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Integrated Approach of GIS and USLE for Erosion Risk Analysis in the Sapanca Lake Watershed

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ABSTRACT

The primary objectives of this study is to establish a Geographical Information System (GIS) for soil loss based upon the Universal Soil Loss Equation (USLE) method, and to determine erosion risk zones in the Sapanca lake watershed. In this study, rainfall erosivity (R) factor was computed from monthly and annual precipitation data of six methodological stations. Soil erodibility (K) factor were extracted from soil map by the Ministry of Food, Agriculture and Livestock. Land cover and management (C) factor were derived from Landsat TM imagery and from Statip 2009 map. Topographic (LS) factor was interpolated from a digital elevation model (DEM). Support practice (P) factor was assigned a value of 1 due to lack of support practices in the watershed. The study indicated that the method can be reasonably used for soil erosion risk analysis in the Sapanca Lake Watershed, and also moderate and highly eroded areas associated with new settlements and bare lands since new settlers either cleared of native forests or used intensively for agriculture. Such analysis is essential for water management practices, specifically identification of critical risk zones for investigating watershed management strategies to achieve management goals.

Keywords*-Erosion Risk Analysis, GIS, Watershed Management, USLE method*

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I. INTRODUCTION

Erosion is a natural process causing soil loss from catchment areas even in the absence of human alterations of land cover. Due to human modifications, erosion rates have been raised above natural levels, a phenomenon known as accelerated erosion. Accelerated erosion, which could be gradual or rapid over time, is a serious matter that reflects increased population and finite arable lands (Douglas, 1967; Meade 1969; Bhan 1988; Walling, 1995; Garg and Seth, 2002; Zuazo and Pleguezuelo, 2009). Anthropogenic disturbance history such as urbanization, deforestation, and tillage can be a significant controlling variable because of their effects on surface conditions (Boardman et al., 2003). Besides these human activities, farming, grazing, road construction, and stream channel management can significantly influence sediment yield in a stream channel (Langbein and Schumm, 1958).Morris and Fan (1997) reported the most significant land degradation factor to be human activities. Isik et al. (2008) identify anthropogenic effects on stream flow hydrology and morphology. The results from this study indicate that sand mining for construction of roads and structures and over-withdrawals of sediment may increase sediment inputs to rivers.

The prevention of accelerated soil erosion relies on sustainable watershed management strategies, which involves reducing the rate of fertile soil loss from upstream areas. The absence of the appropriate watershed management practices, the most productive top soil of the agricultural lands has been transported to downstream regions. In order to prevent accelerated soil erosion, determination of soil erosion risk zones scale is extremely important. Assessment of soil erosion risk mapping in Turkey has been done in various regions (Curebal and Ekinci, 2007; Tagil, 2007; Karabulut and Kucukonder, 2008; Benzer, 2010; Ozsahin, 2011; Degerliyurt, 2011).

Widespread acceptance of the Universal Soil Loss Equation (USLE), of which modified version called Revised Universal Soil Loss Equation (RUSLE) have become a feasible conservation tool for watershed management practices. The main objectives of this study are to generate erosion risk maps using USLE and to compute annual soil loss for the Sapanca Lake watershed. Studying in this particular catchment is also important and would contribute to a better understanding of anthropogenic effects on soil erosion in a region with semi-humid climate.

II. STUDY AREA

The watershed of the Sapanca Lake (E 30° 3' – E 30° 20'; N 40° 47' – 40° 36') is located about 20 km east of the Gulf of Izmit, in the northwest of Turkey (Figure 1). The drainage area of the watershed is 229 km², of which 46 km² of the lake surface. Bilgin (1984), reported the lake of SapancaandİIzmit - Sapanaca Corridor originated from tectonic activities. The mean altitude is below 400 m in north of the watershed due to the Plateau of Kocaeli. In the south portion of the watershed, the mean altitude is slightly higher and the relief is more complex. Samanli Mountains are the mainsource of 5 small creeks, which degrade the surface topography thought time. Over long term records, climate is warm and temperate in Sapanca. Mean annual temperature is 14.3 ºC with the coolest month of January and with the warmest month of August. The mean annual precipitation in Sapanca is 740 mm, the most of the precipitation falls during Winter (32,6 %); the lowest precipitation rate seen in the summer (19,7 %). De Marton climate classification was established based on long term records (1963-2013), and the region is in semi-humid region. The characteristic type of flora is deciduous forests in lower altitude and coniferous forests in the higher elevation. The watershed mainly contains forestry (66,8 %), agriculture (19,0 %), urban areas (12,1 %) as significant land use/cover types.

