SOIL EROSION RISK MAPPING USING GEOGRAPHIC INFORMATION SYSTEMS: A CASE STUDY ON KOCADERE CREEK WATERSHED, İZMİR

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

KIVANÇ OKALP

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEODETIC AND GEOGRAPHIC INFORMATION TECHNOLOGIES

DECEMBER 2005

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Canan Özgen
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Zuhal Akyürek
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Ali Ünal Şorman
Co-Supervisor

Assist. Prof. Dr. Zuhal Akyürek
Supervisor

Examining Committee Members

Assoc. Prof. Dr. Nurünnisa Usul	(METU, CE)	
Assist. Prof. Dr. Zuhal Akyürek	(METU, GGIT)	
Prof. Dr. Ali Ünal Şorman	(METU, CE)	
Assist. Prof. Dr. M. Lütfi Süzen	(METU, GEOE)	
Dr. Murat Ali Hatipoğlu	(DSİ)	

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Kıvanç Okalp

Signature :

ABSTRACT

SOIL EROSION RISK MAPPING USING
GEOGRAPHIC INFORMATION SYSTEMS:
A CASE STUDY ON KOCADERE CREEK WATERSHED, İZMİR

Okalp, Kıvanç

M. Sc., Geodetic and Geographic Information Technologies Department

Supervisor : Assist. Prof. Dr. Zuhal Akyürek

Co-Supervisor: Prof. Dr. Ali Ünal Şorman

December 2005, 109 pages

Soil erosion is a major global environmental problem that is increasing year by year in Turkey. Preventing soil erosion requires political, economic and technical actions; before these actions we must learn properties and behaviors of our soil resources. The aims of this study are to estimate annual soil loss rates of a watershed with integrated models within GIS framework and to map the soil erosion risk for a complex terrain. In this study, annual soil loss rates are estimated using the Universal Soil Loss Equation (USLE) that has been used for five decades all over the world.

The main problem in estimating the soil loss rate is determining suitable slope length parameters of USLE for complex terrains in grid based approaches. Different algorithms are evaluated for calculating slope length parameters of the study area namely Kocadere Creek Watershed, which can be considered as a complex terrain. Hickey's algorithm gives more reliable topographic factor values than Mitasova's and Moore's. Satellite image driven cover and management parameter (C) determination is performed by scaling NDVI values to approximate C values by using European Soil Bureau’s formula. After the estimation of annual soil loss rates, watershed is mapped into three different erosion risk classes (low, moderate, high) by using two different classification approaches: boolean and fuzzy classifications. Fuzzy classifications are based on (I) only topographic factor and, (II) both topographic and C factors of USLE. By comparing three different classified risk maps, it is found that in the study area topography dominates erosion process on bare soils and areas having sparse vegetation.

Keywords: Soil Erosion Modeling, USLE, Geographic Information System (GIS), Slope Length, Fuzzy Classification

ÖZ

COĞRAFİ BİLGİ SİSTEMİ KULLANARAK EROZYON RİSK HARİTALAMASI: İZMİR KOCADERE HAVZASI ÖRNEK ÇALIŞMASI

Okalp, Kıvanç
Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri Bölümü
Tez Yöneticisi : Yrd. Doç. Dr. Zuhal Akyürek
Ortak Tez Yöneticisi: Prof. Dr. Ali Ünal Şorman

Aralık 2005, 109 sayfa

Erozyon, Türkiye'de yıldan yıla artış gösteren küresel ölçekte büyük bir çevre sorunudur. Erozyonun önlenmesi politik, ekonomik ve teknik eylemlere gereksinim duymakta, bu eylemlerden önce de toprak kaynaklarımızın özellik ve davranışlarını öğrenmemiz gerekmektedir. Bu çalışmanın amaçları havzanın yıllık toprak kaybı miktarının tümleşik modellerle CBS çerçevesinde belirlenmesi ve karmaşık arazi yapıları için erozyon risk haritasının oluşturulmasıdır. Bu çalışmadaki yıllık toprak kaybı miktarları dünyada elli yıldır kullanılan Evrensel Toprak Kayıp Eşitliği (Universal Soil Loss Equation, USLE) kullanılarak hesaplanmıştır.

Hücresel tabanlı yaklaşımlardaki ana sorun USLE'nin eğim uzunluğu parametresinin karmaşık arazilere uygun biçimde tespit edilmesidir. Aynı zamanda karmaşık arazi yapısına sahip olan Kocadere Havzası'nın eğim uzunluğu parametresinin hesaplanmasında farklı algoritmalar değerlendirilmiştir. Hickey'in algoritması Mitasova ile Moore'un algoritmalarına kıyasla daha güvenilir topografik faktör değerleri vermiştir. Yüzey örtüsü ve yönetimi (C) parametresinin uydu görüntüsüne dayalı olarak belirlenmesinde Normalize Edilmiş Bitki İndeksi (Normalized Difference Vegetation Index, NDVI) değerleri yaklaşık C değerlerine Avrupa Toprak Ofisi'nin formülüne göre ölçeklendirilmiştir. Yıllık toprak kaybı miktarlarının hesaplanmasını takiben havza klasik ve bulanık sınıflamaya göre üç farklı (düşük, orta, yüksek) erozyon risk sınıfına ayrılmıştır. Bulanık sınıflama, USLE'nin hem sadece (I) topografya faktörüne göre hem de (II) topografya ve C faktörlerine göre gerçekleştirilmiştir. Sınıflandırılmış üç risk haritasının karşılaştırılması sonucu çalışma alanında topografyanın çıplak arazi ve zayıf bitki örtüsüne sahip alanlarda erozyon sürecinin baskın etkeni olduğu ortaya çıkmıştır.

Anahtar Kelimeler: Erozyon Modellemesi, USLE, Coğrafi Bilgi Sistemi (CBS), Eğim Uzunluğu, Bulanık Sınıflama

ACKNOWLEDGMENTS

I wish to express my deepest gratitude to my supervisor Assist. Prof. Dr. Zuhal Akyürek and co-supervisor Prof. Dr. Ali Ünal Şorman for their guidance, advice, criticism, encouragements and patience during this study.

I would like to thank Assist. Prof. Dr. Mehmet Lütfi Süzen for his suggestions and comments.

The technical support of Mrs. Emel Ulu from General Directorate of İzmir Water and Sewerage Administration; and Assist. Prof. Dr. Okan Fıstıkoğlu from Department of Civil Engineering of Dokuz Eylül University and all other persons who have helped me on various stages of this study are gratefully acknowledged.

I would like to give my special thanks to my family for their support and encouragements.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

CHAPTER 1

INTRODUCTION

Erosion is the displacement of solids like soil, mud and also rock by the agents of wind, water, ice, or movement in response to gravity. Erosion is an important natural process, but in many places it is increased by human activities. It becomes a problem when human activity causes it to occur much faster than under natural conditions.

Underlying each landscape is the geological process of uplift and subduction, compression and corrugation, tectonic and volcanic activity, shaping the landscape in a gross way. This is a very slow process, taking millions of years rather than thousands. Erosion then rounds these shapes, quickly at first but gradually more slowly, until it stabilizes at a rate of minimal erosion. Clearly, soil erosion is an urgent problem because new soil forms very slowly; 2.5 centimeters of topsoil may take anywhere from 20 to 1200 years to form. Soil erosion also has a number of serious environmental impacts (Schwab and Frevert, 1985).

Soil erosion has both on-site and off-site effects. The implications of soil erosion extend beyond the removal of valuable topsoil. On-site effects of soil erosion are generally "visible". Crop emergence, growth and yield are directly affected through the loss of natural nutrients and applied fertilizers with the soil. Seeds and plants can be disturbed or completely removed from the eroded site. Organic matter from the soil, residues and any applied manure is relatively light-weight and can be readily transported off the field, particularly during rainfalls. Pesticides may also be carried off the site with the eroded soil. Soil quality, structure, stability and texture can be affected by the loss of soil. The breakdown of aggregates and the removal of smaller particles or entire layers of soil or organic matter can weaken the structure and even change the texture. Textural changes can in turn affect the water-holding capacity of the soil, making it more susceptible to extreme condition such as drought (Morgan, 1995).

Off-site impacts of soil erosion are not always as apparent as the on-site effects. Off-site impacts of erosion relate to the economic and ecological costs of sediment, nutrients, or agricultural chemicals being deposited in streams, rivers, and lakes. Eroded soil, deposited downslope can inhibit or delay the emergence of seeds, bury small seedling and necessitate replanting in the affected areas. Sediment can be deposited on downslope properties and can contribute to road damage. Sediment which reaches streams or watercourses can accelerate bed erosion, clog drainage ditches and stream channels, silt in reservoirs, cover fish spawning grounds and reduce downstream water quality. Pesticides and fertilizers, frequently transported along with the eroding soil can contaminate or pollute downstream water sources and recreational areas (Morgan, 1995).

Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. In the USA, soil has recently been eroded at about 17 times the rate at which it forms: about 90% of US cropland is currently losing soil above the sustainable rate. Soil erosion rates in Asia, Africa and South America are estimated to be about twice as high as in the USA. FAO estimates that 140 million ha of high quality soil, mostly in Africa and Asia, will be degraded by 2010, unless better methods of land management are adopted (FAO, 2001).

The European Union member states have totally 25 million ha of erosion vulnerable areas; unfortunately this rate reaches 61.9 millions ha in Turkey (TFCSE, 2001). General Directorate of Reforestation and Erosion Control (GDREC) defines 20% of our topsoil has moderate, 36% has severe and 22% has very severe soil erosion according to their soil surveys. Turkey losses over 345 million ton sediment only with its rivers and this rate equals to 1/50 of earth's average value (GDREC, 2001). We lost approximately 600 ton topsoil per square km in a year; unfortunately the average loss for entire earth is only 142 tons. The value that we lost per year is enough to cover up the whole area of Cyprus with the height of 10 cm of soil as well. Lost topsoil of Turkey has the potential to turn Turkey into a desert in the near feature and this upcoming environmental problem was pointed in UN Conference on Environment and Development (UN, 2004) in Rio de Janeiro in 1992. Because of the potential seriousness of some of the off-site impacts, the control of non-point pollution from agricultural land has become of increasing importance in the region of Southeastern Anatolia Project (ACC, 2005).

The Americans have, for almost fifty years, pioneered a soil erosion estimating system which requires the farmer to comply with required soil management techniques, if he wishes to continue receiving government support. The Food Securities Act of 1985 requires that farmers apply conservation measures to remain eligible to participate in certain government programs, but there is no similar sanction in Turkey (USDA, 2005).

Model is a simplified description of an actual system, useful for studying the system behavior. Models are used in every branch of science; they are also tools for dealing with complex systems and the interactions of their constituent parts. Decisions need to be made on the suitable level of complexity or simplicity depending on the objective. The starting point for all modeling must be a clear statement of the objective which may be predictive or explanation. Managers, planners and policy makers require relatively simple predictive tools to aid decision making rather than complex systems.

The most widely used and supported soil conservation tool is "Universal Soil Loss Equation, USLE" (SWCS, 2005). USLE is an empirical equation derived from more than 10,000 plot-years of data collected on natural runoff plots and an estimated equivalent of 2,000 plot-years of data from rainfall simulators. The current major USLE guideline manual, Agriculture Handbook 537 was published in 1978.

The annual soil loss is estimated from a number of factors that have been measured for all climates, soil types, topography and kinds of land. These factors are combined in a number of formulas in USLE, which returns a single number, the computed soil loss per unit area, equivalent to predicted erosion in ton acre^{-1} year^{-1} (Wischmeier and Smith, 1978). This technique helps to predict erosion and orients farmers which farming methods to use. It also identifies erosion-sensitive areas, *"but it does not compute sediment yields from gully, streambank, and streambed erosion"* (Wischmeier and Smith, 1978). Although originally developed for agricultural purpose, use of USLE has been extended to watershed with other land uses.

While newer methods are becoming available, most are still founded upon principles introduced by USLE; thus, understanding these principles is quite important. USLE states that the field soil loss in tons per acre per year, A, is the product of six causative factors;

$$A= R\ K\ L\ S\ C\ P \tag{1.1}$$

Where,

R = rainfall and runoff erosivity index

K = soil-erodibility factor

L = length of slope factor

S = degree of slope factor

C = cropping-management factor

P = conservation practice factor

Several attempts have been made to modify and further develop USLE (Cooley and Williams, 1983; Renard et al., 1991), but the original USLE still remains the most widely used method due to its simplicity.

A Geographical Information System is a very useful environment to model because of its advantages of data storage, display and maintenance. Thus, linking or integrating models with GIS provides an ideal environment for modeling processes in a landscape (Burrough and McDonnell, 1998). Process-based models represent our most detailed scientific knowledge, usually considering properties and processes at small spatial and temporal scales, but have extensive data requirements. In contrast to process models, which require a minimum of calibration but a large number of input parameters, empirical models require far less data, and are therefore easier to apply, but do not take full advantage of our understanding of process mechanics and have limited applicability outside conditions used in their development. Once released and publicized, both types of models may end up being used (and misused) in a range of situations, across many spatial and temporal scales, and with data of varying quality (Wischmeier, 1976). With increasing availability and use of geo-spatial data management tools, such as GIS, new issues have arisen with respect to spatial data, application of models to a range of spatial scales, and the role of spatial data handling tools and analytical techniques in decision making (Clarke et al., 2001).

