Turk J Agric For
27 (2003) 105-116

Soil Erosion Risk Assessment With ICONA Model; Case Study: Beypazarı Area

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Received: 05.11.2002

Abstract: In this research, the applicability of geographic information system (GIS) and remote sensing (RS) techniques was tested to assess soil erosion risk with the ICONA erosion model. This study was carried out in the Ankara-Beypazarı area because of its variety of diverse landforms, land uses and land covers. The erosion risk assessment phase of this model consists of seven steps that mainly use slope, geology, land use and land cover information. A potential erosion risk map (step 3) was obtained from the slope (step 1) and lithofacies layers (step 2) generated using a digital elevation model (DEM) and digital geological maps. As a result of this process, the distribution of the erosion risk classes was 8.0% (very low), 24.7% (low), 23.6% (medium), 23.6% (high), and 20.1% (extreme). Land use (step 4) and land cover (step 5) layers derived from Landsat TM image data classification were combined to produce the soil protection map (step 6). The soil protection map showed that 77.8% of the area was classified as low and very low, and 22.2% of the area was classified as very high, high and moderate in terms of protection class. During the final predictive phase, soil erodibility and soil protection layers were combined to generate the ICONA soil erosion status map (step 7). The final map showed that 45.9% of the area had high and very high erosive status. These areas especially included hilly and mountainous areas, and excluded the forested parts. The rest of the study area had lower (very low, low and appreciable) erosion status. The present study shows that GIS and RS techniques have an important role to play in soil erosion risk studies.

Key Words: ICONA erosion model, remote sensing, geographic information system.

ICONA Modeli İle Toprak Erozyon Risk Değerlendirmesi: Pilot Çalışma: Beypazarı

Özet: Bu araştırmada, coğrafi bilgi sistemleri (CBS) ve uzaktan algılama (UA) tekniklerinin ICONA modeli uygulanarak erozyon risk değerlendirmesi çalışmasında kullanılması test edilmiştir. Farklı arazi formları, arazi kullanım türleri ve arazi örtüsüne sahip olması nedeniyle bu çalışma Ankara-Beypazarı yöresinde gerçekleştirilmiştir. Bu model eğim, jeoloji, arazi kullanımı ve arazi örtüsü, bilgilerinin kullanıldığı yedi aşamayı içermektedir. Çalışmanın ilk iki aşamasında, sayısal yükselti modeli ve sayısal jeoloji verilerinden elde edilen eğim ve kayaçların aşınmaya karşı dirençlilik haritalarının çakıştırılması ile üçüncü aşama olan potansiyel erozyon durum haritası elde edilmiştir. Bu işlem sonucunda, çalışma alanının potansiyel erozyon durumları, % 8,0'u çok düşük, % 24,7'si düşük, % 23,6'sı orta, % 23,6'sı yüksek ve % 20,1'i aşırı olarak bulunmuştur. Landsat uydu görüntüsünün sınıflandırılması ile elde edilen, arazi kullanımı (aşama 4) ve arazi örtüsü (aşama 5) haritaları, toprak koruma haritasını (aşama 6) elde etmek için birleştirilmiştir. Toprak koruma haritası çalışma alanının % 77,8'ünün çok düşük, ve düşük % 22,2'sinin ise orta, yüksek ve çok yüksek seviyelerde korumaya sahip olduğunu göstermiştir. Çalışmanın en son aşamasında, potansiyel erozyon durumu ve toprak koruma haritaları çakıştırılmış ve ICONA erozyon risk haritası oluşturulmuştur. Bu sonuçlara göre, çalışma alanının % 45,9'u, genellikle ormanlık alanları dışında bırakan tepelik ve dağlık alanlarda, yüksek ve çok yüksek, geri kalan alanlarda ise orta ve düşük seviyelerde erozyon riskine sahip olduğu belirlenmiştir. Bu çalışmada, toprak erozyon risk tahminlerinde, CBS ve UA tekniklerinin kullanılmasının önemli bir rolü olduğunu göstermiştir.

Anahtar Sözcükler: ICONA erozyon modeli, uzaktan algılama ve cografi bilgi sistemi

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Introduction

The main factor acting against the sustainability of agricultural production is land degradation. Among the different land degradation processes, soil erosion is the biggest threat to the conservation of soil and water resources. Soil erosion has accelerated in most of the world in recent decades due to population pressure and limited resources, which have also led to the increased and more continuous use of steeper lands for agriculture (Millward and Mersey, 1999). Increasing population, deforestation, land cultivation, uncontrolled grazing and higher demands for fire wood often cause soil erosion (Reusing et al., 2000).

According to the ICONA report (1991), approximately 20% of the agricultural lands of European Union (EU) countries had high or very high water erosion vulnerability. It is estimated that 51% of the agricultural areas of EU countries will face serious human-induced land degradation and increasing soil erosion problems by 2050 based on prevailing soil erosion rates.

According to the RIVM's data (2000), water erosion is one of the most important land degradation processes for EU countries. It is also reported that southern EU countries are at greater risk of water erosion, especially with high water erosion risk rates of 58%, 66%, 66% and 85% in France, Italy, Spain and Greece, respectively.

Turkey is a mountainous and hilly country. The average altitude is approximately 1250 m, and 62.5% of the total land has more than 15% slopes. Because of topographic limitations, soil erosion is Turkey's biggest problem; some 58.7% of the land the is exposed to severe and very severe soil erosion problems (Ministry of Agriculture, Forestry and Villages, 1987).

Özel et al. (1999) investigated the erosion risk status of Dalaman Basin by using ICONA erosion model (1997) in Turkey. According to the lithopedological properties, the study area consists of loose and sedimentary rocks that are sensitive to soil erosion and have a low resistance to weathering. They reported that the study area has a 17% low, 23% moderate and 60% high level of soil erosion risk.