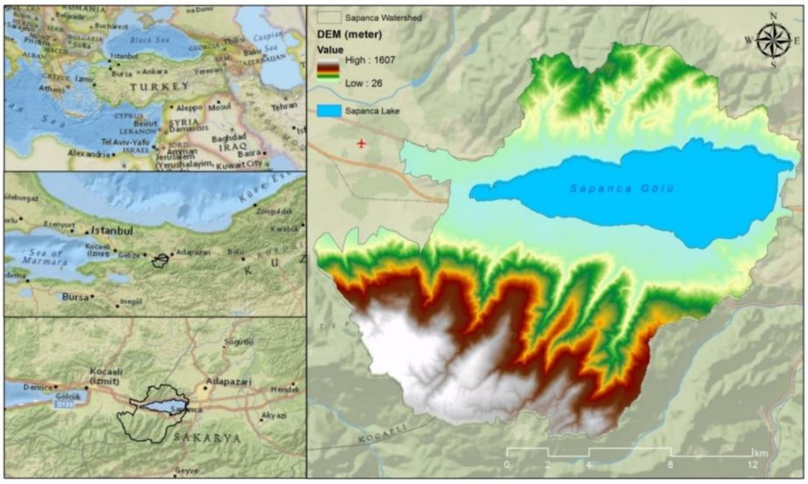


Figure 1: Location of the Sapanca Lake Watershed and Digital Elevation Model of the study area.

The watershed consists of 12 wild creeks, generally characterized by flashy streams in which stream flow rises sharply after rainfall and then falls more gradually. Discharge varies seasonally, with higher flow in the winter and spring and lower flow during summer and early fall. This sub-basin morphologically consists of plateaus, alluvial plains, and low-relief areas ranging from 26 m to 1607 m in altitude. There are four main soil groups of limeless brown forest, colluvial, alluvial, and rendzina in the study area based upon soil group maps of General Direction of Rural Affairs. Limeless brown forest soils (87,2 %) are widespread in the south of the watershed. Colluvial (6,3 %), and alluvial soils *(*3,6 %) become widespread in the lower altitude, and the northwest side has rendzinas*(*1,0 %) lies excluding urban areas.

III. DATA COLLECTION

The ability of soil loss to depict processes in a particular watershed is partially dependent on the quality of input data containing meteorological, soil, topographic, land use/cover and watershed management practices (Table 1).

Table 1. USLE model input data for Sapanca Lake Watershed

Data Type	Data Source	Duration Resolution
Climate	Turkish State Meteorological Organization	1963-2013
Soil	Ministiry of Agriculture and Rural Affairs	1/25.000
Land Use/Cover	USGS, Ministiry of Agriculture and Rural Affairs	30m - 10m
Topography	USGS - DEM	10m
Support Practice	None	None

The total numbers of six stations (Sapanca, Izmit, Adapazari, Geyve, Kaynarca and Kandira) were selected for the study area. The stations located outside of the basin area were selected to generate kriging interpolation by using mean annual precipitation values. The primary source of soil classification map is Soil Map Series (1:25,000) developed by the Ministery of Agriculture and Rural Affairs during the early 1980s. The land cover/use map of the study area was generated from Landsat TM satellite imagery for the year of 2015. The Statip, land cover database in higher resolution was further improved by the Ministry of Agriculture and Rural Affairs in 2009, and the satellite imagery was rectified. A digital elevation map (DEM) with the resolution of 10 m was received from the United States Geological Survey (USGS). Due to the lack of support practices within the study site, the common practice values of 1 were assigned for the P factor.