Erosion modeling within GIS generally focuses on describing the spatial distributions, rather than calculating the values of soil loss. Predicting the location of high risk areas with the highest possible accuracy is extremely important for erosion prevention as it allows for identification of the proper location and type of erosion prevention measures needed (Mitasova et al., 1996).

There are several studies performed in Turkey for erosion modeling by using different approaches. USLE and Topmodel methodologies were studied by Hatipoğlu (1999) for Güveç Basin in his PhD thesis. Hatipoğlu developed an AML script for determining topographic factor and compare the results of his script with Beven and Kirkby's (1979) topographic index values for Topmodel within GIS framework.

İrvem (2003) developed soil loss and sediment yield estimation model, which is based on USLE with GIS for Körkün subwatershed, located in Seyhan River Basin. He compared measured and predicted sediment yield and the model resulted with low performance.

Cambazoğlu and Göğüş (2004) aimed in their study to make an accurate, quick and easy determination of sediment yield in the Western Black Sea region. They compared the results of their study with the results from Turkish Emergency Flood and Earthquake Recovery Project (TEFER) studies. Both studies predict the annual soil loss by using USLE. "*However, the main difference is that the USLE is applied using weighted average values for its factors in the present study, while it is used with the application and help of GIS, in the TEFER studies*" (Cambazoğlu and Göğüş, 2004). They found that the results are mostly close to each other, differences come from using average values for the factors over the area.

CORINE methodology which was developed by European Community based on USLE was applied to Gediz Basin by Okalp (2001). It is found that land cover is major factor that lowers the potential erosion risk in Gediz Basin. Mapping soil erosion risk with CORINE methodology is very important for the integration of future scientific studies between European Community and Turkey.

The applicability of GIS and remote sensing techniques was tested by Bayramin et al. (2003) to assess soil erosion with ICONA. ICONA is useful for large areas but does not consider climatic data. As a result of this research, ICONA and both GIS and RS techniques were found very effective and useful to assess erosion risk (Bayramin et al., 2003). ICONA erosion model which is similar to CORINE needs more detailed geological data input, was also applied to Eymir and Mogan Lakes Watershed by Akgül et al. (2003).

These three empirical models; USLE, CORINE and ICONA were used to erosion risk mapping for Dalaman Basin in 1996. The result of these methodologies were compared with each other in this research project that is supported by TFCSE and General Directorate of Rural Services (TSSA, 2005).

In this study it is aimed to use an applicable erosion model and integrate the selected model with the capabilities of GIS for the study area. USLE is selected as an empirical erosion model because of its fewer requirements compared to the other models which need detailed data sets. A small watershed named "Kocadere Creek, İzmir" was selected as a study area in order to use USLE within GIS to map soil erosion risk. It is also aimed to use different methods in estimating the topographic factor. Finally, two approaches namely boolean and fuzzy classifications are aimed to be used in mapping the soil erosion risk.

The thesis consists of five chapters: introduction, integration of USLE with GIS, study area and data preparation, grid based USLE implementation, and conclusions. These five chapters are described as follows:

Chapter one is introduction chapter meant to provide general background information of the study and the objectives in this study.

Chapter two is a literature review. In this chapter fundamental concepts related to both USLE and integration of USLE with GIS are presented. This chapter is meant to investigate previous works and available methods related with the study.

Chapter three describes the study area and materials used for this study.

Chapter four deals with the actual analysis of the study. Grid based USLE implementation, LS determination algorithms, C factor deriving method and fuzzy implementation are described.

In Chapter five the results of both traditional USLE and fuzzy implementation are discussed.

In Chapter six conclusions drawn from study are presented and recommendations are also given.

Appendices are also attached which contain additional information such as precipitation data sets, yearly precipitation and R factor distributions, charts and AML code.

CHAPTER 2

EROSION MODELS

The aim of predicting soil loss under a wide range of conditions may help decision makers in planning the conservation work. Before planning conservation work how fast soil is being eroded must be estimated and this stage can only be performed by running models.

Most of the models used in soil erosion studies are of empirical grey-box type where some detail of how the system works is known. These are based on defining the most important factors and, through the use of observation, measurement, experiment and statistical techniques, relating them to soil loss.

2.1. Integration of USLE with GIS

Geographic Information Systems are becoming a popular and effective tool when seeking solutions to issues which are spread over large spatial extents like soil erosion and require study of many alternatives (Wijesekera and Samarakoon, 2001). However the most important point is ensuring reasonable erosion estimations by using GIS framework with appropriate USLE modeling technique for realistic decision making.

Several attempts have been made to combine this model with GIS and generate regional soil loss assessments. Hession and Shanholtz (1988) transformed USLE into a raster-based model and combined it with the Map Analysis Package (Tomlin, 1980) and a sediment delivery ratio to estimate sediment loadings to streams from agricultural land in Virginia. A single R was obtained from published maps and used for each county, K was obtained from county soil survey reports, LS was calculated for each cell by inserting slope length and the weighted cell slope into the appropriate USLE equations, C was determined from Landsat imagery and P was assumed to be constant and equal to unity. 100 m sized grid cells were used for all data except elevation. The majority rule was used to assign USLE factor values to cells for discontinuous data such as soil erodibility and the centroid value was assigned to each cell for continuous data such as the topographic factor. Elevation was sampled at a 200 m cell resolution and slopes were determined by weighting the slope between each cell and its eight neighbors. The topographic factor was calculated at this coarse resolution and then interpolated to a 100 m grid size because of computer hardware costs. A sediment delivery ratio was calculated for each agricultural land cell and combined with USLE soil loss to estimate the sediment that reaches the stream.

Some other studies chose the polygon data structure of a vector GIS and treated the USLE as a zone-based model. Ventura et al. (1988) used a series of GIS polygon overlays and FORTRAN programs to estimate soil erosion in Wisconsin. A seamless digital soil data layer for the entire county was prepared from detailed soil maps and used to assign R, K, and LS factor values. Five land cover types were classified from a Landsat Thematic Mapper (TM) scene and combined with boundary information for Public Land Survey System (PLSS) quarter sections, incorporated areas, and wetlands to assign C and P factor values. These land cover and soil data layers were then overlaid and used to estimate soil erosion for the 500,000 polygons.

James and Hewitt (1992) used a series of ARC/INFO coverages and AML scripts to build a decision support system for the Blackfoot River drainage in Montana. Their system was based on the Water Resources Evaluation of Nonpoint Silvicultural Sources (WRENSS) model which, in turn, incorporates a modified version of the USLE to estimate potential soil erosion. R was estimated from published maps and historic snow survey data, K values were estimated from a series of digital and paper USDA-Natural Resource Conservation Service (NRCS) and USDA-Forest Service (FS) soil survey maps, LS values were estimated from 3 arc-second digital elevation models (DEMs) using ARC/INFO's GRID module, and a land cover data layer was prepared from a Landsat TM scene. Some additional data processing was required because some of the soil survey source maps delineated NRCS soil series and others delineated FS land-type units at scales ranging from 1:250,000 to 1:24,000. The topographic factor estimations were resampled to a larger cell size, stratified into classes, and converted into a vector format to ensure compatibility with the other model data layers. The user interface that was developed as part of this decision support system allows data browsing and querying at the basin level and data modeling at the sub watershed level.

GIS was used to transform the USLE into a semi-distributed model in these applications. However, there are a number of important assumptions embedded in USLE that help to explain why the application of this model to landscapes is much more difficult than its application to soil loss plots. The first also the major assumption is no representation of sediment deposition. USLE does not distinguish the neighboring areas between soil losses and gains of hillslope profiles experiencing net erosion and deposition.

The other one is the required process that is for dividing landscapes into uniform slope zones. This process is about how GIS divides the landscape into zones and how the model inputs are estimated in each zone. The original USLE computed average soil loss along hillslope profiles that were defined with reference to a "standard" soil loss plot. These standard plots were 22.1 m long and planar in form although these conditions may not occur very often in natural landscapes (Moore and Wilson, 1992 and 1994). Foster and Wischmeier (1974) divided irregular slopes into a series of uniform segments and modified the original USLE LS equations to calculate the average soil loss on these slope profiles. However, this method still requires the subdivision of landscapes into hillslope facets. Griffin et al. (1988) rewrote the original USLE to calculate erosion at any point in a landscape and thereby avoided this requirement. Their equation is much easier to implement than the original model, although the user must still distinguish those areas experiencing net erosion and deposition.

Using USLE integrated with GIS creates concern since topographic parameter is polygon specific. This situation makes it difficult to determine topographic factor in complex terrains. The reason behind this handicap comes from the nature of USLE which is developed for small agricultural areas having nearly constant slope and slope lengths that are the average values for the selected areas obtained from time consuming and costly field surveys. These average values could be represented in polygon geometry but this polygon based approach generally fails on complex terrains having unsteady slopes and slope lengths. Polygon based topographic factor classification also limits USLE results because of averaging; this limitation could give over or under estimated soil loss rates.

In the last decade soil erosion models become more complicated than USLE, including ANSWERS, AGNPS, WEPP and RUSLE (Hickey, 2000). All soil erosion models have topographic parameter and have their own equations for this component. It is important to note that these equations use both slope and slope length that could be derived from DEM easily on any GIS software but it needs care to select the suitable algorithm.

The Universal Soil Loss Equation has been used for a number of years to predict soil erosion rates. One of the required inputs to this model is the cumulative uphill slope length. Calculating slope length has been the largest problem in using USLE. Traditionally, the best estimates for L are obtained from field measurements, but these are rarely available or practical. While field estimates of cumulative slope length may be more accurate than this model, for larger areas they are typically neither practical nor affordable. The only necessary data for this calculation is a digital elevation model (Hickey et al., 1994).

Particular algorithms that have been developed to calculate slope length include grid-based methods (Hickey et al., 1994; Hickey, 2000; Van Remortel et al., 2004), unit stream power theory (Moore and Burch, 1986; Moore and Wilson, 1992; Mitasova, 1993; Mitasova et al., 1996), contributing area (Desmet and Govers, 1995; Desmet and Govers, 1996), and Cowen's (1993) study developed the means to calculate cumulative downhill slope length from a TIN (triangular irregular network) within ARC/INFO. Unfortunately, these methods cannot be applied to any DEM, if to do so, problems will occur. Each model has different limitations and will calculate different values for the same DEM.

After the topography, vegetation cover is the second most important factor that controls soil erosion risk since it measures the combined effect of all interrelated cover and management variables and it is the factor which is most easily changed by men (Folly et al., 1996). In the Universal Soil Loss Equation, the effect of vegetation cover is incorporated in the cover management factor (C factor). It is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith, 1978). The value of C mainly depends on the vegetation's cover percentage and growth stage. The effect of mulch cover, crop residues and tillage operations should also be accounted for in estimating the C-factor. Generally the C-factor will range between 1 and almost 0. Hereby C=1 means no cover effect and a soil loss comparable to that from a tilled bare fallow. C=0 means a very strong cover effect resulting in no erosion.

De Jong (1994) investigated the use of Landsat Thematic Mapper (TM) imagery for deriving vegetation properties like Leaf Area Index (LAI), percentage cover and the USLE-C factor. For this, areal estimates of percentage cover, LAI and C were obtained from 33 plots in France. The plot values were compared with the corresponding NDVI-values on the Landsat TM imagery yielding regression equations that are able to predict LAI, percentage cover and USLE-C from NDVI-values. Using a linear model he found –0.64 correlation between NDVI and USLE-C. According to De Jong, the somewhat poor results could possibly be explained by the sensitivity of the NDVI for the vitality of the vegetation: for a canopy under (water) stress NDVI will be low, even if the canopy cover is dense. This seriously limits the use of NDVI images in erosion studies, because for erosion the condition of the vegetation is not important.

The USLE rainfall erosivity factor (R) for any given period is obtained by summing for each rainstorm the product of total storm energy (E) and the maximum 30-minute intensity (I_{30}). Unfortunately, these datasets are rarely available at standard meteorological stations. Da Silva (2004) illustrated how rainfall erosivity influences soil erosion and to deliver an important source of information for predicting erosion in his study. He applied an adapted equation using pluviometric records obtained from 1600 weather stations in Brazil, and used GIS to interpolate the values. The resulting map showed the spatial variations of erosivity.

The soil erodibility factor (K) is usually estimated using the nomographs and formulae that are published; for example Wischmeier and Smith (1978). While these equations are suitable for large parts of the USA (for which USLE was originally developed), they produce unreliable results when applied to soils with textural extremes as well as well-aggregated soils (Römkens et al., 1986). Therefore, they are not ideally suited for use under European conditions. It should be noted that at present only the USLE model is widely used in many countries.

Lufafa et al. (2003) evaluated different methods of USLE input parameter derivation and to predict soil loss within a microcatchment of the Lake Victoria Basin. In the terrain units, soil loss was highest within back slopes followed by the summits and valleys. This study pointed that GIS USLE approach has the ability to predict soil loss over large areas due to the interpolation capabilities. *"It is therefore possible to circumvent the constraint of limited field data on soil loss and/or its factor controls at meso- and macro-scale, by capturing and overlaying the USLE parameters in a GIS"* (Lufafa et al., 2003).

Traditional methods for erosion risk classification are based on Boolean logic and designed to assign a pixel to a single erosion class. *"However, the soil and other physical parameters might vary spatially within a pixel and it may not correspond entirely to a single erosion class"* (Ahamed et al., 2000). Fuzzy class membership approach can account for determining the loss of information on erosion susceptibility by assigning partial grades to the erosion classes (Metternicht and Gonzales, 2005). Ahamed et al. (2000) used a fuzzy class membership approach in soil erosion classification and developed a criteria table specifying the erosion parameter values related to erosion susceptibility classes. They integrated fuzzy approach with the USLE model in their study.

