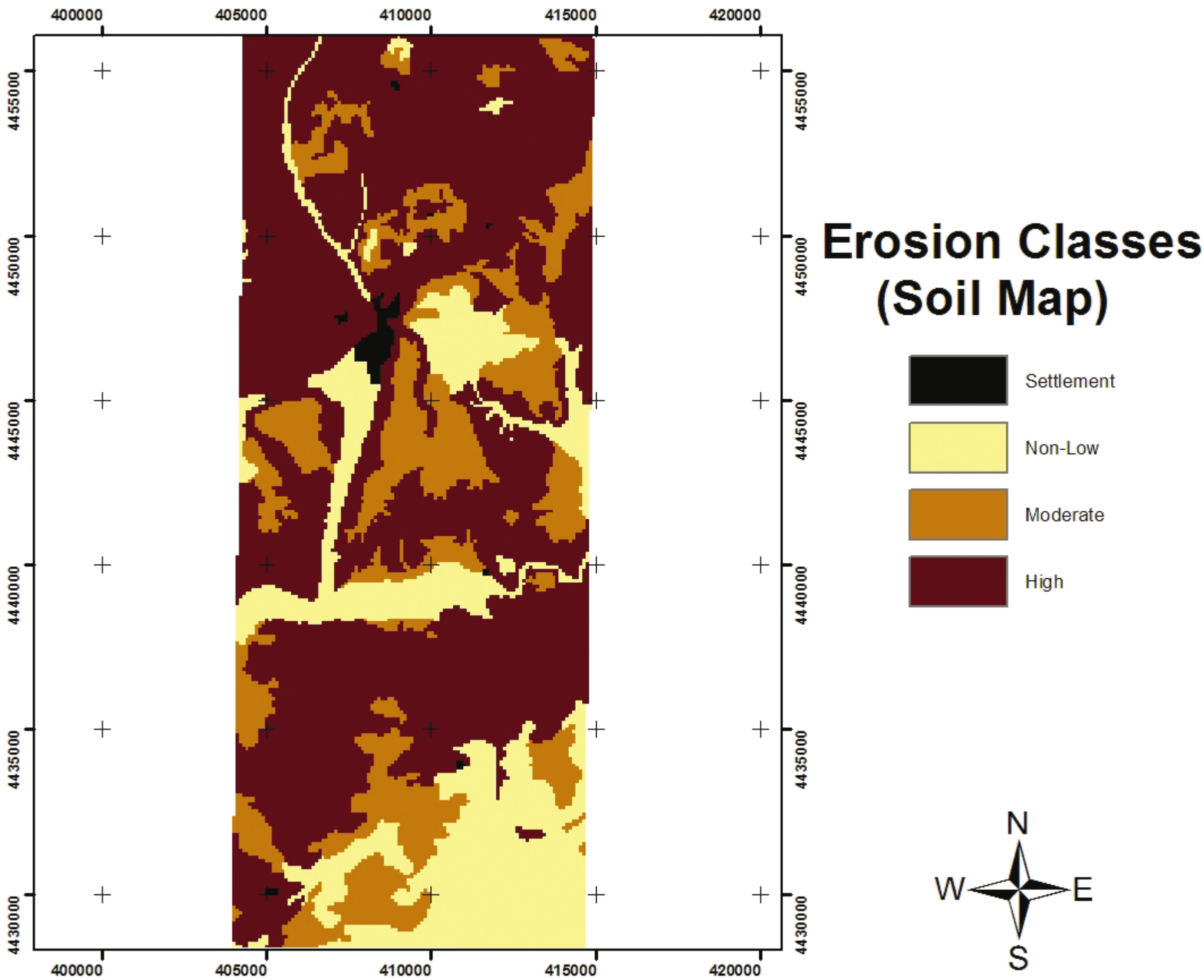

Figure 13. Soil erosion map of the study area.