IV. METHOD

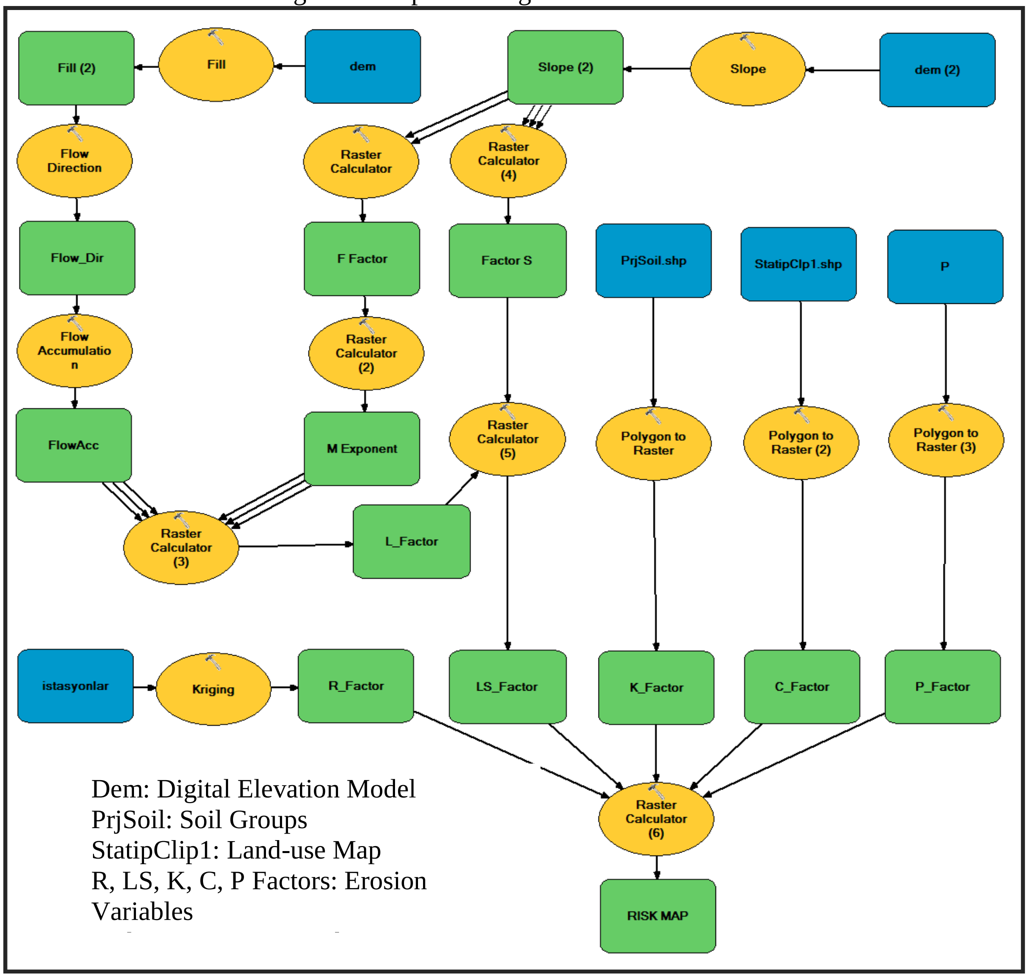
Modelling soil erosion requires many complex field measurements and spatial data, which are unsuitable for most developing countries due to limited financial supports. Therefore, Geographic Information Systems (GIS) and Universal Soil Loss Equation (USLE) have become widely accepted conservation planning tool throughout the world. Due to great variance among a large number of interrelated hydrologic and physical factors, this method is user-friendly and applicable for a watersheds with limited data. USLE is an empirical method for determining relevant parameters among the many physical variables comprising climate, soil profile, relief, vegetation, and land use and land management practices which are respectively indicated by R, K, LS, C, and P factors. The input parameters in the GIS framework comprise erosion factors such as rainfall erosivity, soil erodibility, and topography factor and cover factor (Basson et al., 2009). Gross erosion was estimated by USLE for soil loss caused by sheet, rill, and rain splash, but erosion caused by landslides and gullies cannot be computed using this equation in a Geographic Information System (GIS) framework. USLE equation is (Renard et al., 1994):

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad \text{(Eq. i)}$$

Where A is expected annual soil loss (tones / ha / yr), R is rainfall erosivity in (MJ mm ha^{-1} h^{-1} yr^{-1}), L-S is topographic factors that describe hill slope length and hill slope steepness (dimensionless), respectively, K is soil erodibility in (Mg ha h ha^{-1} MJ^{-1} mm^{-1}), C and P are cover-management practices and support practices factors that describe land use/cover.

ArcMap is the primary application where the data were stored, analyzed, and processed in this study. All the thematic layers were converted to be applicable in the software of ArcGIS 10.1. All the required data were generated using UTM projection system consisting of raster data were in WGS 84 format; and layers in ED 50 Datum. The use of the same projection allows raster images to overlap with others since the layers were finally multiplied to calculate the estimated annual soil loss rate (ton / ha / year). A diagram of the workflow is given in the Table 2.

Table 2: Diagram of implementing the USLE Factors with ArcGIS



Rainfall - Runoff Erosivity Factor (R Factor)

Rainfall erosivity factor represents a meteorological factor determining potential erosive forces of rainfall that is a critical input parameter for USLE method. Wischmeier (1960) defined R factor as a numerical description of the potential of rainfall corroding top soil. Rainfall erosivity (R factor) is usually computed as the long term average product of total storm energy (E) and the maximum 30 minutes rainfall intensity (I_{30}) (Renard et al., 1997). Due to the lack of long term (> 30 years) for the watershed, an established rainfall erosivity method was proposed from annual precipitation data. The following equation was suggested to calculate the R factor because the mean annual precipitation of the watershed is below 850 mm (Renard and Freimund, 1994):

$$R = 0.04830 * P^{1.610} \qquad P < 850 \text{ mm,} \qquad \text{(Eq. ii)}$$

Where R is annual rainfall erosivity (Mj mm ha^{-1} h^{-1} $year^{-1}$) and P is mean annual precipitation (mm).
In this study, Renard and Freimund‘s (1994) equations (Eq II) were used to estimate the rainfall-runoff erosivity factor because of no site specific rainfall intensity or rainfall-runoff erosivity data available for the Sapanca Lake Watershed. To compute R factor values, annual precipitation data from 6 meteorological stations (Figure 2) were used spread across the studied watershed.