The popularity of the USLE probably lies in its simplicity and ease of use. Most process-based erosion models require the collection of substantial amounts of complex data, in addition to their complex mechanics. Most of the models are based on Wischmeier's equation, such as EPIC. The USLE gives an approximation of the extent of soil erosion. However, users should not try to extend the use of the equation in order to estimate soil loss from drainage basins, because it is not intended to estimate gully and streambank erosion. A good ten years must pass before other models can be used on a daily basis in the field. Moreover, it is not certain that such physical models will be more effective than the best locally adapted versions of present empirical models (Renard et al., 1991).

In recent years significant advances have been made in our knowledge of the mechanics of erosion processes and, as a result, greater emphasis is now being placed on developing white-box and physically-based models. Along with this goes a switch from using statistical technique to employing mathematical ones frequently requires the solution of partial-differential equations.

2.2. Physically-based Erosion Models

2.2.1. WEPP - Water Erosion Prediction Project

WEPP (Water Erosion Prediction Project) is a process-based simulation model, based on modern hydrological and erosion science, designed to replace the Universal Soil Loss Equation for the routine assessment of soil erosion by organizations involved in soil and water conservation and environmental planning and assessment. The WEPP model developed by the United States Department of Agriculture (USDA), the United States Forest Service (USFS), the United States Department of the Interior (USDI), and other cooperators; mathematically describes the processes of soil particles detachment, transport, and deposition due to hydrologic and mechanic forces acting on hillslope profile. The WEPP calculates runoff and erosion on a daily basis. Erosion processes may be simulated at the level of a hillslope profile or at the level of a small watershed. In addition to the erosion components, it also includes a climate component which uses a stochastic generator to provide daily weather information, a hydrology component, a daily water balance component, a plant growth and residue decomposition component, and an irrigation component. The WEPP model computes spatial and temporal distributions of soil loss and deposition, and provides explicit estimates of when and where in a watershed or on a hillslope that erosion is occurring so that conservation measures can be selected to most effectively control soil loss and sediment yield (Flanagan and Nearing, 1995).

The overall package contains three computer models: a profile version, a watershed version and a grid version. The profile version estimates soil detachment and deposition along a hillslope profile and the net total soil loss from the end of the slope. It can be applied to areas up to about 260 ha in size. The watershed and grid versions allow estimations of net soil loss and deposition over small catchments and can deal with ephemeral gullies formed along the valley floor. The models take account of climate, soils, topography, management and supporting conservation practices (WEPP Software, 2004). They are designed to run on a continuous simulation but can be operated for a single storm. A separate model, CLIGEN, is used to generate the climatic data on rainfall, temperature, solar radiation and wind speed for any location in the USA for input to WEPP (CLIGEN Weather Generator, 2004). All the datasets needed for running WEPP summarized in Table 2.1.

Table 2.1 WEPP model data input requirements.

Input File	**Data Needs**
Climate File *(hillslope and watershed components)*	Meteorology Data, Precipitation, Wind, Temperature, Dew Point
Slope File	Overland Flow Elements (OFE), Hillside Length, Width, Slope
Soil File *(one for each OFE and channel)*	Soil Type, Texture, Porosity, Conductivity, organic matter (OM), cation exchange capacity (CEC), Albedo, Number and Depth of Soil Layers
Plant/Management File *(one for each OFE and channel)*	Plant Types, Characteristics, Growth Parameters, Management Practices
Watershed Structure File	Describes Watershed Configuration
Watershed Channel File	Characteristics of Channel, Shape, Depth, Erodibility, Hydraulic Parameters
Impoundment File	Characteristics of Impoundment and Outlets

The Geo-spatial interface for the WEPP model (GeoWEPP) ArcX software uses the Geographic Information System (GIS) ArcView software and its Spatial Analyst Extension - both developed by the Environmental Systems Research Institute (ESRI) - as a platform to apply the erosion prediction model (WEPP) and the Windows interface (WEPPWIN) with geospatial datasets for topography (Digital Elevation Model). The interface accesses databases, organizes WEPP simulations, creates all necessary input files for WEPP. The current version of GeoWEPP only allows assessments of small watersheds (<500 hectares) and only the dominant land use and soil for each subcatchment as well as for each flowpath to a channel (GeoWEPP Software, 2004).

Shortly WEPP,

- is process based,
- computes sheet - rill erosion from rainfall,
- computes average annual soil loss of the landscape,
- estimates erosion in detail due to climate, soil, topography and land use,
- is planning and assessment tool,
- Grid version of WEPP allows computations over a field.

2.2.2. EPIC – Erosion Productivity Impact Calculator

The EPIC model was developed to assess the effect of soil erosion on soil productivity. Since its initial design, the model has been expanded and refined to allow simulation of many processes in agricultural management. EPIC is a continuous simulation model that can be used to determine the effect of management strategies on agricultural production and soil and water resources. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, plant growth, soil temperature, tillage, economics, and plant environment control. The model is large and requires significant computer resources (EPIC, 2004).

In the calculations for surface runoff, runoff volume is estimated by using a modification of the Soil Conservation Service (SCS) curve number technique. There are two options for estimating the peak runoff rate; namely the modified Rational formula and the SCS TR-55 method. The EPIC percolation component uses a storage routing technique to simulate flow through soil layers. When soil water content exceeds field capacity the water flows for the soil layer. The reduction in soil water is simulated by a derived routing equation. Lateral subsurface flow is calculated simultaneously with percolation. The evapotranspiration is calculated in four ways. EPIC uses the following methods: Hargreaves and Samani, Penman, Priestley-Taylor, and Penman-Monteith. The water table height is simulated without direct linkage to other soil water processes in the root zone to allow for offsite water effects. EPIC drives the water table up and down between input values of maximum and minimum depths from the surface (Williams, 1994).

The EPIC precipitation model developed by Nicks is a first-order Markov chain model. Temperature and radiation are simulated in EPIC by using a model developed by Richardson. The EPIC wind erosion model, WECS, (Wind Erosion Continuous Simulation) is used to calculate wind characteristics including erosion due to the wind. The relative humidity model simulates daily average relative humidity from the monthly average by using a triangular distribution (Sharpley and Williams, 1990).

To simulate rainfall/runoff erosion, EPIC used six equations; the USLE, the Onstad-Foster modification of the USLE, the MUSLE, two variations of MUSLE, and a MUSLE structure that accepts input coefficients. The six equations are identical except for their energy components. Contaminants, such as nitrogen and phosphorus are used in the EPIC model. EPIC simulates the following processes involving contamination: nitrate losses, contaminant transport due soil water evaporation, organic nitrogen transport due to sediment, denitrification, mineralization, immobilization, nitrification, volatilization, soluble phosphorus loss in surface runoff, and mineral phosphorus cycling (Williams, 1994).

One drawback of this model is that it does not model the subsurface flow of the watershed. There is also no mention of how the model would deal with tile drains. The model does meet the majority of the project criteria. However, the model does not simulate sediment routing in great detail. The EPIC model does analyze effects of agricultural process and it can simulate the fate of agricultural pesticides.

Shortly EPIC,

- calculates the loss of crop yield from erosion,
- more detailed except for erosion component,
- operates on individual storms,
- emphasizes the impact of erosion on change in soil type and its impact on productivity,
- is not intended for day-to-day field operations,
- is a continuous simulation model,
- requires more detailed inputs,
- applies to a point on the landscape and thus does not consider sediment transport, deposition or concentrated flow erosion.

2.2.3. ANSWERS - Areal Nonpoint Source Watershed Environment Response Simulation

ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) model was developed by Beasley et al. (1980) in the late 1970s. The model was based on one of the first true distributed parameter hydrologic models. The original ANSWERS was a distributed parameter, event-oriented, planning model developed to evaluate the effects of best management practices (BMPs) on surface runoff and sediment loss from agricultural watersheds. ANSWERS subdivides the watershed into a uniform grid of square cells. Land use, slopes, soil properties, nutrients, crops, and management practices are assumed uniform within each cell. Differences between cells allow the model to consider the heterogeneous nature of watersheds and the site specific effectiveness of individual BMPs. Typical cell sizes range from 0.4 to 1 ha with smaller cells providing more accurate simulations. Ten to twelve parameter values must be provided for each homogeneous cell. Within each cell, the model simulates interception, surface retention/detention, infiltration, surface runoff, percolation through the infiltration control zone, sediment detachment and sediment transport. Flow was from routed downslope to adjacent overland flow cells or in channel cells. The model could simulate BMPs such as conservation tillage, ponds, grassed waterways, tile drainage (Bottcher et al., 1981) and other practices whose effects on the physically based model input parameters could be described. An original weakness of the ANSWERS model was its erosion model, which was largely empirical and simulated only gross sediment transport. The model was modified in the early 1980s to simulate the particle size distribution of eroded sediment (Dillaha and Beasley, 1983) and to estimate sediment transport. Rewerts and Engel (1991) developed GIS interfaces for this version of the model. In the mid 1980s, phosphorus (Storm et al., 1988) and nitrogen (Dillaha et al., 1982) transport versions of the event-oriented model were developed. They considered the transport of dissolved and adsorbed orthophosphorus, nitrate and dissolved and adsorbed ammonium and total ammonia plus organic nitrogen (TKN).

The current version of the model, ANSWERS-2000, is a continuous simulation model that was developed in the mid 1990s (Bouraoui and Dillaha, 1996). In this version, the nutrient submodels were overhauled and improved infiltration, soil moisture and plant growth components were added to permit long-term continuous simulation. ANSWERS-2000 simulates transformations and interactions between four nitrogen pools including stable organic N, active organic N, nitrate and ammonium. Transformations of nitrogen include mineralization simulated as a combination of ammonification and nitrification, denitrification, and plant uptake of ammonium and nitrate. The model maintains a dynamic equilibrium between stable and active organic N pools. Four phosphorus pools are simulated: stable mineral P, active mineral P, soil organic P and labile P.

Equilibrium is maintained between stable and active mineral P and between active mineral P and labile P. Plant uptake of labile P and mineralization of organic P are also simulated.

Ease of use is an important component of any model. For this reason "Questions" was developed for ANSWERS-2000. A question is a user-friendly interface to ANSWERS-2000, a Fortran-based, nonpoint source model. Questions currently run on the Windows platform using Visual Basic 6.0, ArcView GIS 3.2, and Map Objects 2.0 (Questions, 2004).

Shortly ANSWERS,

- is watershed planning tool for erosion modeling and sediment yield control on complex watersheds,
- is water quality analysis associated with sediment associated chemicals,
- is process based,
- is event based,
- has grid topography representation,
- is primarily limited to single storm,
- has limited capability for concentrated flow erosion,
- is a fully dynamic model.

2.2.4. Model Summaries

In this chapter empirical-based and physically-based erosion models are evaluated and their characteristics are summarized in Table 2.2 according to different scales. Only USLE is used for erosion modeling but the others can be used for other environmental problems as listed in Table 2.3.

Table 2.2 Model characteristics.

Model		**USLE**	**WEPP**	**EPIC**	**ANSWERS**
Time scale	*Event*		✔		✔
	Continuous	✔	✔	✔	✔
Spatial scale	*Point*				
	Field/Farm	✔	✔	✔	✔
	Watershed				✔
	Regional				
Computational time steps	*Second*				✔
	Hour			✔	
	Day	✔	✔	✔	
	Year				

Table 2.3 Processes simulated.

Model		**USLE**	**WEPP**	**EPIC**	**ANSWERS**
Surface water flow/Runoff				✔	✔
Surface water flow				✔	
Chemical transport	*Nutrients*			✔	✔
	Pesticides			✔	
Erosion		✔	✔	✔	✔
Precipitation			✔	✔	✔
Snowmelt				✔	
Lake/stream water quality					

Due to its modest data demands and transparent model structure the Universal Soil Loss Equation (USLE) remains the most popular tool for water erosion hazard assessment and this is the main factor for this study why USLE is selected. However, the model has a shortcoming, which is likely to have prominent implications for the model results. The mathematical form of USLE, the multiplication of six factors, easily leads to large errors whenever one of the input data is misspecified. These miscalculations raise questions about its mathematical model structure and the robustness of parameters that are implicitly assigned to the model. In this study we aimed to minimize miscalculations especially for topographic factor by evaluating various sub models.

Erosion is the outcome of many different interacting factors, data upon that are available from different sources and systems. The erosion process and its patterns can be studied in an integrated manner by using the multi-disciplinary expertise combined with the information on the particular properties of the location (Adinarayana et al., 1998).

Such a site specific systems-approach model for assessing soil erosion was designed by Adinarayana et al. (1998). The different data sources were integrated in a raster-based GIS. GIS was used as the base for an analysis module to integrate and process information applying fuzzy logic and using knowledge based rules. In the implementation of the fuzzy rules, the multi-disciplinary and heuristic estimated opinion from experts concerning the field parameters were taken into consideration, as well as the author's expertise in soils, land-use planning, remote sensing and GIS (Adinarayana et al., 1998, Skidmore, 1982).

Real world situations are very often not crisp and deterministic, hence impeding precise description. Likewise, certain indicators of soil erosion cannot be measured quantitatively. Compared to crisp classification, fuzzification of model parameters reduces the distance between the real world and the data world.