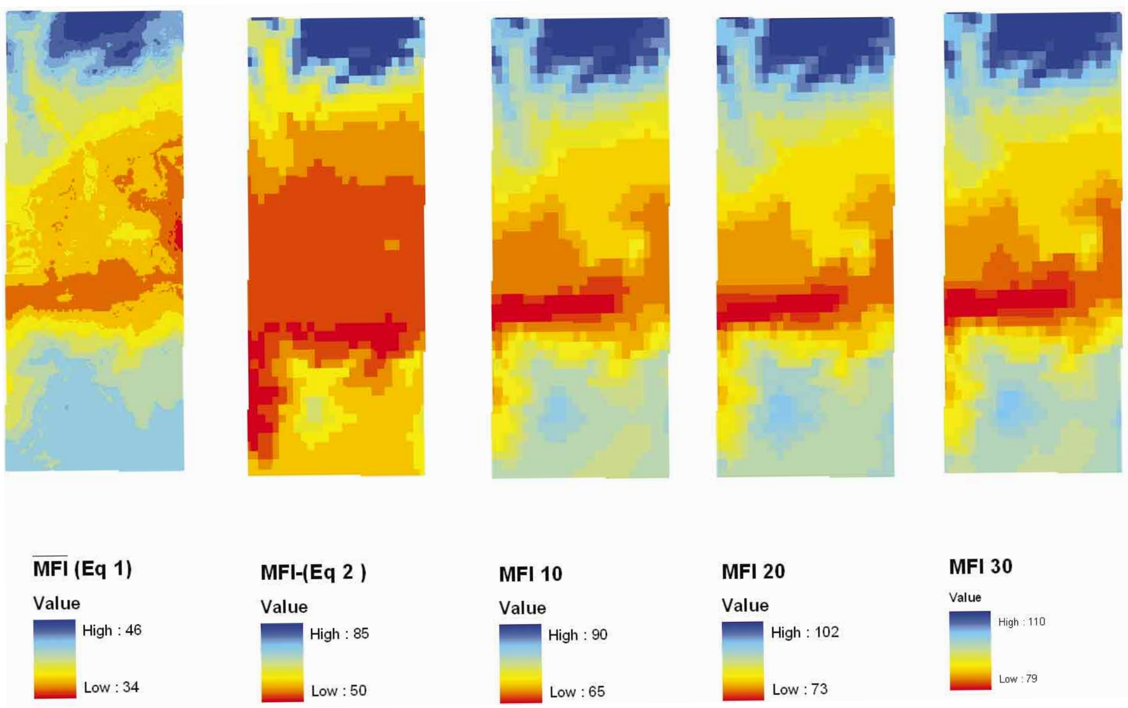

Figure 14. MFI surfaces calculated by Eq. [1] and [2] and from monthly return frequencies of rainfall events for 10, 20, and 30 years.

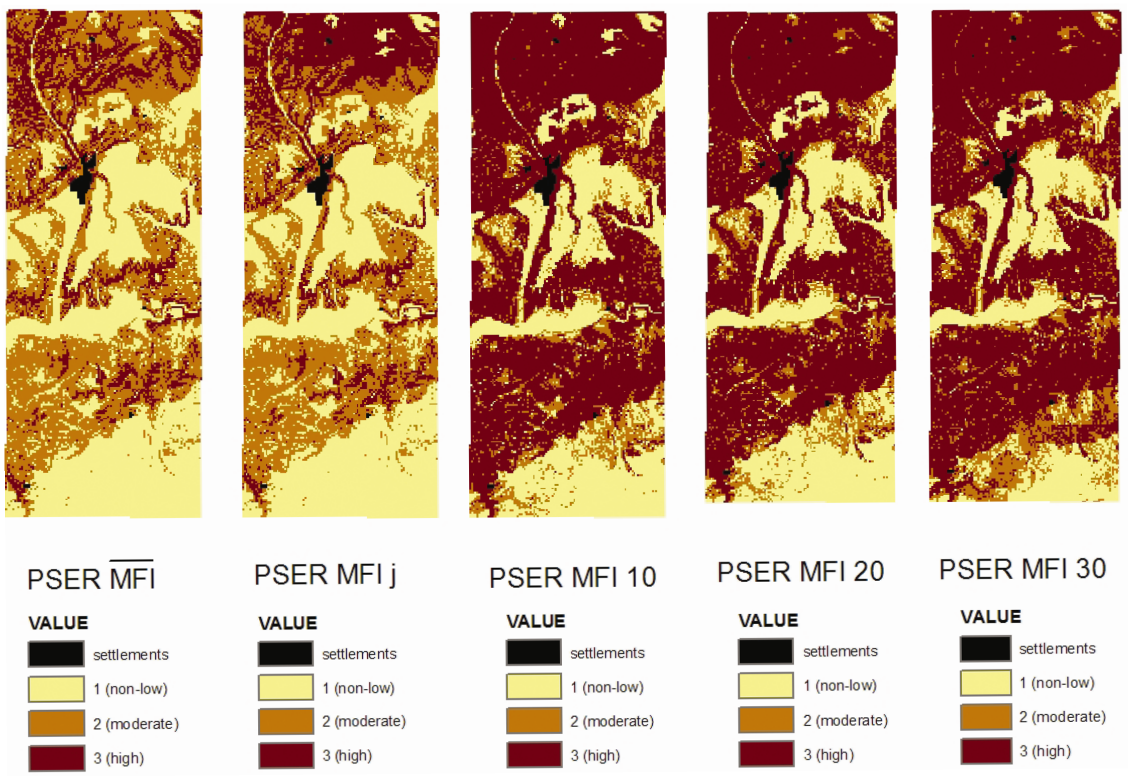

Figure 15. Maps of Potential Soil Erosion Risk (PSER) of the study area generated by the surfaces of $\overline{MFI}$ (a), $MFI_{\bar{j}}$ (b), MFI10 (c), MFI20 (d), and MFI30 (e).