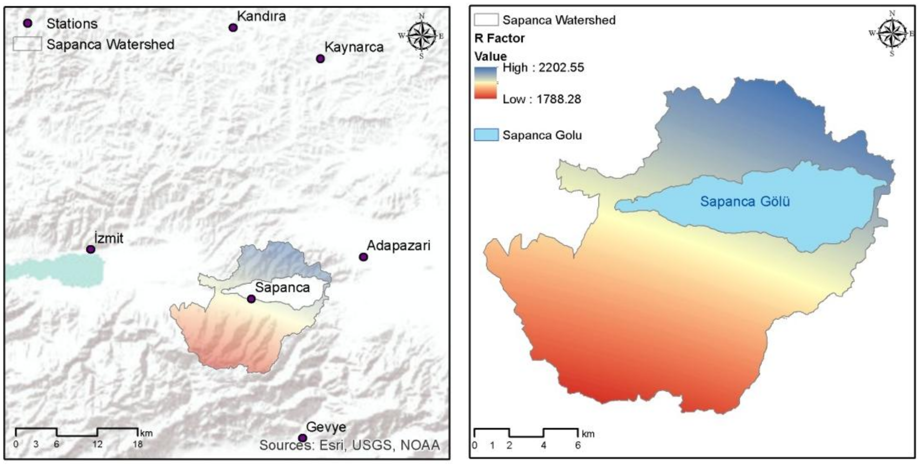


Figure 2: Locations of the weather stations and spatial distribution of R factor

Table 3 presents the rainfall runoff erosivity factor in SI customary units for the rain gauge stations. R values ranges from 1778 (Mj mm ha^{-1} h^{-1} $year^{-1}$) to 2202 (Mj mm ha^{-1} h^{-1} $year^{-1}$). That can be reported here, variation and spatial distribution of R factor associated with topography of the region. The R values reduced from north to south due to decrease in altitude. The lowest R factor was shown in Geyve and the highest in Kaynarca.

Table 3: Results of the R factor for the six weather stations

ID	**Name**	**Elv (m)**	**R_Factor (Mj mm ha^{-1} h^{-1} $year^{-1}$)**
1	Sapanca	74	2011
2	Adapazari	30	2255
3	Izmit	74	2045
4	Geyve	100	1669
5	Kaynarca	53	2553
6	Kandira	47	2508

Soil Erodibility Factor (K Factor)

The soil erodibility (K) factor is associated with infiltration rate, integrated influences of rainfall and runoff on soil loss during storm events at the regions with higher gradient. This factor is a lumped variable representing an integrated relationship among annual average soil loss and hydraulic processes. The values of soil erodibility factor (K) were estimated based on digital soil group maps (1/25.000) by Ministery of Agriculture and Rural Affairs. First, each soil types were added as a layer into ArcGIS, then the soil map attribute table was edited and K factors were assigned for a particular soil regions based on the previous studies (Dogan et al., 2000; Karabulut and Kucukonder, 2008, Degerliyurt, 2013). Finally the feature class was converted to raster format (Figure 3, Figure 4).

Table 4: Attribute values of K factor layers

Soil Types	**K Factor**	**Percentage (%)**
Rendzina	0.12	1,0
Alluvial	0.15	3,6
Colluvial	0.18	6,3
Limeless Brown Forest	0.29	87,2
Urban Areas	0.001	0,10

Soil erodibility factor (K) is related to the integrated effect of rainfall, runoff, and infiltration on soil loss. This factor accounts for the influences of soil properties on soil loss during storm events on upland areas (Renard et. al., 1997). In practical sense, K is a lumped parameter representing an integrated relationship between annual average erosion, profile reaction to erosion, and hydrological processes.