Recent advances in space and computer technologies have provided us with the opportunity to process large amounts of data (multi-source), not only spectral but also other data such as elevation, slope, aspect and relief about the earth environment (Bayramin, 1998). Simulation models are the most effective way to predict soil erosion processes and their effects by using a geographic information system (GIS) and remote sensing (RS). Therefore, models have the potential to make major contributions toward developing better conservation practices and improving the management of land resources (Meyer, 1980). Olsson (1985) indicated that land degradation and erosional processes appear to be increasing in severity in semi-arid environments.

Landsat TM images and GIS analysis techniques were used for land degradation and erosion mapping (Szabo et al., 1998). Bojie et al. (1995) integrated DEM, slope, aspect and land use to study soil erosion types and they suggested that GIS analysis could help organize erosion surveys and facilitate mapping. Many researchers have employed GIS and RS technologies to model soil erosion (Rode and Frede, 1997; Millward and Mersey, 1999). Jong et al. (1999) used multi-temporal Landsat TM images to account for vegetation properties, a digital terrain model within a GIS to account for topographical properties. One of the most important factors to determine soil erodibility is the vegetation cover. As a general rule, the erosion risk decreases as plant intensity rises. Morgan et al. (1978), Berney et al. (1997) and Ahlcrona (1988) successfully applied RS data to determine vegetation cover and land use related to soil erosion.

Berney et al. (1997) noted that soil erosion processes in Mediterranean coastal areas bear serious consequences for the rational use of resources. The fragility of the Mediterranean ecosystems, the permanently increasing coastal population, the importance of Mediterranean agriculture, and the need for higher production require a comprehensive assessment and evaluation of the erosion phenomena.

There are numerous soil erosion models, such as agricultural non-point source pollution model (AGNPS), agricultural non-point source pollution model, modified (AGNPS-M), areal nonpoint source watershed environment response simulation (ANSWERS), chemicals, runoff and erosion from agricultural management systems (CREAMS), ephemeral gully erosion model (EGEM), erosion-productivity impact calculator (EPIC), european soil erosion model (EUROSEM), groundwater loading effects of agricultural management systems (GLEAMS), revised universal soil loss equation 1 (RUSLE 1), revised universal soil loss equation 2 (RUSLE 2), soil and water assessment tool (SWAT), universal soil loss equation (USLE), universal soil loss equation 2D (USLE-2D), universal soil loss equation modification (USLE-M) and water erosion prediction project (WEPP) (http://soilerosion.net/doc/models_menu.html). Most of the simulation models have been developed to predict soil erosion like the ICONA model. This model has been used by EU countries and by some Mediterranean states (e.g., Turkey, Tunisia, Syria and Egypt) for the assessment and mapping of soil erosion risk.

Widespread soil erosion studies are difficult to perform due to cost, labor and time. The objective of this study was to evaluate and determine the erosion risk of Beypazarı using the ICONA model and to test applicability of GIS and RS techniques on soil erosion risk assessment studies.

Materials and Methods

The survey was conducted in the Beypazarı area located in the northwest of the city of Ankara (Figure 1). The study area is located 382.825 m – 425.725 m East and 4.428.185 – 4.470.365 m North (UTM) coordinates. The study area is approximately 168,724 ha in size and consists of various topographical features (flat, rolling, hilly and mountainous). Elevation varies from 450 to 1600 m above mean sea level. Average annual precipitation and temperature are 390 mm and 13.1 °C, respectively. Forest and forage generally cover the northern part of the study area, while dry farming and forage are common in the southern part of the study area. Alluvial plains formed by the Kirmir stream, which is located in the central part of the study area, are under irrigation. According to Thornthwaite (1948), the study area was classified as ($C_2B^1{}_2\ s_2b_3{}^1$), which is dry to semi-arid, second- degree mesothermal, under a sea climate effect and has a water deficit during summer.

DEM (Figure 2), Landsat 5 TM scene and digital geological data were used for the ICONA model. This method consists of predictive, descriptive and integration phases, and in this research the first phase was studied. The predictive phase mainly consists of seven steps (Figure 3). First the slope layer was generated from DEM data and classified into five groups, and by analyzing the digital geological map, geological formations were classified into five groups according to their resistance to weathering in order to prepare the lithofacies layer. The slope layer and the lithofacies layer were then overlapped to produce a potential erosion risk (PER) map. Ground truth information was collected in the field with global positioning system (GPS), and Landsat TM imagery was classified using the maximum likelihood algorithm to determine different land use categories in the study area. A normalized difference vegetation index (NDVI = NI band

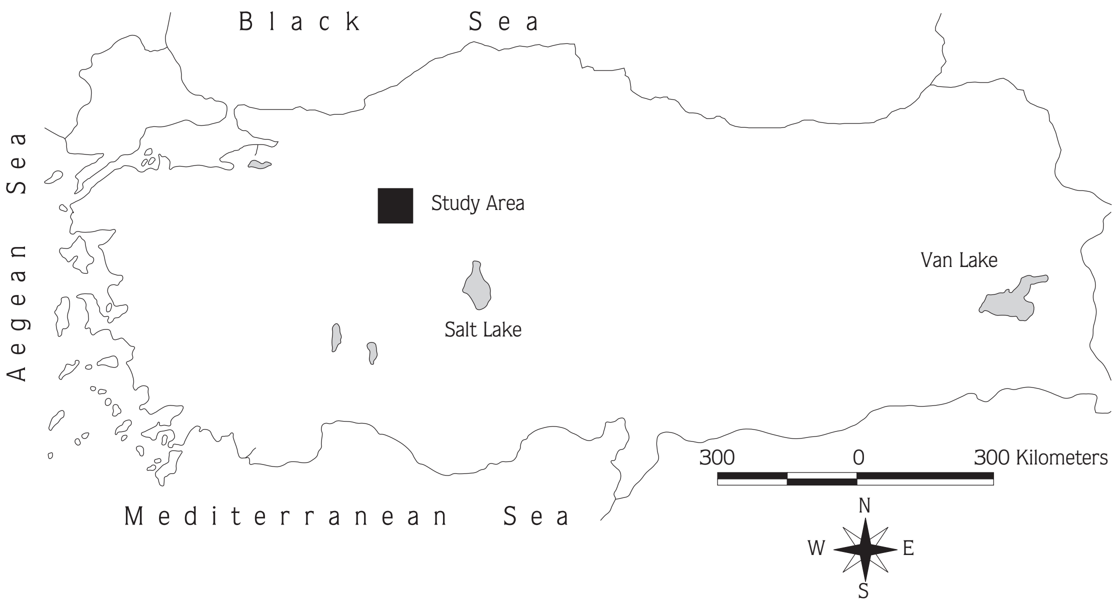

Figure 1. Location of the study area.