CHAPTER 3

STUDY AREA AND DATA PREPARATION

Çamlı Dam project has not been completed since 1984. The project was not found feasible twenty years ago. With the population increase in Urla and Güzelbahçe regions water demand has also been increased from the middle of 90's. Preliminary design of Çamlı Dam was prepared by Temelsu in 1997. In 1998, State Water Works (SWW) gave both construction and operation licenses to General Directorate of İzmir Sewerage and Water Administration (GDISW). İzmir Chamber of Commerce (ICC) claims for the construction of Çamlı Dam as soon as possible (ICC, 2003). Construction of Çamlı Dam would not be tendered by GDISW up to 2003 and SWW has taken back the license for construction. SWW has programmed the construction of Çamlı Dam; after the construction in 2007, GDISW will operate the dam.

GDISW bought high resolution satellite images at the end of 2004 in order to monitor slum areas in both Tahtalı and Çamlı Dam Watersheds. GDISW thought that these satellite images would be base maps for the watershed information system that is going to be installed (Arkitera, 2004).

Tüprag which is the branch firm of Eurogold that was operating Bergama Gold Mining Complex got the license from Ministry of Energy and Natural Resources in 1999 in order to set up gold mining complex in Efem Çukuru that is located in Kocadere Creek Watershed. SWW let Tüprag set up the complex and operate up to the construction of Çamlı Dam. GDISW stands against this permission and explained that this gold mining complex would change the topography, erosion would occur and also water balance in the watershed would be broken. In 2002, according to the report of GDISW this complex is located on long distance protection zone and would not be settled up. Expected lifetime of the gold mine with the reserve of 18 ton in Efem Çukuru is 8 years. Some persons of İzmir prosecuted Tüprag in order to keep water resources of İzmir and the court decided to stop the execution. It seems that the danger is stopped at least for today (Tıp Dünyası, 2005).

Çamlı Dam will irrigate agricultural areas in Kocadere Creek Watershed and also supply water to İzmir. The other aim of the dam is flood protection. Design life time of the project is 50 years (Temelsu, 1997).

3.1. Description of the Study Area

The Kocadere Creek Watershed is an agricultural watershed of 62.7 square km in southwest of İzmir, 30 km away from the city center. The previous potential erosion risk classification results with very strong level (Esengin, 2002). Additionally, there are flood-prone areas in the watershed, which may be exacerbated by channel aggradations and subsequent reductions in flow conveyance. Study area, Kocadere Creek Watershed is displayed on Landsat TM image acquired on 11 May 1987 with red polygon as given in Figure 3.1.

3.2. Description and Preparation of Data Layers

Some of datasets used in this study obtained from Esengin (2002). Used datasets from his study are raw DEM, forest map, soil map and climatic data (rainfall and temperature). The others are Landsat images, digital contour maps and aerial photographs that do not cover the whole area. All data layers are transformed into UTM-35N projection and ED-50 datum.

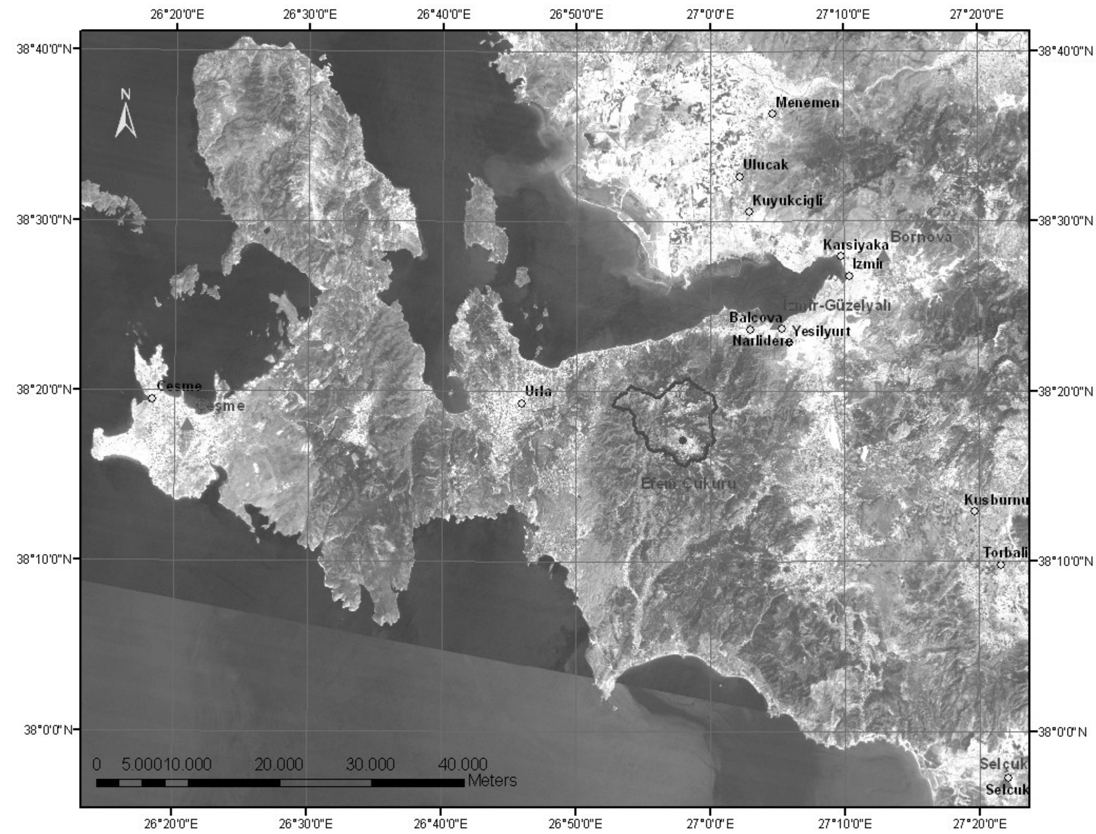


Figure 3.1 Study region (red triangles represent meteorological stations).

3.2.1. Rainfall Erosivity Map

Rainfall erosivity index is calculated from the annual summation of rainfall energy (E) in every storm (correlated with raindrop size) times its maximum 30 - minute intensity (I_{30}). As expected, it varies geographically. This index can be calculated by using Eq. (3.1). Kinetic energy of the rainstorm, E is in *J/m²* and I_{30} is in *mm/h*.

$$R = \frac{EI_{30}}{1000} \tag{3.1}$$

There is no meteorological station inside the study region. Annual maximum 30 minute precipitation values were purchased from National Meteorological Service for the nearest meteorological stations to the region, which are Çeşme, Selçuk, Bornova and İzmir-Güzelyalı. $I_{30,max}$ values were interpolated by using Inverse Distance Weighted (IDW) method for the years between 1966-2000. Year of 1979 has maximum values for the region. $I_{30,max}$ values for the stations were selected as 1985 for Bornova, 1978 for Çeşme, 1979 for İzmir-Güzelyalı and 1966 for Selçuk. These maximum values were interpolated by using IDW as the worst case scenario tabulated in Table 3.1. This resulting precipitation layer was transformed into uniform intensity using Eq. (3.2).

$$I = \frac{h*60}{t} \quad (3.2)$$

Where;

I: Rainfall intensity (cm/hr)

h: Depth of precipitation (cm)

t: Duration of precipitation (min)

Unit kinetic energy and kinetic energy values were calculated by using Eqs. (3.3) and (3.4).

$$E_U = 210.3 + 89 * \log I \quad (3.3)$$

Where;

E_U: Unit kinetic energy (ton-m/ha/cm)

I: Rainfall intensity (cm/hr)

$$E = E_U * h \quad (3.4)$$

Where;

E: Total kinetic energy (ton-m/ha)

E_U: Unit kinetic energy (ton-m/ha/cm)

h: Depth of precipitation (cm)

Table 3.1 Interpolated precipitation values for the region.

Year	Min	Max	Mean	Median	Mode	Std. Dev.
1966	30.858	32.204	31.584	31.584	31.626	0.280
1967	15.763	16.124	15.926	15.911	15.858	0.085
1968	15.809	16.748	16.210	16.165	16.044	0.215
1969	13.812	14.550	14.162	14.172	14.273	0.173
1970	11.054	12.076	11.605	11.637	11.768	0.248
1971	13.529	14.920	14.148	14.148	14.338	0.300
1972	16.344	16.625	16.441	16.424	16.422	0.055
1973	15.408	16.948	16.150	16.100	15.817	0.341
1974	15.873	16.304	16.118	16.136	16.205	0.103
1975	21.918	22.455	22.265	22.293	22.385	0.114
1976	24.534	26.140	25.257	25.193	24.867	0.392
1977	8.495	10.783	9.773	9.863	10.211	0.538
1978	16.357	19.553	17.805	17.818	18.255	0.688
1979	41.277	46.585	43.527	43.288	42.542	1.298
1980	20.059	20.613	20.441	20.481	20.570	0.130
1981	18.773	20.509	19.585	19.526	19.302	0.415
1982	22.735	24.486	23.698	23.761	23.959	0.414
1983	13.042	13.961	13.508	13.530	13.692	0.208
1984	14.191	15.391	14.753	14.767	14.889	0.273
1985	18.469	19.083	18.864	18.884	18.889	0.111
1986	11.926	12.262	12.101	12.091	12.069	0.064
1987	18.305	19.534	18.706	18.636	18.545	0.243
1988	4.611	6.024	5.254	5.268	5.538	0.314
1989	19.886	22.726	21.069	20.929	20.563	0.679
1990	7.535	7.717	7.612	7.605	7.598	0.037
1991	19.056	20.664	19.837	19.791	19.602	0.353
1992	14.546	15.627	15.048	15.049	15.163	0.227
1993	9.791	12.517	11.320	11.420	11.750	0.662
1994	17.609	18.131	17.841	17.852	17.890	0.097
1995	28.997	33.663	31.219	31.056	30.418	1.084
1996	17.158	17.868	17.527	17.524	17.546	0.146
1997	16.349	17.729	16.990	17.007	17.098	0.319
1998	28.944	31.601	30.116	30.002	29.639	0.612
1999	12.709	13.386	13.072	13.092	13.166	0.166
2000	21.068	22.031	21.596	21.587	21.410	0.212
Worst Case	46.800	49.019	47.666	47.545	47.094	0.539

Finally, erosive potential of rainfall (metric ton-m/ha) is calculated by dividing the product of total kinetic energy (ton-m/ha) with maximum 30 minutes intensity (cm/hr) by 100.

$$EI = \frac{E * I}{100} \tag{3.5}$$

This USLE rainfall erosivity index layer shown in Figure 3.2 was compared with R distribution map of Turkey as a result of Doğan's (1987) studies given in Figure 3.3 and found that the results are close to Doğan's (1987) results.

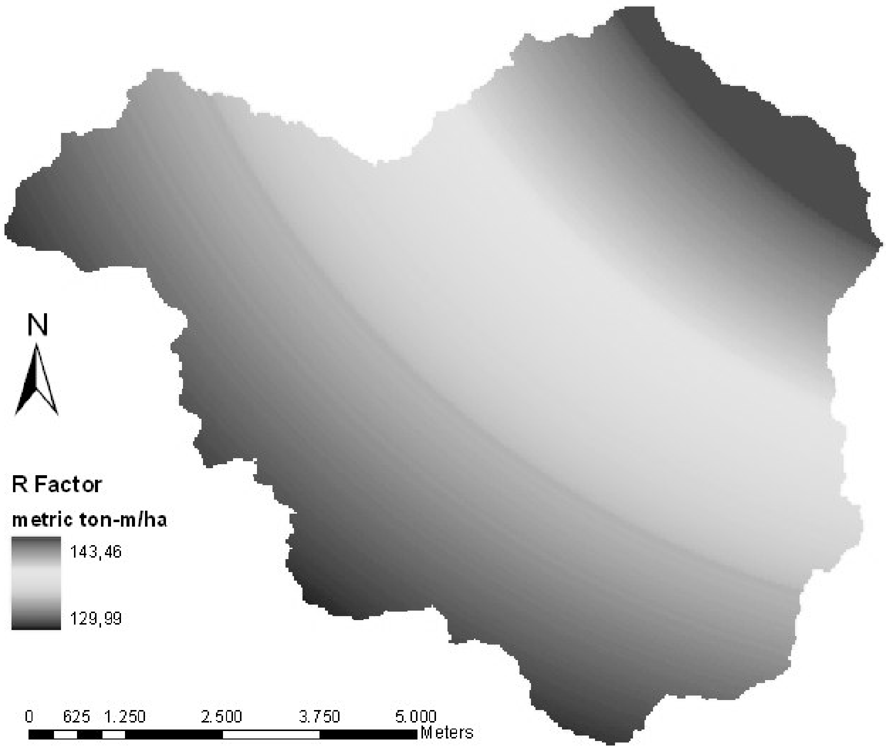


Figure 3.2 R factor distribution map of the region.