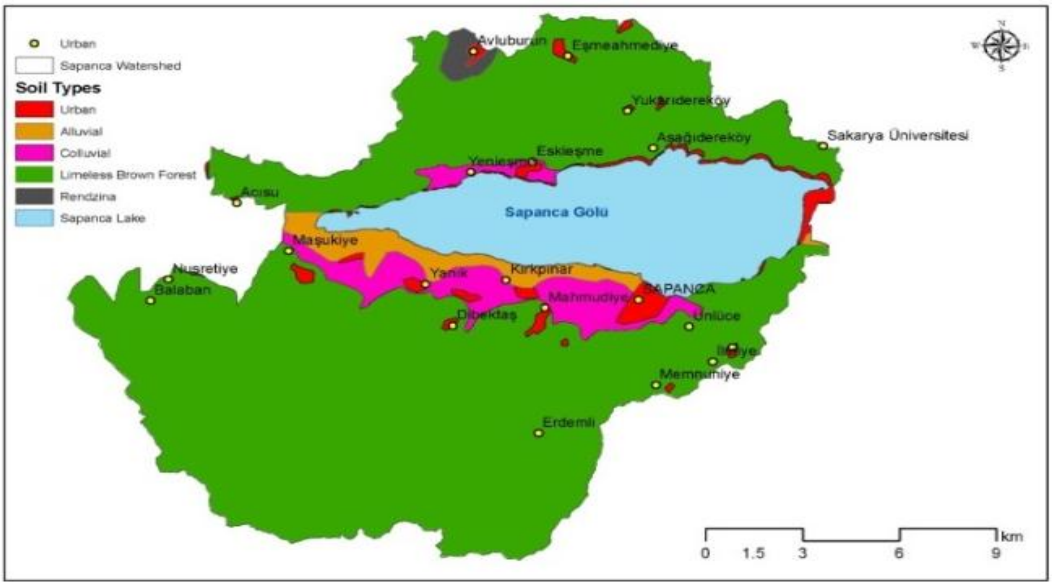


Figure 3: Spatial distribution of soil types and K Factor

K factor ranges from 0.001 to 0.29 (ton ha · h ha⁻¹ Mj mm⁻¹), principally due to their resistance to detachment in the soil. In the watershed, the main soil type is limeless brown forest (87,2 %), which tends to be more resistant to erosion than rendzina or azonal soils because organic residuals bind soil particles together. Besides the soil type, alluvial (3,6 %) and colluvial (6,3 %) are widespread at lower elevation as well as small amount of Rendzina (1%) is seen at the northwest portion of the watershed. The regions with limeless brown forest soil on upland areas tend to have relatively higher value of K (0.29) meaning this type of soil is moderately susceptible to detachment and it produces moderate runoff. The lowest K factor assigned for urban areas (Table 4).

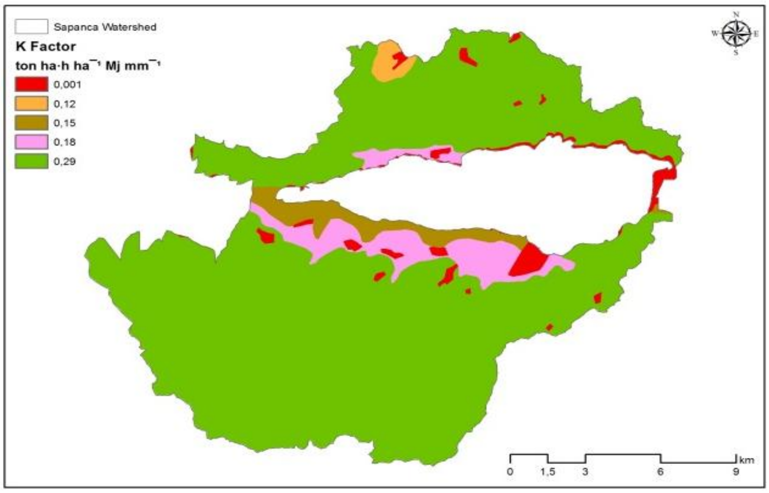


Figure 4: Spatial distribution of soil types and K Factor

Slope Length and Steepness Factor (LS Factor)

Topography potentially influences sediment behaviors since coarser materials in suspension are temporarily deposited in the floodplain and stream bed until stream power exceeds the threshold for movement. Increasing relief corresponds to greater overland flow, which accelerates soil erosion. Early geomorphologists also found a strong relationship between slopes and soil erosion rate. According to Powell (1876) and Gilbert (1877), greater relief and steeper slopes lead to faster soil erosion rate and thus to higher soil erosion risk. Increase in slope length and slope steepness enhanced soil erosion (Agassi, 1996). This also reflects more potential energy available for erosion and sediment transport by runoff. In the early 1960s, Schumm reported a linear relationship between erosion rate and drainage basin relief for basins in the United States (Ahnert, 1970; Pazzaglia and Brandon, 1996).

The influences of topography on erosion are accounted for by the LS factor in USLE, which typically combined together slope length (L factor) and slope steepness (S factor). In order to estimate LS factor in USLE, the required data of flow accumulation and slope map were computed from Digital Elevation Map (DEM) in ArcGIS.