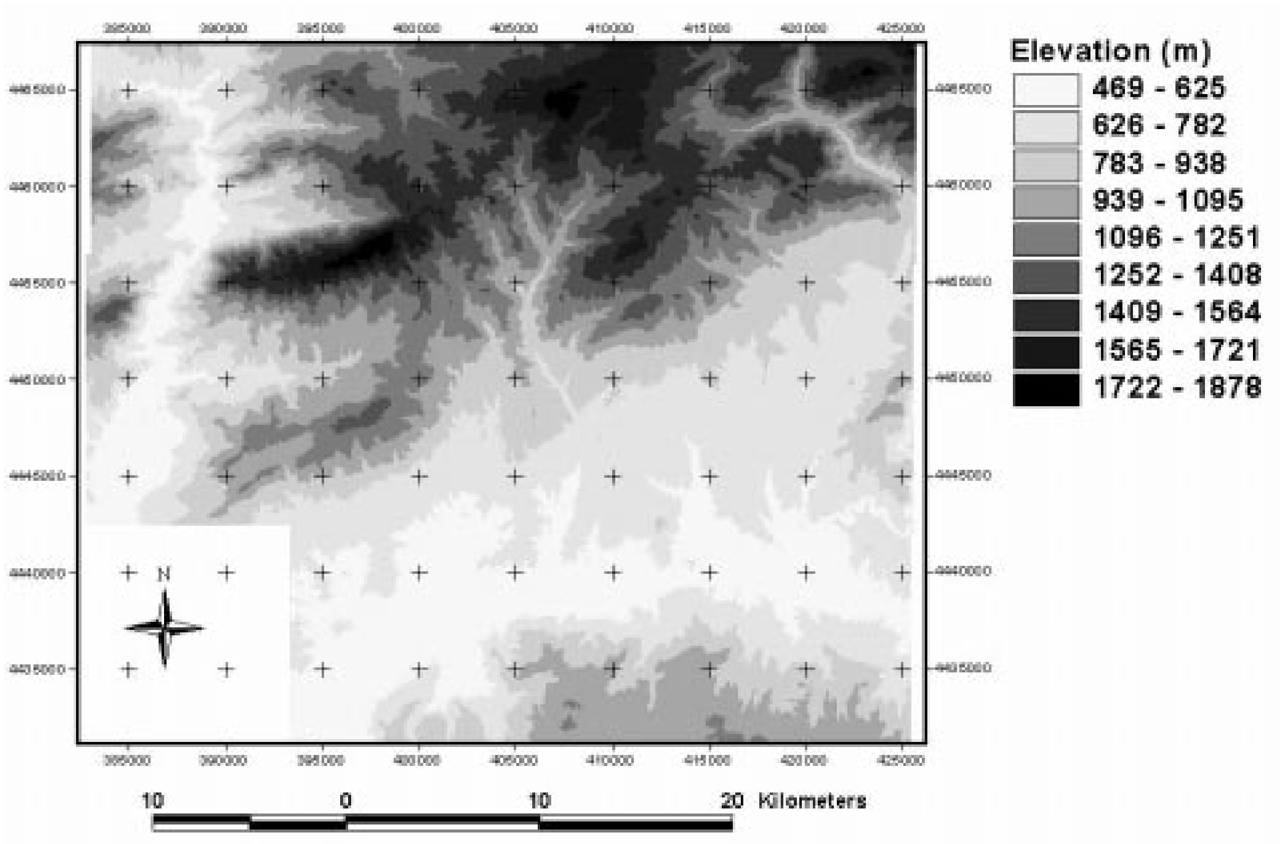

Figure 2. DEM of the study area.

Figure 3. Flow diagram of the study.

– R band / NI band + R band) defined by Tucker et al. (1985) was performed and applied to the Landsat TM image. The NDVI layer was classified into four groups and a vegetation cover layer was produced, which was then merged with land use for generating a soil protection layer. During the final predictive phase, soil erodibility and soil protection layers were combined to generate the ICONA soil erosion status map.

Results and Discussion

Slope groups (Figure 4) derived from DEM data are presented in Table 1. It can be seen that 64.9% of the study area has more than a 12% slope varying from steep to extreme slopes from which runoff can easily occur. As Millward and Mersey (1999) explained, soil erosion has accelerated due to limited land resources for agricultural practices, and the more continuous use of steeper lands for agriculture. A digital geology map of the study area was analyzed and discussed with experts, a