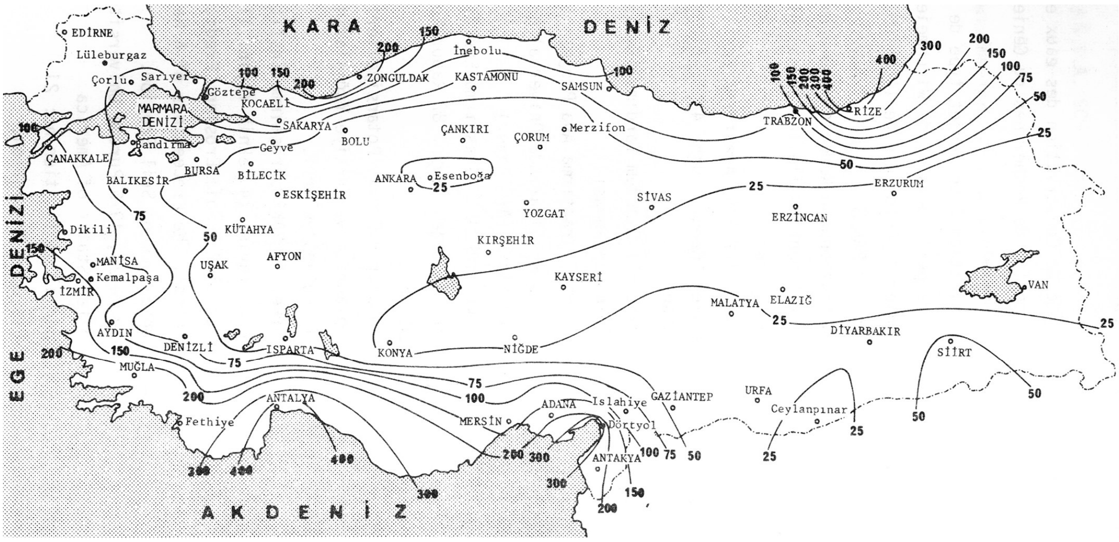


Figure 3.3 R factor distribution map of Turkey (Doğan, 1987).

3.2.2. Soil Map

Great soil groups in soil map form the soil erodibility factors. Soil erodibility factor quantifies the cohesive or bonding character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow. In order to determine this factor accurately, on-site observations and laboratory works should be done. Landuse and erosion class maps were obtained from General Directorate of Village Affairs in digital format. Watershed consists of two 1/25000 scaled soil map frames. These maps were merged and classified according to great soil groups as shown in Figure 3.4.

This classified soil map is reclassified in order to derive USLE's soil erodibility factor, K. In this stage erosion rates were calculated by using TURTEM (Turkey Erosion Estimation Model) (Özden and Özden, 1997). TURTEM is the project name that was developed by General Directorate of Village Affairs for determining erosion rates by using laboratory analysis results on USLE. The resulting K factor map is shown in Figure 3.5.

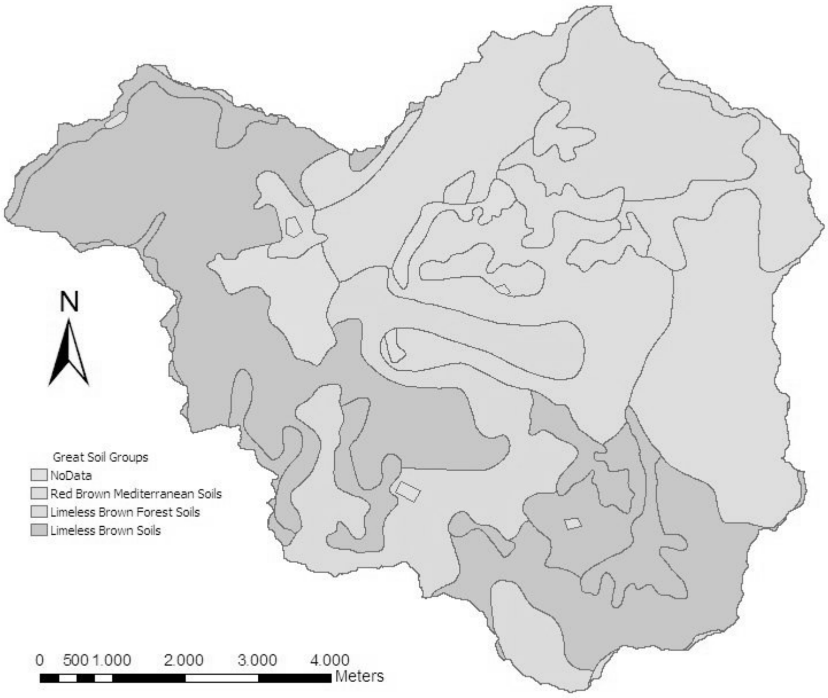


Figure 3.4 Soil map, classified according to great soil groups.

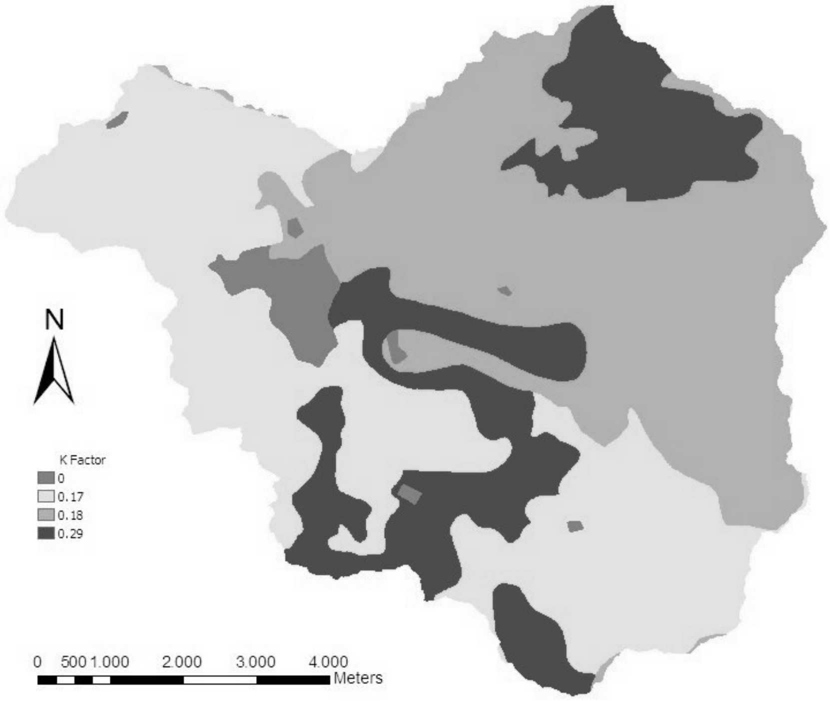


Figure 3.5 Soil erodibility map, K-factors for the region.

There are grey colored null valued soil polygons obtained from General Directorate of Village Affairs in the study area. These null polygons would affect the USLE result. Red colored soil polygons in Figure 3.5 elongate from south west to north east in the eastern part of the watershed. These red polygons have greater K values than the other zones in the region. This condition enhances soil loss rates for these zones.

3.2.3. Topographic Maps

Required data for DEM creation was obtained from Esengin (2002) with scale of 1/25000. Also 1/5000 scaled digital contour maps of the region were obtained from IZSU in DGN format. This dataset has more detail than Esengin's, but needs some processes like scaling, cleaning up, filling up missing elevation values of contour lines, etc. that are time consuming. These processes were performed on Autodesk Land Desktop 2004 in 3D environment. Finally these maps were merged and exported into shp format.

3.2.4. DEM Construction

DEM construction needs the estimation of elevations for each point of the grid. Gaps between the known points must be filled with estimated values to obtain a DEM with the desired resolution. This is where the interpolation process is needed. Kriging was chosen as interpolation method because it accounts for the spatial continuity inherent in the data set. Spatial continuity implies that two points located close together more likely have similar values than two separated points. Kriging differs from the more conventional methods, such as inverse distance to a power that uses a strictly mathematical expression to weight known points and estimate an unknown value. In other words, kriging utilizes the statistical, rather than geometrical, distance between points. Unlike ordinary interpolators, kriging also accounts for clustering of sample values by redistributing weights from neighboring clustered sample values to points farther afield but less redundant (Isaaks and Srivastava, 1989). This process was performed on Surfer software with 2.1 millions of point data. The spatial resolution was selected as 5 m which is feasible for 1/5000 scale. The resulting DEM is visualized on ArcScene and shown in Figure 3.6.

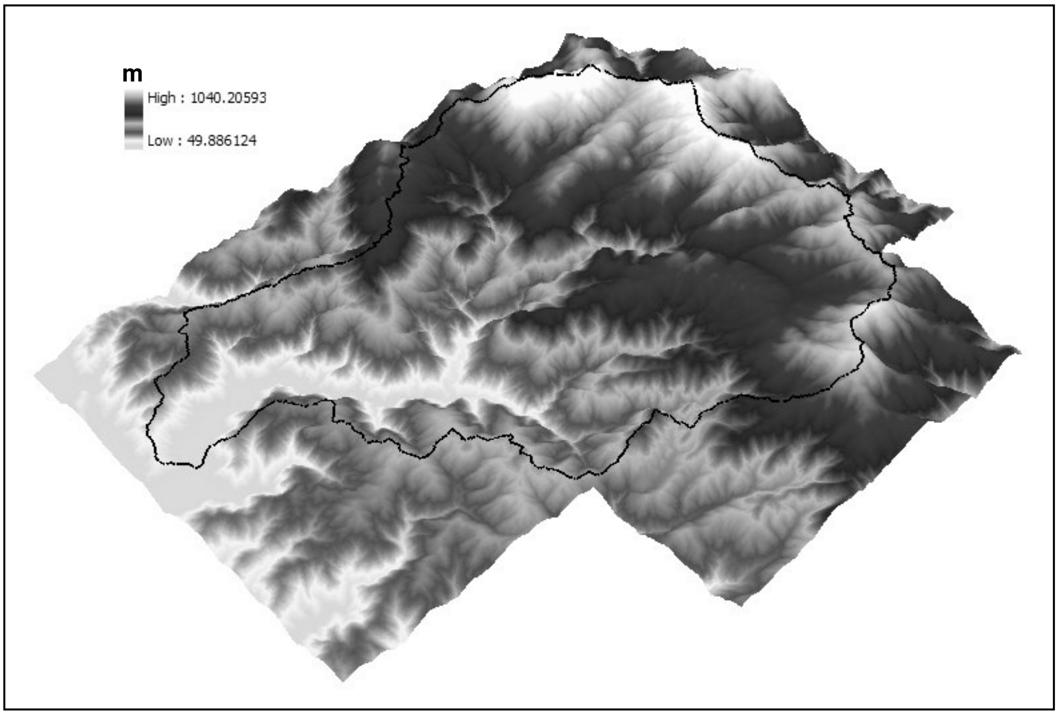


Figure 3.6 Digital Elevation Model (DEM) constructed from 1/5000 scaled maps.

3.2.5. Watershed Geomorphometry

Hypsometric curve which is sometimes called as hypsographic curve is the cumulative elevation frequency curve for the terrain. A hypsometric curve is essentially a graph that shows the proportion of land area that exists at various elevations by plotting relative area against relative height (Britannica, 2005).

In GIS environment this method is based on a vectorization (polygons) of the DEM (elevation values as integers). In vector format it is easy to loop through the features and calculate the area. This curve can be drawn by using Spatial Analyst of ArcGIS. Firstly DEM was clipped with watershed area (calculated by using ArcHydro Tools) and then floating values of cells were converted to integer values by using Raster Calculator of Spatial Analyst extension. The aim for performing this transformation was reducing the amount of cells that have various values; this operation is a simple classification of elevation. This integer valued DEM was converted to shape file through the Spatial Analyst. In order to summarize the area values of polygons with the same elevation values that are distributed over the terrain, shape file was converted to coverage. Summarized area values were exported to a dbf file. This file was manipulated with Microsoft Excel and hypsometric curve of this watershed was created and shown in Figure 3.7. Median value of this curve gives us the mean elevation value of this terrain (577 m).

Main channel was created by using Longest Flow Path command of ArcHydro. Shape file of the longest flow path was converted to 3D and profile was obtained with this 3D shape file by using 3D Analyst. In the attribute table of longest flow path file slope value of the main channel can be found. This value is calculated automatically by ArcHydro with the following Eq. (3.6) and the profile of main channel is shown in Figure 3.8. Plan view of main channel is also shown in Figure 3.9.

$$\textit{Main Channel Slope} = \frac{H_{.85} - H_{.10}}{0.75 * L} \tag{3.6}$$

where;

L: The distance measured along the main channel from the watershed outlet to the end of the channel.

$H_{.85-.10}$: Elevations measured along the main channel at two points located 85% and 10% of the distance along the longest flow path from the outlet.

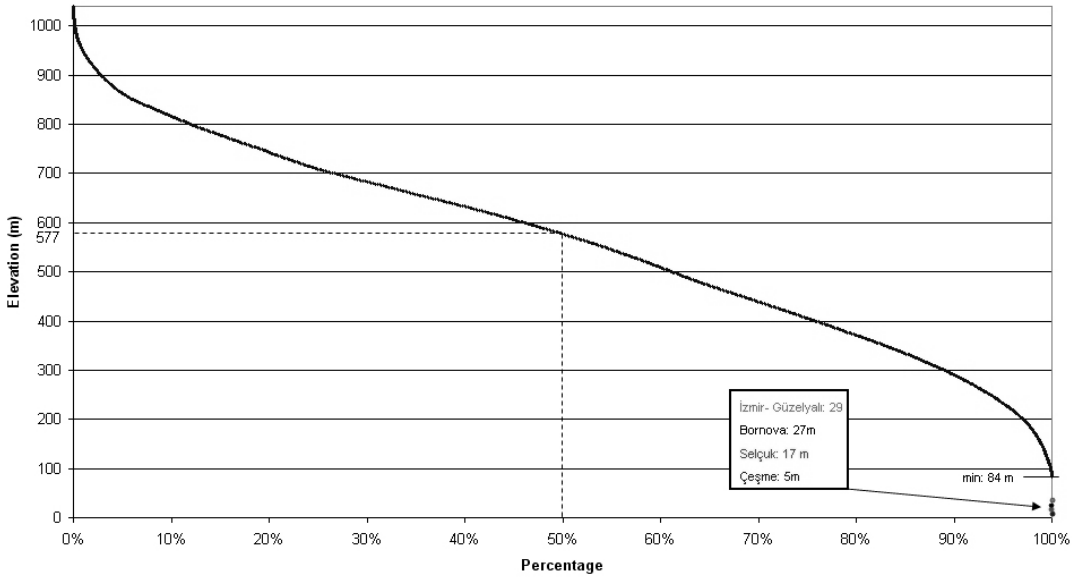


Figure 3.7 Hypsometric curve of the watershed and elevations of meteorological stations.