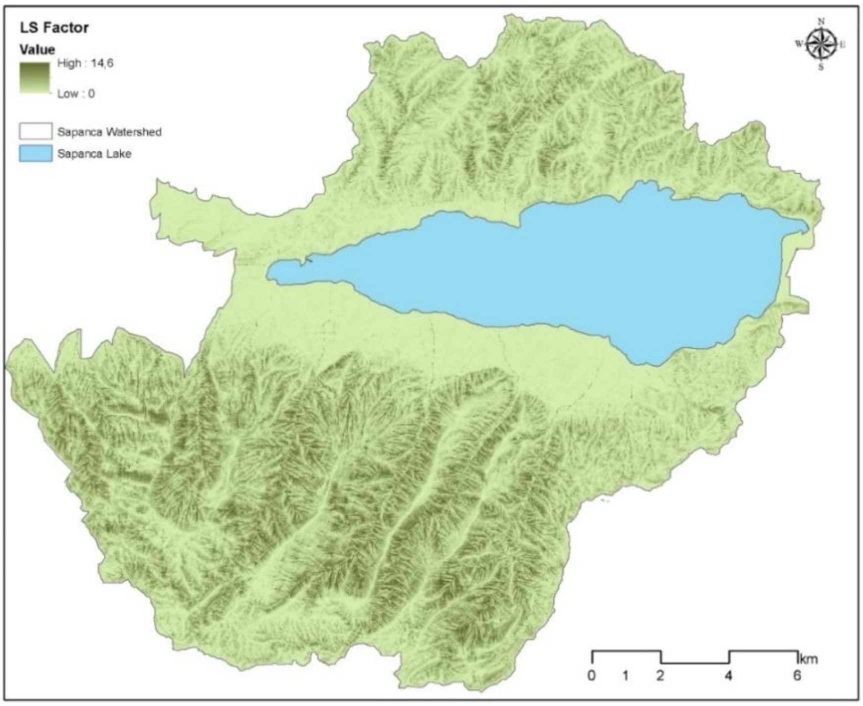


Figure 5: Spatial distribution of soil types and LS Factor

To compute LS factor, the following equation proposed by Moore and Burch, (1986) used in this study:

LS = Pow((flowacc)*resolution/22.1, 0.6) * Pow(Sin((slope) * 0.01745)/0.09, 1.3), (Eq. iii)

This equation was developed on the raster calculator from spatial analysis toolbar, and (Figure 5) illustrates the raster data generated for LS factor, which is higher in the north and south portion of the watershed due to the effects of steeper slopes. The LS factors values ranged between the value of 0 to 14, 5. The regions with LS values greater than 10 tends to have higher potential energy to transport soil particles to downstream, therefore these areas may potentially be more susceptible to gross soil loss.

Cover Management Factor (C Factor)

Higher intensity of vegetation assists in stabilizing top soil, accordingly preventing soil degradation, erosion and the loss of valuable lands. The effects of vegetation cover, cropping and management practices on soil loss, associated with the cover management (C factor), which is the ratio of soil loss from particular site with a vegetative cover and management to soil loos. The regions with dense and mature vegetation tends to have lower C value which is close to zero meaning there may not need soil conservation to prevent soil erosion.

Due to lack of developed C factor table, applicable for USLE in the study site, two main strategies employed to determine C factor depending on landsat TM satallite images. ISODATA (Iterative Self Organizing Data Analysis) and NDVI (Normalized Difference Vegetation Index) methods in ArcGIS were used to obtain a detailed look through the land use/cover (Figure 6), (Table 5). To do so, 150 points were randomly selected and categorized into 4 different homogenous land use/cover classes (forest, urban, orchard, agriculture) due to coarser resolution of Landsat TM image (30 m). Besides, Statip (Project of Detection and Remediation Problematical Agricultural Areas) is a higher resolution dataset produced by the Ministry of Agriculture and Rural Affairs was spatially assigned the C factor values based on previous studies (Table 6). After producing C values for each specific land use types, the feature classes were converted to raster format. Figure 7 represents long term mean crop management (C) factor for the maps generated from both Landsat TM and Statip. Finally, two different thematic risk maps were produced by using various land use/cover dataset as input.

Table 5: Attribute values of C factor layers from Landsat TM

Types	Area (km²)	%	C Factor
Forest (Anonymous, 2001)	129.5	56.4	0.005
Urban (Anonymous, 2001)	33.1	14.4	0.25
Orchard (Anonymous, 2001)	31.6	13.8	0.05
Agriculture (Wischmeier, 1960)	35.4	15.4	0.2

. **Table 6:** Attribute values of C factor layers from Statip 09

Types	Area (km²)	%	C Factor
Forest (Anonymous, 2001)	153.6	66.8	0.005
Urban (Anonymous, 2001)	27.7	12.1	0.2
Orchard (Anonymous, 2001)	27.7	12	0.05
Irrigated Farming (Kizilelma and Karabulut, 2014)	10.1	4.4	0.28
Dry Farming (Kizilelma and Karabulut, 2014)	5.9	2.6	0.07
Highways (Soo H., 2011)	2.2	0.97	0.01
Rangelands (Shin, 1999)	1.6	0.67	0.09
Barelands (Shin, 1999)	0.99	0.43	0.35
Marslands (Wischmeier, 1960)	0.08	0.03	0

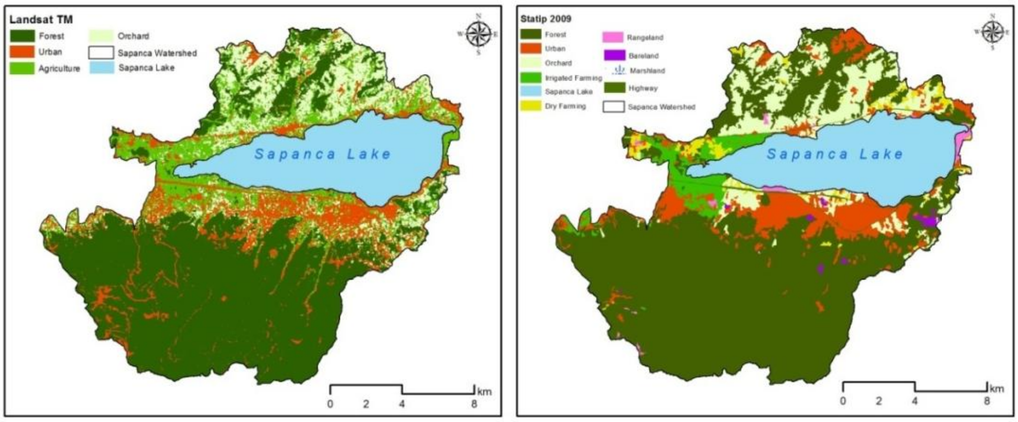


Figure 6: Spatial distribution of land use/cover types from Landsat TM and from Statip 2009