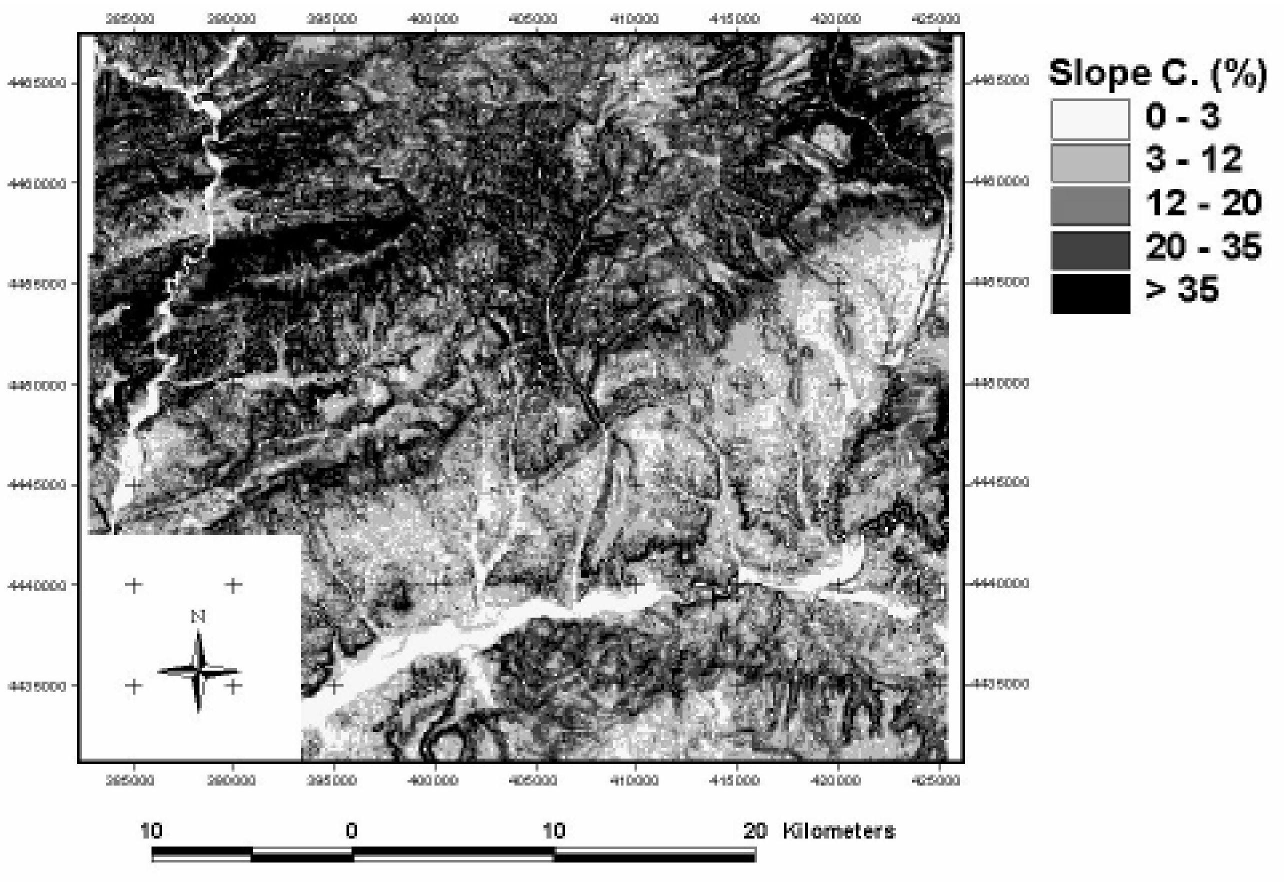

Figure 4. Slope groups of the study area.

Table 1. Slope groups of the study area.

Slope Classes		Area (ha)	Area (%)
Flat and gentle	0-3%	15,497	9.6
Medium	3-12%	41,536	25.6
Steep	12-20%	31,344	19.3
Very Steep	20-35%	39,343	24.3
Extreme	> 35%	34,477	21.3
TOTAL		162,197	100.0

reclassification process was applied and lithofacies classes (Table 2) were prepared (Figure 5). The lithofacies map shows the kind of rock, parent material or surface sediment or soil, with emphasis on their inherent resistance to both mechanical and chemical erosion. More than half of the study area has slight to medium compact sedimentary rocks and soils (54.5%). A smaller part of the study area consists of soft and low resistant or deeply weathered rocks like marls, gypsum and clayey slates.

Table 2. Lithofacies classes of study area

Lithofacies classes (Type of material)	Area (ha)	Area %
(1a) Non-weathered compact rock, strongly cemented conglomerates or soils, crusts, hard pans (massif, limestone, highly stony soils, igneous or eruptive rocks)	22,404	13.8
(2b) Fractured and/or medium weathered cohesive rocks or soils.	8758	5.4
(3c) Slightly to medium compacted sedimentary rocks (slate, schists, compacted marls etc.) and soils.	88,413	54.5
(4d) Soft, low-resistant or strongly/deeply weathered rock (marl, gypsum, clayey slates, etc.) or soils	681	0.4
(5e) Loose, non-cohesive sediment/soils and detritic material	41,941	25.9
TOTAL	162,197	100.0