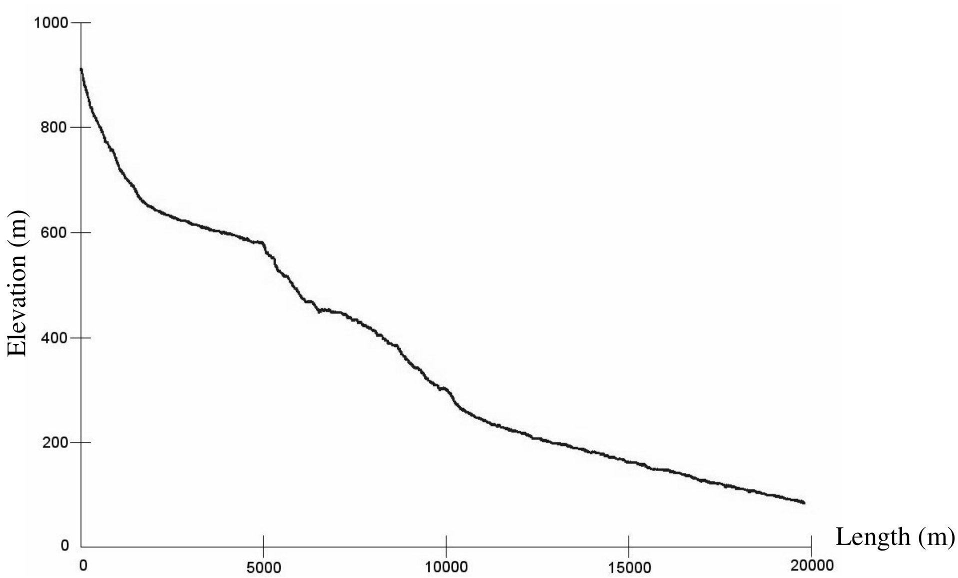


Figure 3.8 Profile of main channel.

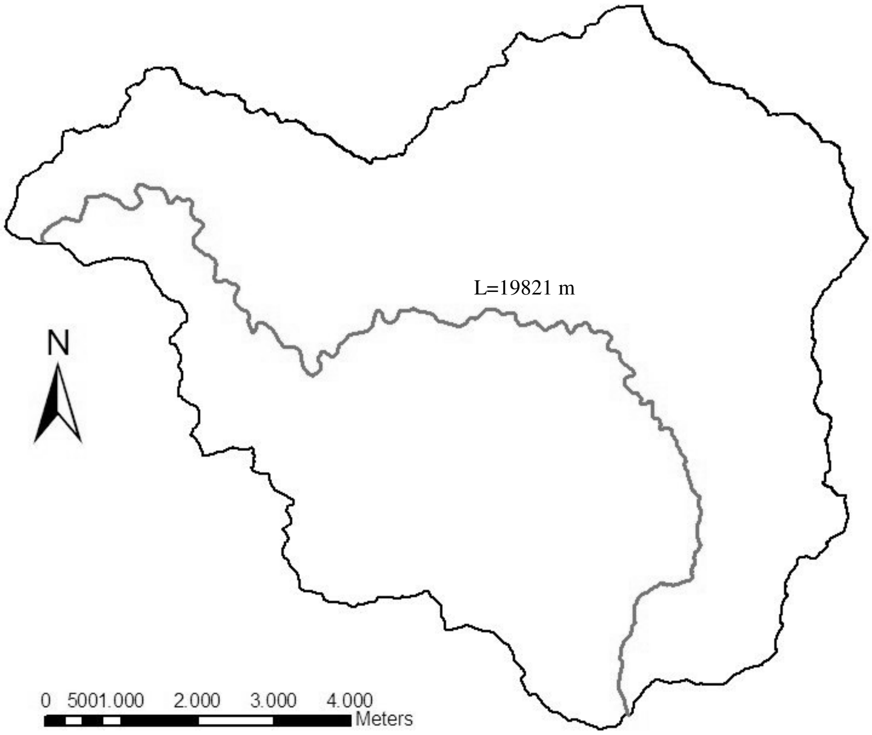


Figure 3.9 Plan view of main channel.

3.2.6. Forest Map

Digital forest map of the study region was obtained from Esengin's (2002) study. This dataset was created by on screen digitizing of hardcopy forest maps of General Directorate of Forestry. This dataset has UTM35N projection in ED50 datum. Thematic forest map is shown in Figure 3.10. Damaged forest zones were colored in gray tones. These areas were masked for further analysis.

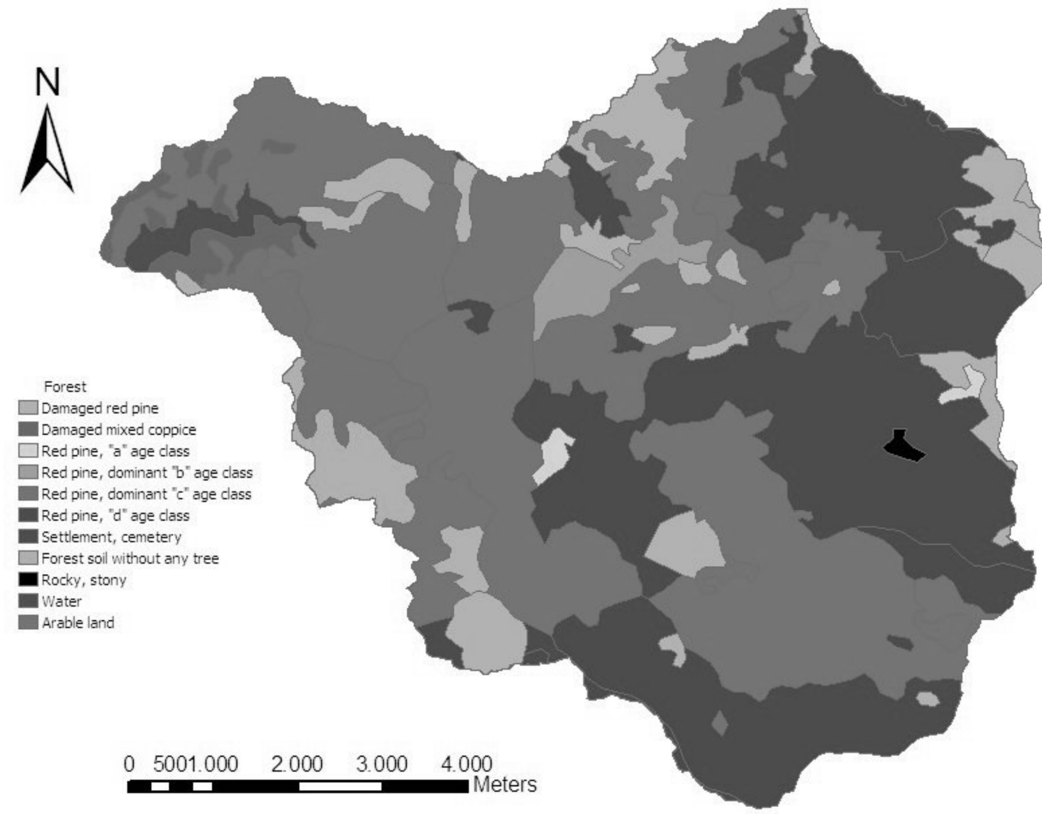


Figure 3.10 Thematic forest map of the study area.

3.2.7. Satellite Images and NDVI Maps

All bands of Landsat TM image acquired on 11 May 1987 and Landsat ETM+ image acquired on 7 June 2000 were downloaded from GLCF (2003). These bands were converted into ERDAS img format and stacked into one file by using Layer Stack command of ERDAS Imagine. NDVI map is also created for further analysis by using built-in function of ERDAS Imagine. NDVI maps are shown in Figure 3.11 and Figure 3.12.

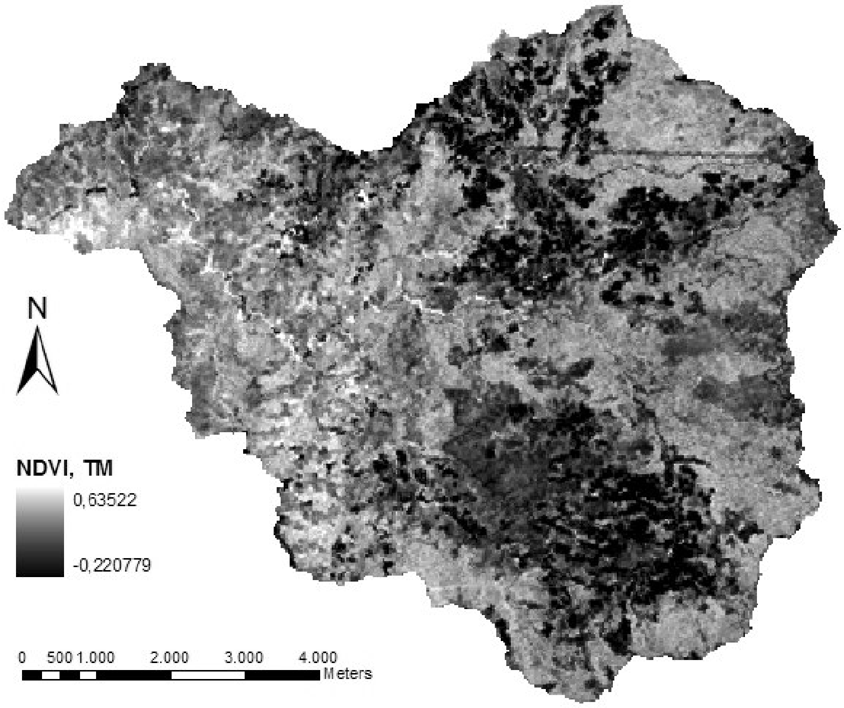


Figure 3.11 NDVI map of Landsat TM imagery (May, 1987) for the study area.

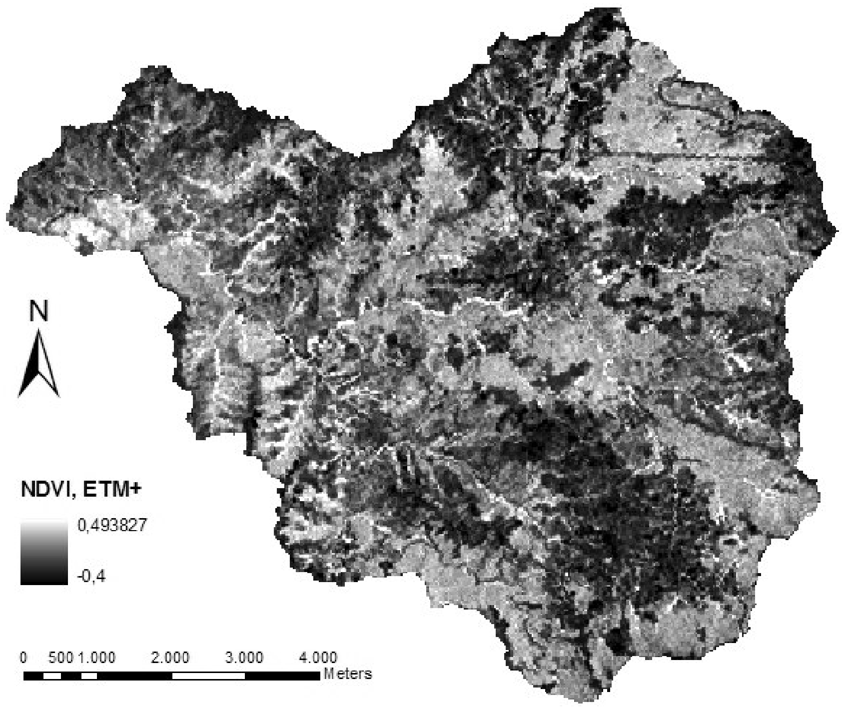


Figure 3.12 NDVI map of Landsat ETM+ imagery (June, 2000) for the study area.

Histograms of these NDVI maps are shown in Figure 3.13 and Figure 3.14.

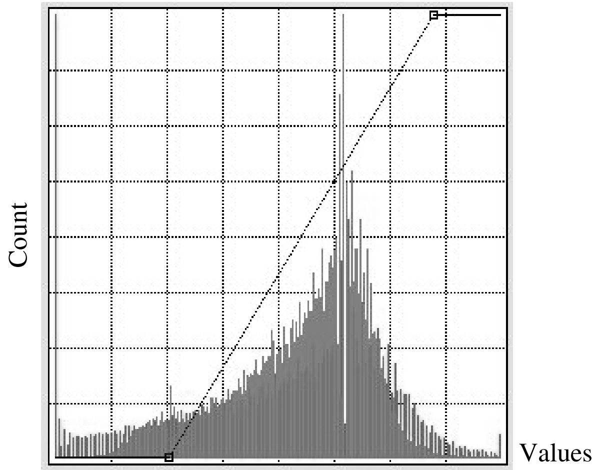


Figure 3.13 NDVI histogram of Landsat TM imagery for the study area (gray colored area).