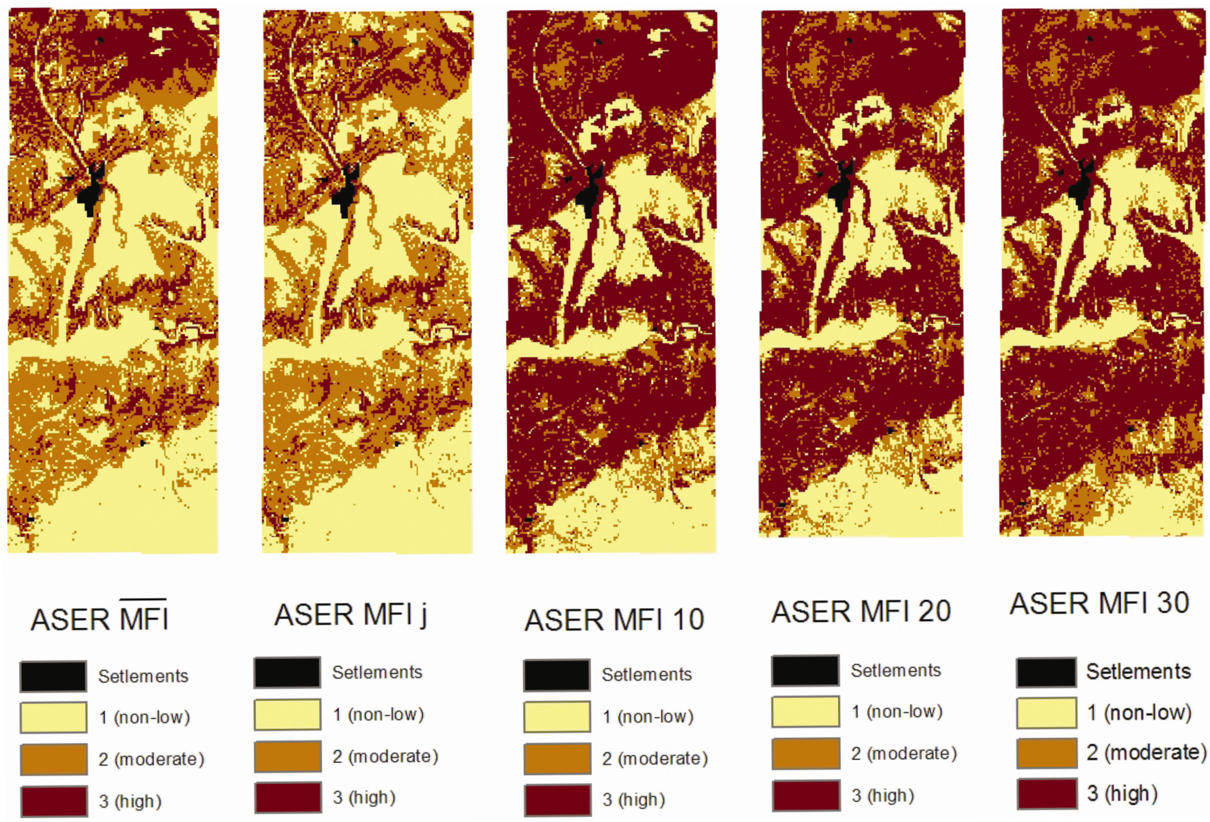

Figure 16. Maps of Actual Soil Erosion Risk (ASER) of the study area generated by the surfaces of $\overline{MFI}$ (a), $MFI_{\bar{j}}$ (b), MFI10 (c), MFI20 (d), and MFI30 (e).

PSER and ASER surfaces changed according to the variations in MFI calculations. Percent distributions of class 3 in both PSER and ASER produced by $MFI_{\bar{j}}$, MFI_{10}, MFI_{20}, and MFI_{30} significantly increased when they were compared with the surface by $\overline{MFI}$. On the other hand, there was no significant difference among the percent distributions of PSER and ASER classes of MFI_{10}, MFI_{20}, and MFI_{30}; for example, percent distributions of class 3 were 55.7%, 55.7%, and 58.8% in the ASER surfaces, respectively (Table 6). Obviously, ASER surfaces by MFI_{10}, MFI_{20}, and MFI_{30} assessed higher soil erosion risks than those by $\overline{MFI}$ and $MFI_{\bar{j}}$. These results suggested more carefully implemented erosion control activities for these regions where there is very high climatic unevenness in which extreme events occur. Although the map in the national level climatologically shows that Central Anatolia has a very low index and erosivity values (Figure 1c) (Doğan and Denli, 1999), our analysis, considering the rainfall seasonality and the incidence of extreme storms for the aim of assessing soil erosion risk by CORINE methodology, indicated that the climatic characteristics of these regions could result in high risk of soil erosion on local scales.