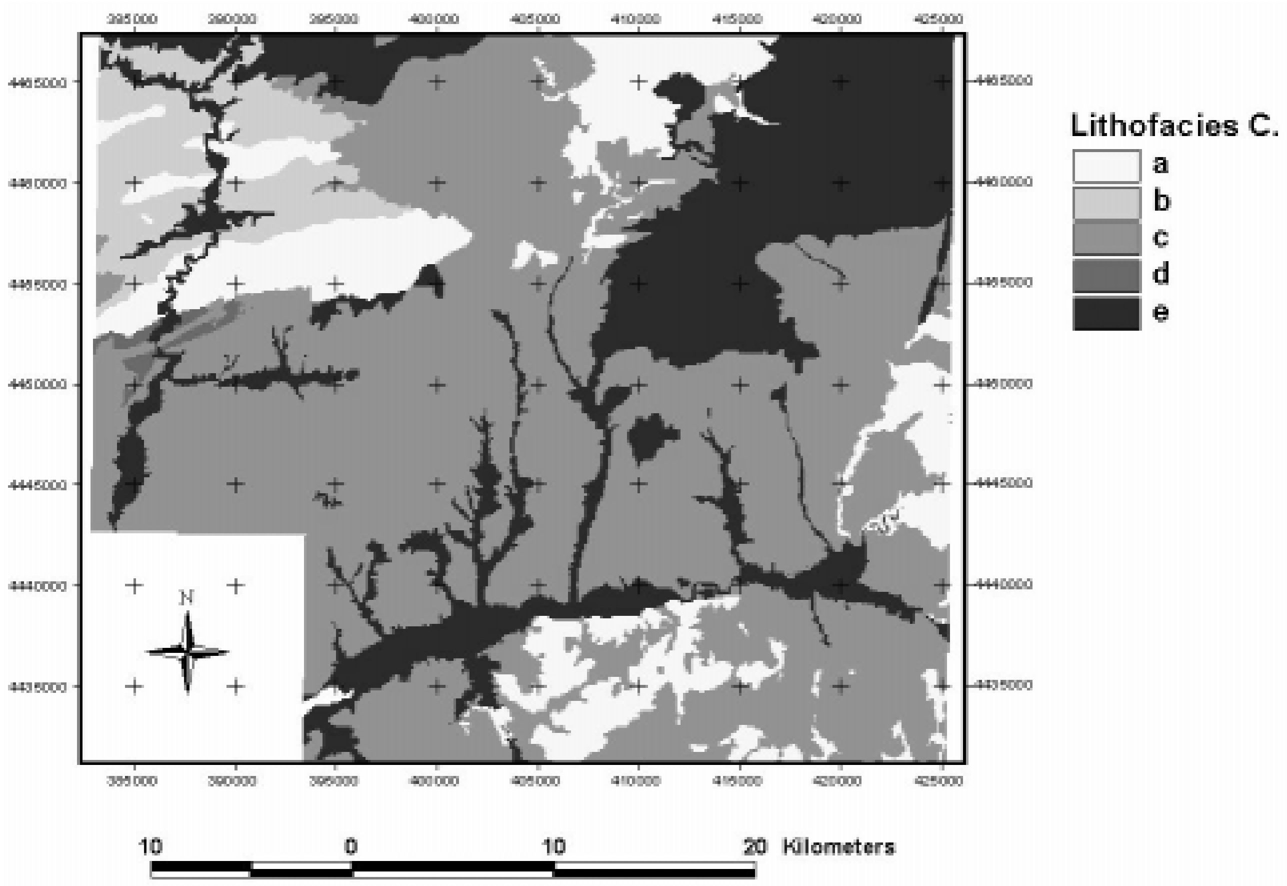

Figure 5. Lithofacies classes of the study area.

These rocks and sediments are sensitive to erosion processes. Only 13.8% of the total area has non-weathered compact rocks. By overlapping slope and lithofacies maps and using the erodibility matrix (slope vs. lithofacies) (Table 3), a potential erosion risk map was prepared (Figure 6); soil erodibility classes are presented in Table 4. While 43.7% of the study area has high or extreme soil erodibility, 32.7% of the study area has a very low or low erodibility risk. Our results are similar to those of Özel et al. (1999). They reported that loose and sedimentary rocks were sensitive to soil erosion and showed low resistance to weathering.

Georeferencing processes were applied to Landsat TM data acquired on 9 September 1998 over the study area. The imagery was geometrically corrected and rectified using 1:25,000 scaled topographic maps and registered to the UTM map projection system. The imagery was classified using the maximum likelihood decision rule and five land use types (Figure 7) were determined. Classification results were checked in the field using GPS at 176 control points and 79.2% classification accuracy was obtained. The distribution of the land use types is presented in Table 5. According to the classification results, rangelands have the largest area coverage (53.2%), and irrigated areas (6.4%), water surfaces (0.1%) and forests to (7.0%) occupy the smallest area covered in the study area. In this research water surfaces

Table 3. Erodibility matrix: slope vs. lithofacies.

	Lithofacies Class				
Slope Class	1(a)	2(b)	3(c)	4(d)	5(e)
1	1(EN)	1(EN)	1(EN)	1(EN)	2(EB)
2	1(EN)	1(EN)	2(EB)	3(EM)	3(EM)
3	2(EB)	2(EB)	3(EM)	4(EA)	4(EA)
4	3(EM)	3(EM)	4(EA)	5(EX)	5(EX)
5	4(EA)	4(EA)	5(EX)	5(EX)	5(EX)