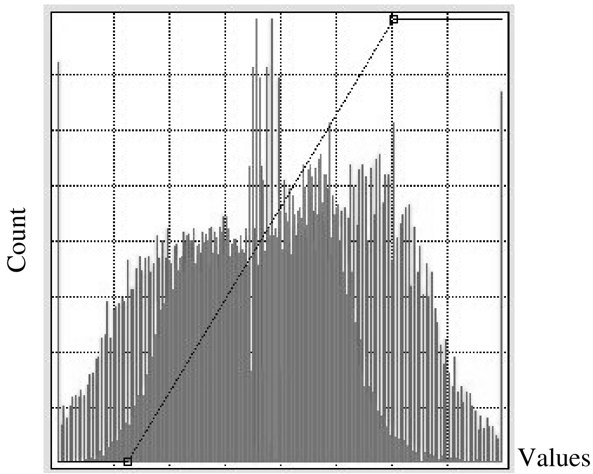


Figure 3.14 NDVI histogram of Landsat ETM+ imagery for the study area (gray colored area).

NDVI value varies between -1 and 1, where low values can be found at water bodies, bare soil and built-up areas. NDVI is positively correlated with the amount of green biomass, so it can be used to give an indication for differences in green vegetation coverage. NDVI-values were scaled to approximate C-values using the following formula, Eq. (3.7), developed by European Soil Bureau:

$$C = e^{-\alpha \frac{NDVI}{\beta - NDVI}} \tag{3.7}$$

where;

α, β : Parameters that determine the shape of the NDVI-C curve. An α-value of 2 and a β-value of 1 seem to give reasonable results (Van der Knijff et al., 1999).

This formula developed on NDVI values derived from AVHRR sensor, but in this study Landsat TM and ETM+ sensor imageries were used to derive NDVI distribution for the study area. NDVI values obtained from these imageries caused C values exceed the maximum value of 1. In order to keep the nature of C factor, NDVI values below 0 was not put into Eq. (3.7), only the positive NDVI values processed and shown in Figure 3.15 and Figure 3.16.

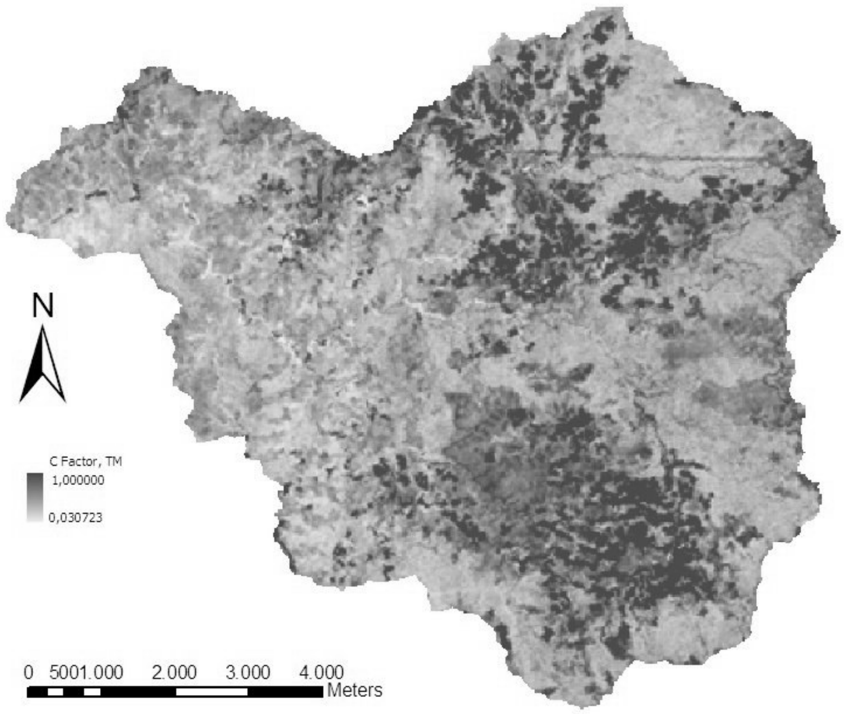


Figure 3.15 C-factor distribution map of Landsat TM for the Study Area (May, 1987).

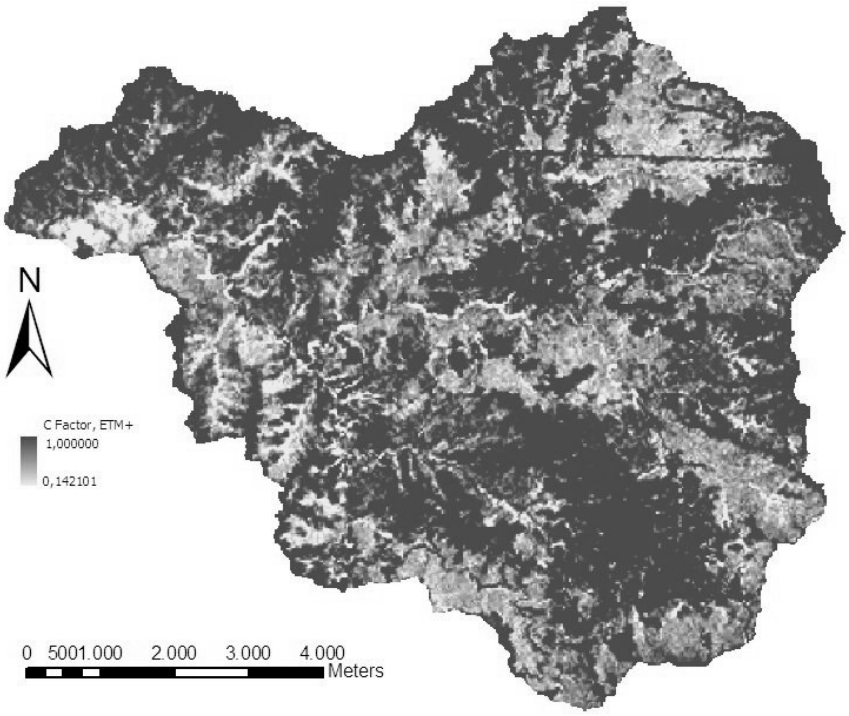


Figure 3.16 C-factor distribution map of Landsat ETM+ for the Study Area (June, 2000).

CHAPTER 4

GRID BASED USLE IMPLEMENTATION

The Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) or the revised version of USLE (RUSLE; Renard et al., 1997) are often used to predict rainfall erosion in landscapes using GIS. Using a grid cell representation of the landscape, and the assumption that each cell is internally uniform with respect to rainfall, soil, crop, aspect and slope gradient, enables the average annual soil erosion for any given cell to be calculated from six factors:

$$A = R\ K\ L\ S\ C\ P \tag{4.1}$$

where R is the long term annual average of the product of event rainfall kinetic energy (E) and the maximum rainfall intensity in 30 minutes (I_{30}), K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the crop and crop management factor and P is the conservation support practice factor. The slope length factor is one of the main factors for soil loss predictions in both RUSLE and USLE. It is also one of the most variable factors dicussed in erosion scientific literature. The slope length factor has been expressed as (Wischmeier and Smith, 1978):

$$L = \left(\frac{\lambda}{22.13} \right)^m \tag{4.2}$$

where λ is the projected horizontal distance in meters between the onset of runoff and the point where runoff enters a channel larger than a rill or deposition occurs and shown in Figure 4.1. In USLE (1978), the m value was recommended as 0.2, 0.3, 0.4 and 0.5 for slope gradients less than 1%, 1-3.5%, 3.5-5%, and 5% or greater, respectively. This means that when slope gradient is greater than 5%, the slope length factor does not change with slope steepness. However in RUSLE, m continues to increase with the slope steepness according to Eqs. (4.3) and (4.4).

$$m = \frac{\beta}{1+\beta} \tag{4.3}$$

$$\beta = \frac{\sin\theta}{0.0896*\left[3.0*(\sin\theta)^{0.8}+0.56\right]} \tag{4.4}$$

Where β is the ratio of rill erosion to interrill erosion, and θ is the slope angle.

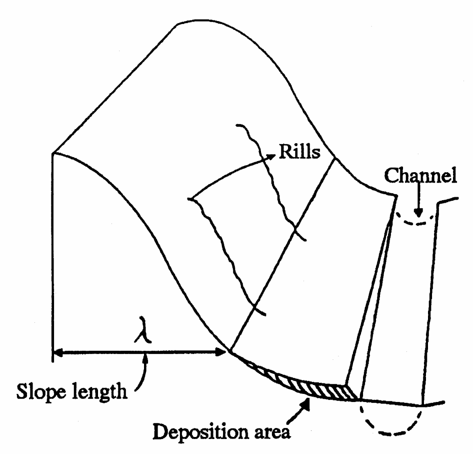


Figure 4.1 Definition of slope length as used in RUSLE (Renard et al., 1987).

When slope increases from 9% to the 60%, the exponent, m, increases from 0.5 to 0.71. According to Eqs. (4.3) and (4.4) the slope length exponent, m, is 0.7 for 50% slope with 60 meters slope length and moderate rill/interrill erosion ratio. These will predict 22% more soil loss than USLE (m=0.5). When slope steepness is equal to 9%, slope length exponent for both USLE and RUSLE is 0.5, and they predict the same soil loss. When slope is less than 9% USLE will predict more soil loss than RUSLE. When slope is steeper than 9%, RUSLE will predict more soil loss than USLE. The greatest difference is on the very steep slopes (The University of Alabama, 2005). That work indicated that USLE greatly indicated over-predicted, and that RUSLE somewhat under-predicted the slope length factor on steep slopes. The slope gradient factor for USLE is expressed as follows:

$$S = 65.4 \sin^2 \theta + 4.56 \sin \theta + 0.0654 \tag{4.5}$$

where θ is the angle to horizontal. The following equations stand for RUSLE; Eq. (4.6) is used for slopes less than 9% and Eq. (4.7) is used for slopes steeper than 9%.

$$S = 10.0 \sin \theta + 0.03 \tag{4.6}$$

$$S = 16.8 \sin \theta - 0.50 \tag{4.7}$$

The L- and S-factors are often frequently lumped into a single term, LS-factor (topographical factor). In modeling erosion in GIS environment, it is common to calculate the LS combination using a formula such as

$$LS = \left(Flow\ Accumulation * \frac{Cell\ Size}{22.13} \right)^{0.4} * \left(\frac{\sin slope}{0.0896} \right)^{1.3} \tag{4.8}$$

where Flow Accumulation is the number of cells contributing to flow into a given cell and Cell Size is the size of the cells being used in the grid based representation of the landscape. This formula is based on the suggestion by Moore and Burch (1986) that was a physical basis to the USLE L and S factor combination. However, approach often used does not produce appropriate values for the LS product for a grid cell. Moore and Burch's (1986) algorithm was executed in ArcGIS environment for the study area. The results for LS are given in Table 4.1 and shown in Figure 4.2.

Table 4.1 LS factor values derived from Moore and Burch's Algorithm.

min	***max***	***mean***	***Std. dev***
0	4598.73	25.12	113.93

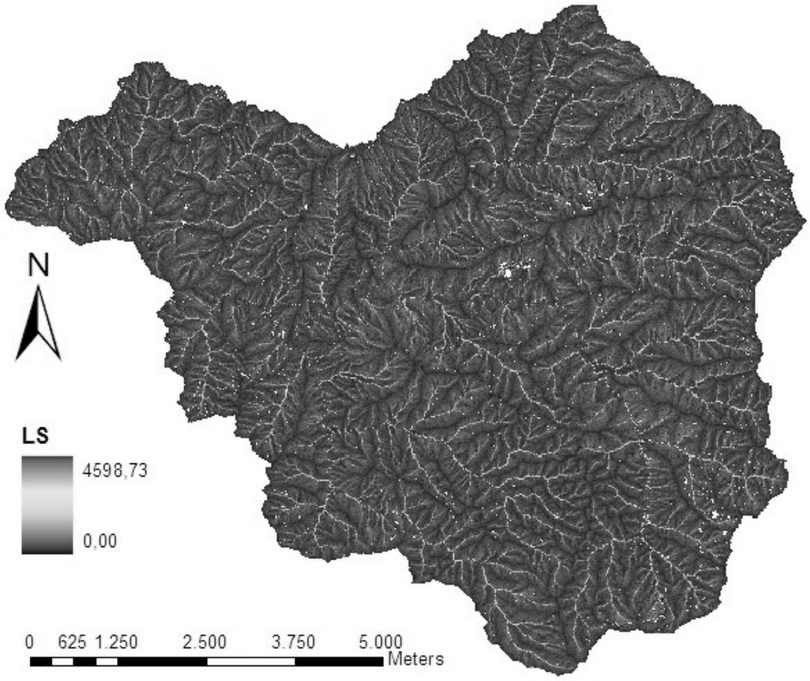


Figure 4.2 LS factor derived from Moore and Burch's Algorithm.