C factor values range from 0 to 0.25 and 0 to 0.35 for the land use/cover maps generated from Landsat TM and Statip respectively (Figure 7). The main classifications such as forest, urban, farming assigned the same values for these two datasets. Due to various resolutions, Statip 09 dataset has more detailed types consisting of irrigated farming, dry farming lands, and barelands etc. Although forested lands (66.8 %) are dominant in the south portion of Sapanca Lake watershed, Orchards (12.0 %) are mainly located northern side. Urban (12.1 %) is also widespread at the lower altitude, especially near by the lake shoreline. The C factor value assigned for forested lands as 0.005; for orchards as (0.05); for urban as (0.25) based on previous studies (Anonymous, 2001).

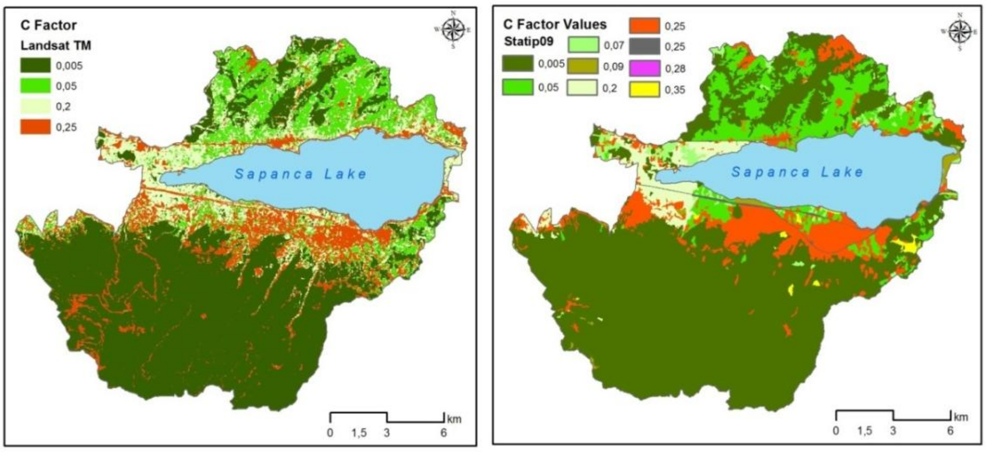


Figure 7: Spatial distribution of C factor values for two various input datasets of USLE.

Performing two different datasets generated from the ISODATA (Iterative Self Organizing Data Analysis) and Statip 2009 (Project of Detection and Remediation Problematical Agricultural Areas) contributes to determine the relative importance of higher resolution images for the model accuracy. In some studies, higher resolution data simulates the physical processes with better accuracy.

Support Practice Factor (P Factor)
Support Practice (P) Factor in USLE reflects the effects of support practices corresponding to gross soil loss. Support practices have a huge impact on soil erosion in consequence of altering the flow characteristics by reducing runoff (Reynard and Foster, 1983). Because of the lack of support practices inthe watershed, a value of 1 for the P factor was assigned, and the feature class converted to raster format.

V. RESULT AND DISCUSSION

Gross soil erosion is computed by USLE equation applied to the watershed by overlaying the 5 thematic layers. The soil erosion map shown in Figure 8, which refers to soil erosion rate of each pixel and reflects the sensitivity of the zones to erosion. As seen in the risk map, the study area revealed that regions covered very low, low, moderate, high, and very high soil loss potential zones are 92.7%, 5.4%, 1.6%, 0.26%, 0.004%, respectively (Table 7).
The soil erosion risk map of Landsat TM illustrates that the most of the study area particularly forested lands showed arelatively low erosion risk. However, roads, barelands and new settlements have high erosion risk with the higher rate in the northern portion of the watershed than other parts (Figure 8).
Figure 9 shows erosion risk zones with the input dataset of Statip 09, expressed with five broad classes and rangingfrom very low to very high risk zones are 95.6% to 0.02, respectively (Table 8). Although, USLE overestimated soil loss for lower erosion risk zones and underestimate gross soil loss for the regions with higher magnitude of erosion risk.

Table 7: Mean annual soil loss quantity (t/ha/yr) and rate (%) from Landsat TM.

Classes	**Soil Loss (t/ha/yr)**	**Area (km²)**	**Percentage (%)**
Very Low	(< 3)	213	92.7
Low	(3-8)	12.6	5.4
Moderate	(8-20)	3,6	1.6
High	(20-50)	0.6	0.26
Very High	(> 50)	0.01	0.004

Figure 8: Soil erosion risk map (Landsat TM).