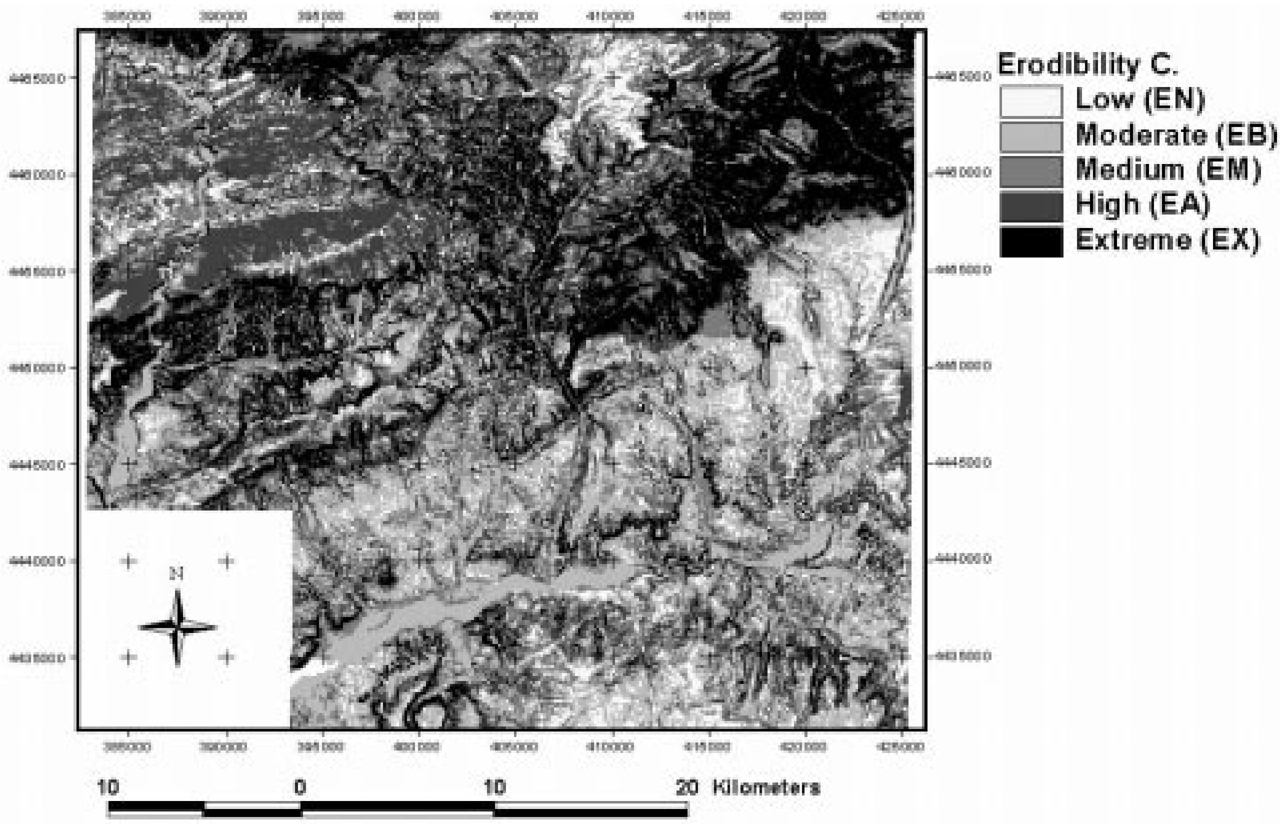

Figure 6. Soil erodibility (potential erosion risk) classes of the study area.

Table 4. Soil erodibility (potential erosion risk) classes of the study area.

Level of Erodibility	Area (ha)	Area (%)
1. Very Low (EN)	12,903	8.0
2. Low (EB)	40,075	24.7
3. Medium (EM)	38,269	23.6
4. High (EA)	38,327	23.6
5. Extreme (EX)	32,623	20.1
TOTAL	162,197	100.0

were masked and were not used in calculations. To produce a vegetation cover map, the NDVI values were classified into four groups according to field observations and surface canopy (Table 6). Only 18.0% of the study area has more than 50% surface coverage. One of the main limitations of this research was using a single image to determine land use classes and vegetation cover classes. This index is an indicator of the energy reflected by the Earth related to various cover type conditions. NDVI values range between -1.0 and +1.0. When the measured spectral response of the earth surface is very similar for both bands, the NDVI values will approach zero. A large difference between the two bands results in NDVI values at the extremes of the data range. Photosynthetically active vegetation presents a high reflectance in the near IR portion of the spectrum (Band 4, Landsat TM), in comparison with the visible portion (red, Band 3, Landsat TM); therefore, NDVI values for photosynthetically active vegetation will be positive. Areas with or without low vegetative cover (such as bare soil, urban areas), as well as non-photosynthetically active vegetation (senescent or stressed plants) will usually display NDVI values fluctuating between -0.1 and +0.1. Clouds and water bodies will give negative or zero values. During the growing period plants show different reflectance values in different bands in the electromagnetic spectrum, and NDVI values also change. This situation can be solved with hand-held spectro-radiometer or in large areas multi-temporal data acquired during the growing season. The use of multi-temporal data will increase the efficiency of the preparation of the soil protection layer. In this study, we tried to solve this

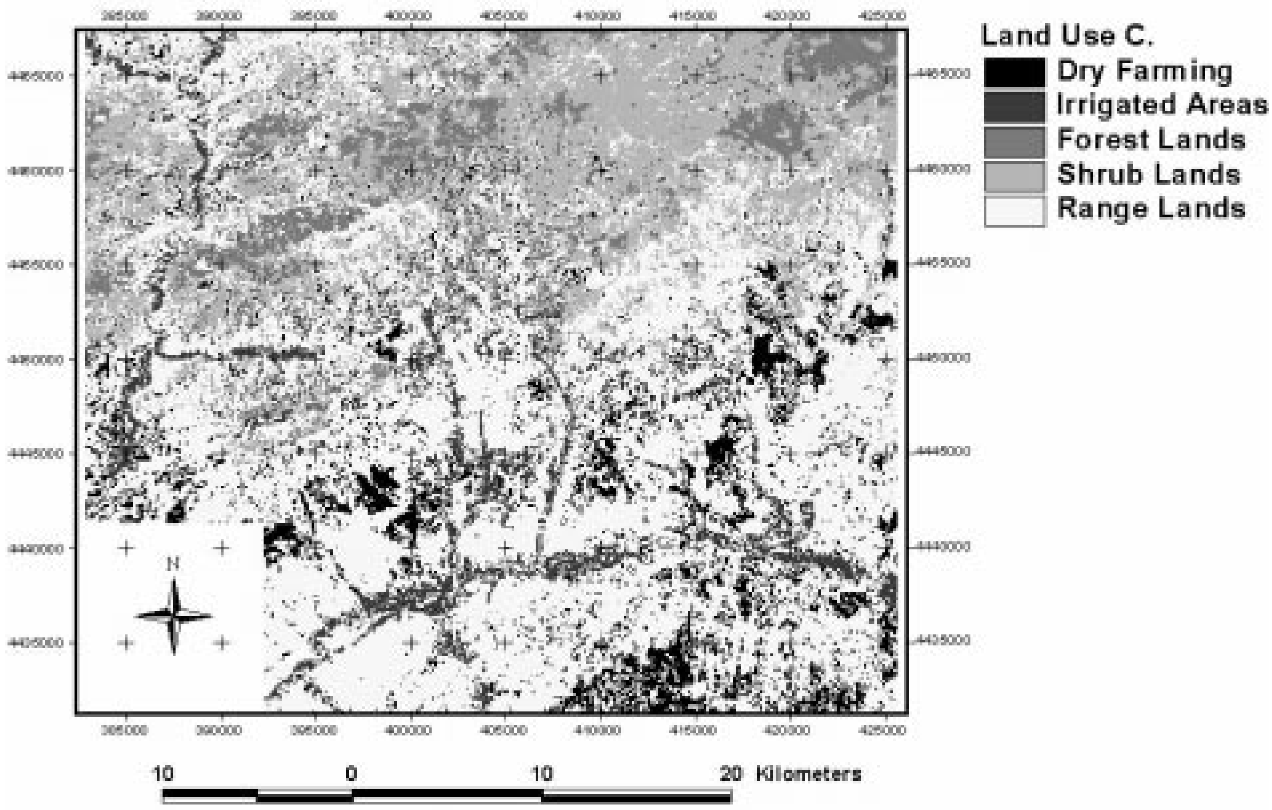

Figure 7. Land use types of the study area.