Finally, we furthered our analysis in order to know how the ASER surfaces of CORINE shown in Figure 16 represented the pattern of actual erosion determined by a conventional soil survey of the study area after overlaying the layers. Percent agreements between ASER and the conventional erosion map are tabulated in Table 7. While percent agreements of class 1 were very high in $\overline{MFI}$ and $MFI_{\bar{j}}$, 95.3% and 95.2%, respectively, they decreased significantly as the interval of the return frequencies increased (78.2%, 77.7%, and 66.3%, respectively, for ASER surfaces generated by MFI_{10}, MFI_{20}, and MFI_{30}); thus, there were considerable increases in the percent agreements of class 2 and class 3. In particular, ASER by MFI_{30} had 35.8% and 86.1% agreement for class 2 and class 3, respectively, with the

Table 7. Percent agreements between ASER surfaces and soil erosion map obtained by conventional soil survey of the study area.

Erosion Classes of Soil Survey	CORINE Erosion Classes														
	$\overline{MFI}$			$MFI_{\bar{j}}$			MFI_{10}			MFI_{20}			MFI_{30}		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1	95.3*	77.3	13.2	95.2	76.5	12.2	78.2	51.2	1.5	77.7	49.9	1.4	66.3	36.0	1.2
2	4.7	20.1	62.4	4.8	20.5	56.8	17.1	27.2	13.3	17.6	28.5	13.4	23.8	35.8	12.6
3	-	2.6	24.3	-	3.0	31.0	4.7	21.6	85.2	4.7	21.7	21.7	10.0	28.2	86.1
Overall Agreement		30.0			42.0			71.9			72.0			71.8	

* numbers in bold indicate the percent agreements of corresponding erosion classes of CORINE and the conventional soil survey.

conventional soil map. Overall agreements were 30.0%, 42.0%, 71.9%, 72.0%, and 71.8% for the surfaces by $\overline{MFI}$ and $MFI_{\bar{j}}$, MFI_{10}, MFI_{20}, and MFI_{30}, respectively (Table 7). In conclusion, a comparison of the agreements of the ASER surfaces with the traditional map showed that introducing the effect of extreme storms into the calculation of MFI surfaces and evaluation of erosion risk by CORINE methodology greatly improved our ability to understand and predict the pattern of actual erosion in the semi-arid areas of Central Anatolia, Turkey.

Conclusions

In order to show the effect of improving MFI calculations using knowledge on total variability in rainfall data and incidence of extreme storms on the evaluation of soil erosion risk by CORINE methodology in the semi-arid area of Beypazarı, Ankara, Turkey, 5 different procedures were carried out with the daily rainfall amounts recorded from 1958 to 2003 from 11 climate stations in the study area by the Turkish State Meteorological Service. $\overline{MFI}$ and $MFI_{\bar{j}}$ were respectively calculated from the averages of i_{th} monthly rainfall amounts and averaged over a number of years (Eq. [1]) and from the monthly rainfall amounts of each individual year and averaged over a number of years (Eq. [2]), and MFI_{10}, MFI_{20}, and MFI_{30} were estimated from monthly return frequencies of rainfall events for 10, 20, and 30 years, respectively. $\overline{MFI}$ resulted in a serious underestimation in ASER because it statistically neglected the year-to-year variations and accounted only for within-year variations in the rainfall data set. Although $MFI_{\bar{j}}$ represented either variation, there was insignificant refinement in the ASER surface. On the other hand, ASER surfaces generated by MFI_{10}, MFI_{20}, and MFI_{30} indicated significant improvements in assessing the soil erosion risk and showed better agreements with the soil erosion classes of the conventional soil survey of the study area. These results suggested that to have dependable MFI surfaces and accordingly ASER surfaces, there is also a need for true accounting for the incidence of extreme storms together with the total variation expressed by within-year and year-to-year variations in the rainfall data.

The development of better surfaces of ASER allowed us to avoid the underestimation of soil erosion risk in the terrestrial part of Turkey, for which low climatological risk of erosion was entirely assessed by $\overline{MFI}$, and required more protective conservation measures.

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