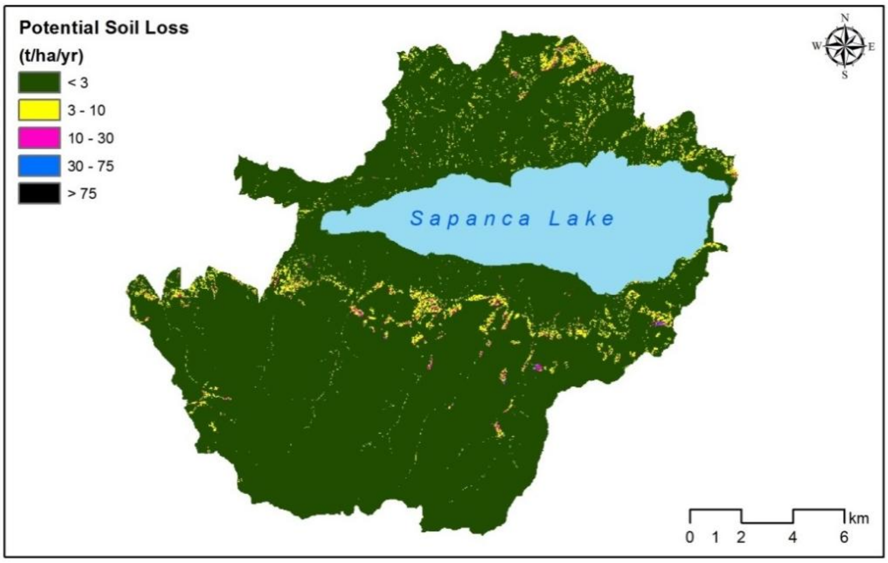


Figure 9: Soil erosion risk map (Statip 2009).

Table 8: Mean annual soil loss quantity (t/ha/yr) and rate (%) from Statip 2009.

Classes	Soil Loss (t/ha/yr)	Area (km²)	Percentage (%)
Very Low	(< 3)	219.5	95,6
Low	(3-10)	8,15	3,57
Moderate	(10-30)	1.68	0,73
High	(30-75)	0,19	0,08
Very High	(> 75)	0,04	0,02

The resulting map similarly shows barelands and new settlements under higher erosion risk. Furthermore, the pattern of the growth in the southern portion of the watershed is orthogonal and its direction of growth is towards the southern direction along the major routes. Newly settled places in the southern portion, such as Balkaya, Mahmudiye, Dibektasi, Yanik, Kurtkoy show higher magnitude of soil erosion risk. In terms of northern part of the watershed, orchards and deforested lands are widespread, for instance in the villages of Dagyoncali, Esme, Asagiderekoy, Yukariderekoy. Therefore, regions with higher magnitude of erosion risk in the northern portion associated with barelands and intensive farming techniques.

VI. CONCLUSION

In conclusion, the research demonstrates that an integrated approach of GIS and an empirical method, specifically the USLE, can be reasonably used for erosion risk analysis in the Sapanca Lake Watershed. By overlaying different land use/cover maps assess to reveal the relative importance of higher resolution dataset for erosion risk mapping. Despite the risk map overlaid with higher resolution land use/cover dataset produces more realistic erosion risk zones. Both resulting GIS maps emphasized that steeper slopes particularly nearby roads, along barelands or new settlements associated with greater soil erosion risk. About 2 % of the study region using the Soil erosion risk map (Landsat TM) and about 1 % of the studied region from Soil erosion risk map (Statip 2009) experiencing the soil loss greater than 8 (t/ha.yr) and 10 (t/ha/y), respectively. The erosion risk maps indicate that more than 90% of the watershed is ranked gross soil loss of less than 3 (t/ha.yr).

Even though, the areas with minor soil erosion risk are widespread in the study area, adverse effect of soil erosion can be still seen in the water and soil quality. Therefore, watershed management programs should be implemented to reduce sediment fluxes before it gets severe condition because the cost of practices is more affordable andapplicable at this stage. Determination of the potential sources of sediment particles assesses to be developed and established more efficient practices, especially for areas of heightened erosion risk zones defined by this method.

An integrated method of ArcGIS and USLE is an empirical based soil erosion model that is easy to parametrize and thus more applicable simulation for developing countries due to requiring lower amount of input dataset. However, there is considerable uncertainty associated with the model statistics in the Sapanca Lake Watershed, due to lack of finer resolution database including soil, land use/cover, and precipitation. Future studies in the Sapanca catchment should focus on improving the database by obtaining higher resolution soil data and more accurate climate data, which will likely help to reduce model uncertainty.Such studies also established a basis for future multidisciplinary studies on effective methodology of defining soil erosion risk zones and would contribute to a better understanding of anthropogenic effects on soil erosion in the region with semi-humid climate. In further stage, using a different analysis method for instance a physically based model could be done with higher resolution input dataset for this specific watershed.

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