Table 5. Distribution of the land use types of the study area.

Level of Erodibility	Area (ha)	Area (%)
Dry farming	17,394	10.7
Irrigated agriculture	10,381	6.4
Forest	11,386	7.0
Shrub	36,790	22.7
Range, sparse shrubs	86,246	53.2
TOTAL	162,197	100.00

Table 6. Distribution of the vegetation cover classes of the study area.

	Coverage	
Vegetation cover	(ha)	(%)
Less than 25%	46,032	28.4
25-50%	86,877	53.6
50-75%	16,137	9.9
More than 75%	13,151	8.1
TOTAL	162,197	100.0

problem through intensive field studies. Additional information was also gathered from AVHRR and SPOT vegetation instrument 10-day composite data sets. AVHRR-NDVI data for 1992-1996 and SPOT-NDVI data for 1998-2001 were downloaded from the Internet (http://edcdaac.usgs.gov/1KM/comp10d.html and http://www.spotimage.fr/home/appli/apvege/welcome.htm). These data were simply analyzed and interpreted to obtain information about seasonal changes on vegetation indices. The study on relationships between NDVI values and climatogical data during the growing season using SPOT and AVHRR data has not yet been completed. Land use and vegetation cover maps were combined and a soil protection map was produced. The soil protection index (land use vs. vegetation cover) (Table 7) was used to produce a soil protection layer map. According to the soil protection map, 77.8% of the area was classified as having low or very low levels of soil protection (Table 8). Berney et al. (1997) and Ahlcrona (1988) implied the importance of land use vegetation cover and its effect on controlling erosion. Lower vegetation coverages in the

Table 7. Soil protection index: land use vs. vegetation cover.

	Vegetation Cover			
Land Use	1	2	3	4
1	5(MB)	5(MB)	4(B)	4(B)
2	5(MB)	5(MB)	4(B)	3(M)
3	3(M)	2(A)	1(MA)	1(MA)
4	4(B)	3(M)	2(A)	1(MA)
5	5(MB)	4(B)	3(M)	2(A)
6	5(MB)	4(B)	3(M)	2(A)

Table 8. Distribution of the soil protection classes of the study area.

Level of Erodibility	Area (ha)	Area (%)
Very high	11,242	7.1
High	12,553	7.6
Medium	12,430	7.5
Low	68,922	41.7
Very Low	57,050	36.1
TOTAL	162,197	100.0

study area were one of the most important factors behind higher erosion rates.

An ICONA erosion risk map was generated by combining the soil erodibility map (step 3) and soil protection map (step 6). The codification of the erosion status (level of soil protection vs. level of erodibility) (Table 9) matrix was used for the reclassification of the classes generated with overlaying processes. The distribution of the soil erosion risk classes (Figure 8) is presented in Table 10. As is seen from Table 10, 18.6% of the study area showed low and very low erosion risk and the rest of the study area was under high erosion risk.

The ICONA erosion classes were overlaid with land use classes and the distribution of the ICONA erosion classes on different land use types was analyzed and is presented in Table 11. Results showed that 23.2% of the dry farming areas have a very low and low erosion risk, and 29.1% of the dry farming lands have a high and very high erosion risk and 47.8% of the dry farming lands have an

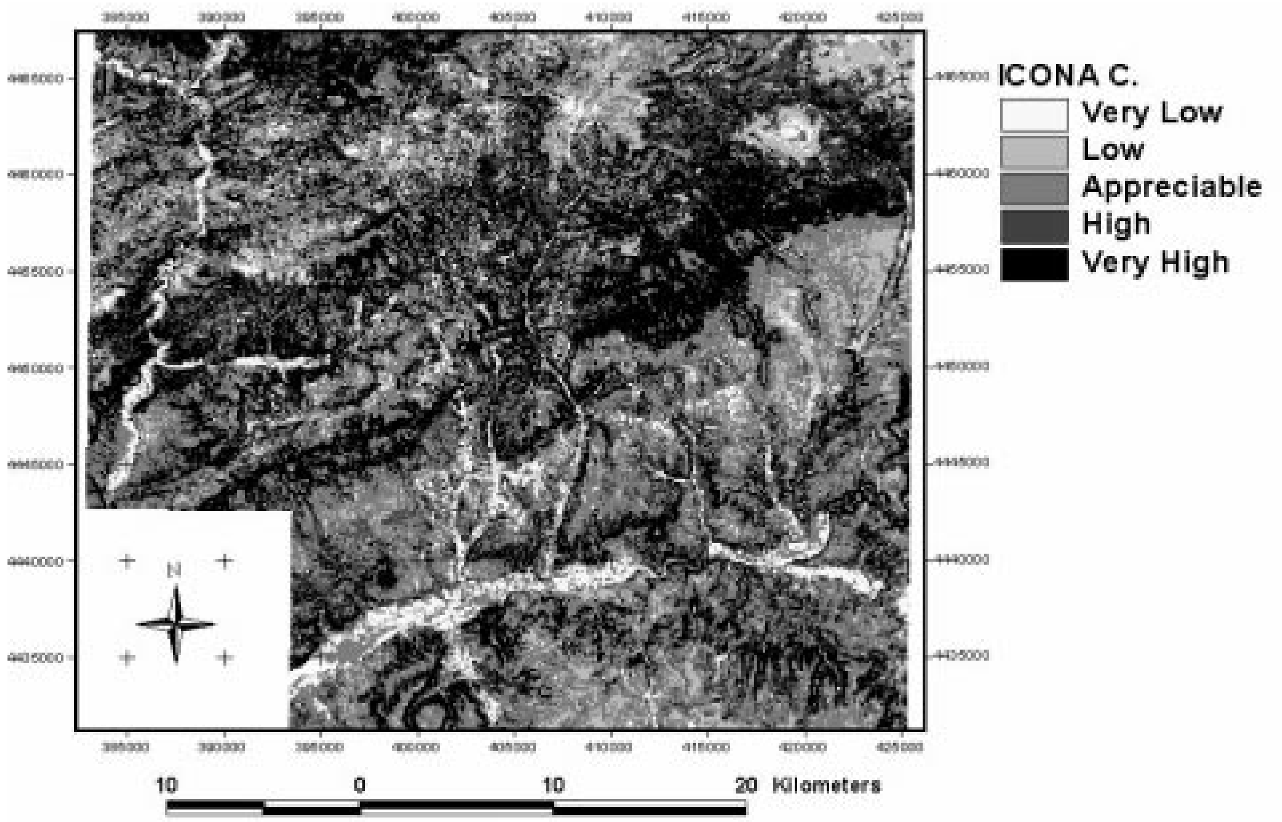

Figure 8. ICONA soil erosion risk map.

Table 9. Codification of erosion status; Matrix: level of soil protection vs. level of erodibility

		Erosion Status				
		1 (EN)	2 (EB)	3 (EM)	4 (EA)	5 (EX)
		Level of erodibility				
Level	1 (MA)	1	1	1	2	2
of	2 (A)	1	1	2	3	4
soil	3 (M)	1	2	3	4	4
protection	4 (B)	2	3	3	5	5
	5 (MB)	2	3	4	5	5

Table 10. Distribution of the ICONA soil erosion risk classes.

Level of Erodibility	Area (ha)	Area (%)
Very Low	8477	5.2
Low	21,677	13.4
Appreciable	57,479	35.4
High	24,737	15.2
Very High	49,827	30.7
TOTAL	162,197	100.0

appreciable erosion risk. Most of the irrigated areas (77.9% very low and low) do not have serious erosion problems. Forested areas have a great impact on soil erosion protection. Only 15.1% of the forestlands have serious erosion problems. Shrub lands have a higher erosion risk (86.3%) that varies from an appreciable to very high erosion risk. Only 7.4% of the rangelands do not have an erosion risk, showing that most of the rangelands are under severe erosion risk.

The susceptibility of Mediterranean ecosystems to soil erosion was indicated by Berney et al. (1997). Similar views stating that semi-arid regions have more higher erosion problems were also presented by the ICONA report (1991) and RIVM's data (2000).

RS and GIS techniques were used and applied to determine vegetation cover and land use related to soil erosion assessment by Szabo et al. (1998). The GIS and RS techniques of Bojie et al. (1995), Rode & Frede, 1997, Millward and Mersey (1999), Jong et al. (1999) Morgan et al. (1978), Berney et al. (1997), and Ahlcrona (1988) were successfully applied for erosion risk assessment in this research.

Table 11. Distribution of the ICONA erosion classes on different land use types.

ICONA Land Use Classes	ICONA Erosion Classes	Distribution of Erosion Classes		
		ha	% (in class)	% (in total)
Dry Farming	1	0	0	0.0
	2	4027	23.2	2.5
	3	8309	47.8	5.1
	4	3232	18.6	2.0
	5	1826	10.4	1.1
	Total	17,394	100	10.7
Irrigated Lands	1	5618	54.1	3.5
	2	2468	23.8	1.5
	3	1321	12.7	0.8
	4	974	9.4	0.6
	5	0	0.0	0.0
	Total	10,381	100	6.4
Forestlands	1	1943	17.1	1.2
	2	5824	51.2	3.6
	3	1890	16.6	1.2
	4	1724	15.1	1.1
	5	5	0.0	0.0
	Total	11,386	100	7.1
Shrublands	1	671	1.8	0.4
	2	3245	8.8	2.0
	3	12,325	33.5	7.6
	4	7294	19.8	4.5
	5	13,255	36.1	8.2
	Total	36,790	100	22.7
Rangelands	1	245	0.3	0.2
	2	6113	7.1	3.8
	3	33,634	39.0	20.7
	4	11,513	13.3	7.1
	5	34,741	40.3	21.4
	Total	86,246	100	53.2
	Total	162,197	100	100.0

Conclusion

This study demonstrated that rangelands and barren lands, especially found on steep slopes and hilly and mountainous areas, have high erosion risks and rangelands need good management practices that are sensitive to erosion. Land use, vegetation cover, parent material, topographic conditions, rainfall and soil properties are the major factors that affect soil erosion. In this era, all of these factors can be analyzed and evaluated easily with new technologies such as RS and GIS.

The ICONA erosion model is very useful for forming erosion risk assessment studies in large areas. However, the model does not consider climatic data. Integrating climatic data such as rainfall intensity and distribution parameters into the model may improve estimations of rainfall erosivity.

Because of the spatial and temporal variability of landscape and land use, high labor costs, and the time needed to collect data, there are difficulties in measuring soil erosion over large areas with conventional methods. Therefore, these problems can be overcome by using predictive models and new techniques. The ICONA model and GIS and RS techniques were very effective and useful in this research to assess erosion risk. In this study, RS techniques were found to be a very powerful tool to collect and monitor land cover and land use information; GIS technologies were also very effective at providing and processing large amounts of spatial data and provided more accurate and accessible information about soils and soil erosion.

Acknowledgments

The authors acknowledge the Scientific and Technical Research Council of Turkey (TÜBİTAK, project no: TARP 2097) and Ankara University Research Foundation (project no: 20-07-11-02) for their valuable support during the course of this research.

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