The amount of erosion which is calculated by using the USLE/RUSLE has units of mass per unit area and A value is calculated as the average for the area contributing runoff to the cell being considered. However, erosion is not uniform over space. L for a hillslope area increases with λ so that the L factor values for a cell at the bottom of a hillslope is greater than the average. Eq. (4.9) was developed by Renard et al. (1997) for USLE and RUSLE. The LS value generated by the Eq. (4.7) when the slope gradient is 9% will calculate the L factor value for the hillslope above any given cell assuming that m = 0.4, not the L factor for the cell.

$$L_i = \frac{\lambda_i^{m+1} - \lambda_{i-1}^{m+1}}{(\lambda_i - \lambda_{i-1}) * 22.13^m} \tag{4.9}$$

Desmet and Govers (1996) extended the equation given above to the calculation of grid cell L for non rectangular hillslopes by replacing λ by the contributing area divided by the width of the cell, an approach consistent with Moore and Burch (1986) in the context of L. The resulting equation is Eq. (4.10).

$$L_{i,j} = \frac{\left(A_{i,j-in} + D^2\right)^{m+1} - A_{i,j-in}{}^{m+1}}{D^{m+2} * x_{i,j}{}^{m} * 22.13^{m}} \tag{4.10}$$

where $A_{i,j-in}$ is the area (m^2) contributing runoff to the cell with coordinates i,j and D is cell size (metres), x is a factor that accounts for variations in the width of flow resulting from the orientation of the cell with respect to the contour. In the case where flows exit the cell in one of 8 directions (D8), it has a value of 1.0 when the flow exits over a side and 1.41 when the flow exits over a corner. Both Eqs. (4.9) and (4.10) are based on the assumption that runoff is produced uniformly over the hillslope. However, this is not the case when the hillslope contains a variety of soils and crops. In order to account for non uniformity in runoff production, the effective value of the length of slope or upslope area used in the calculation of the L factor must differ from the physical length of slope or upslope area (Kinnell, 2005).

Ignoring the x factor, the Eq. (4.10) replaces λ_{i-1} by $A_{i,j-in}$ / D and the term λ_i-λ_{i-1} by D. Thus, the formula for determining $L_{i,j}$ could be

UP_{λ} = Flow Accumulation * Cell Size
$SLOPE_{\lambda}$ = UP_{λ} + Cell Size
L = ($SLOPE_{\lambda}{}^{1.4}$ – $UP_{\lambda}{}^{1.4}$) / (Cell Size * $22.13^{0.4}$)
LS = L * (sin slope / 0.0896)$^{1.3}$

It should be noted that this approach will probably give LS values which are too high for steep slopes. The RUSLE approach in determining m and S may be more appropriate.

Moore and Wilson (1992) observed that the product of L and S in the RUSLE could be approximated by Eq. (4.11).

$$LS = \left(\frac{A_S}{22.13}\right)^{0.6} \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{4.11}$$

where A_S is the upslope contributing area divided by the width of the contour that area contributes. The equation considers m = 0.6 and n = 1.3. For erosion at a point, they recommend LS as given in Eq. (4.12).

$$LS = 1.6 * \left(\frac{A_S}{22.13}\right)^{0.6} \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{4.12}$$

This approach tends to overestimate cell LS values if A_S is based on the area contributing to the runoff from the cell, particularly when the contributing area is small.

Traditionally, the best estimates for L are obtained from field measurements, but these are rarely available or practical. Unfortunately, because of the lack of detailed slope length measurements or reliable software algorithms, regional average slope length values are often used – thereby a variable is treated as a constant.

The effects of topography and hydrology on soil loss are characterized by the combined LS factor. Soil loss predictions are more sensitive to slope steepness than slope length. Estimation of the LS factor poses more problems than any of the other factors in the USLE and is a particular problem in applying it to landscapes as part of a GIS (Wilson, 1986; Renard et al., 1991; Moore and Wilson 1992, 1994).

4.1. LS Factor Modified for Complex Terrain

To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area A. The modified equation for computation of the LS factor in GIS in finite difference form for erosion in a grid cell representing a hillslope segment was derived. A simpler, continuous form of equation for computation of the *LS* factor at a point r=(*x,y*) on a hillslope, (Mitasova, 1996) is

$$LS(r) = (m+1)\left[\frac{A(r)}{a_0}\right]^m \left[\frac{\sin b(r)}{b_0}\right]^n \tag{4.13}$$

where A[meter] is upslope contributing area per unit contour width, b [deg] is the slope, m and n are parameters, and a_0 = 22.1m = 72.6ft is the length and b_0 = 0.09 = 9% = 5.16° is the slope of the standard USLE plot. Impact of replacing the slope length by upslope area is that the upslope area better reflects the impact of concentrated flow on increased erosion. The values of m=0.6, n=1.3 give results consistent with the RUSLE LS factor for slope lengths <100 m and slope angles <14°, for slopes with negligible tangential curvature. Exponents, m and n can be calibrated if the data are available for a specific prevailing type of flow and soil conditions.

Both the standard and modified equations can be properly applied only to areas experiencing net erosion**.** Depositional areas should be excluded from the study area because the model assumes that transport capacity exceeds detachment capacity everywhere and erosion and sediment transport is detachment capacity limited. Therefore, direct application of USLE/RUSLE to complex terrain within GIS is rather restricted. The results can also be interpreted as an extreme case with maximum spatial extent of erosion possible. Mitasova's (1996) algorithm is run in ArcGIS environment for the study area. The result for LS is given in Table 4.2 and shown in Figure 4.3.

Table 4.2 LS factor values derived from Mitasova's Algorithm.

m	*n*	*min*	*max*	*mean*	*Std. dev*
0.4	1.0	0	1241.62	8.93	13.47
0.4	1.3	0	2377.88	13.81	19.53
0.4	1.4	0	2952.96	16.03	22.44
0.6	1.0	0	19367.79	20.22	126.92

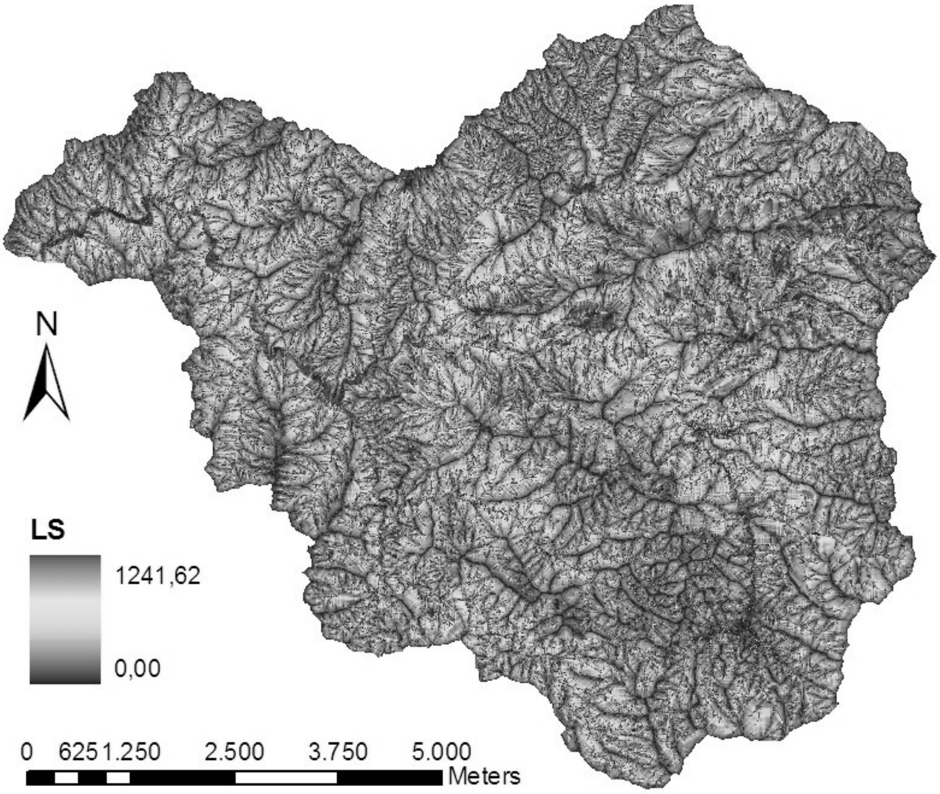


Figure 4.3 LS factor derived from Mitasova’s Algorithm (m=0.4, n=1.0).

4.2. Hickey’s Grid Based Algorithm

Hickey’s (2000) algorithm for calculating the L and S factors is illustrated in Figure 4.4. The first requirement for the algorithm is a depressionless DEM. The reason for this suggestion is when using the maximum downhill slope angle algorithm; depressions will return negative slope values. This will eventually result in negative erosion estimates (deposition). *“AML code is available for ARC/INFO which eliminates all depressions”* (Hickey, 2000).

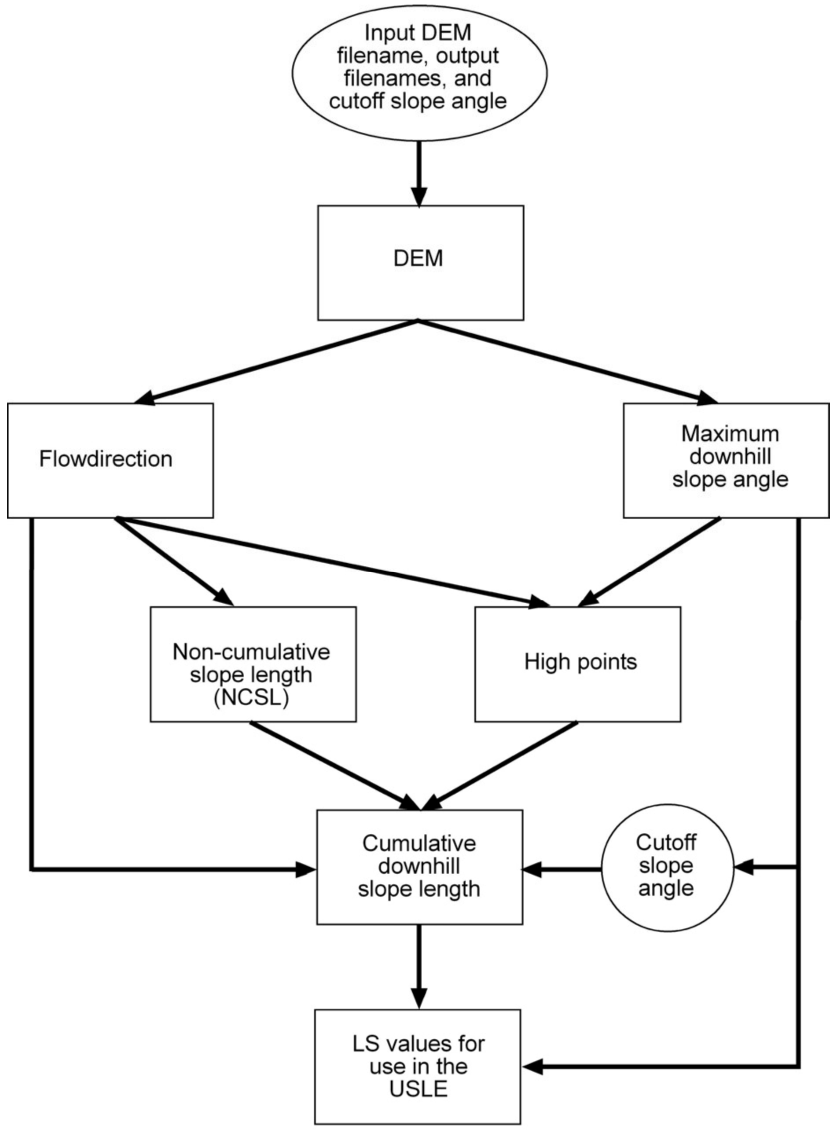
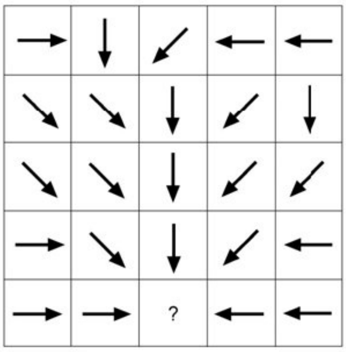


Figure 4.4 Hickey's Grid Based Algorithm (2000).

Example code outputs shown in Figure 4.5 represent the stages of Hickey's algorithm. Figure 4.5a stands for the test DEM with the resolution of 100 meters. Flow direction (aspect) that is calculated from the cell in question downhill along the maximum downhill is shown in Figure 4.5b. The maximum downhill slope angle is shown in Figure 4.5c. Non-cumulative downhill slope length (in meters) is measured from the centre of cell to the centre of the next cell along flow direction and the values are given in Figure 4.5d. This measurement is performed in two dimensional (x,y) space in order to conform to USLE input requirements. Figure 4.5e shows cumulative downhill slope length (in meters) with a cutoff slope of 0.5. The code was re-run using cutoff slope of 0.25 in order to compare effects of different cutoff values. These values are shown in parentheses with a "*".

150	125	125	135	150
125	115	175	130	135
120	110	100	115	120
115	100	90	100	130
105	95	80	90	120

(a)



(b)

14.04	5.71	4.04	5.71	8.53
6.05	6.05	36.87	11.98	8.53
8.05	8.05	5.71	10.02	8.05
8.53	8.05	5.71	8.05	16.70
5.71	8.53	0	5.71	16.70

(c)

50	100	141	100	50
71	141	50	71	50
71	141	100	71	141
50	141	100	141	50
50	100	0	100	50

(d)

50	0 (*150)	291	150	50
71	432	50	71	50
71	212	532	71	191
50	212	632	332	50
50	150	0	0 (*150)	50

(e)

Figure 4.5 Example code outputs from test DEM (Hickey, 2000).

Hickey's AML script was run in ArcInfo Workstation with the cutoff value of 0.5. The result for LS is shown in Figure 4.6.

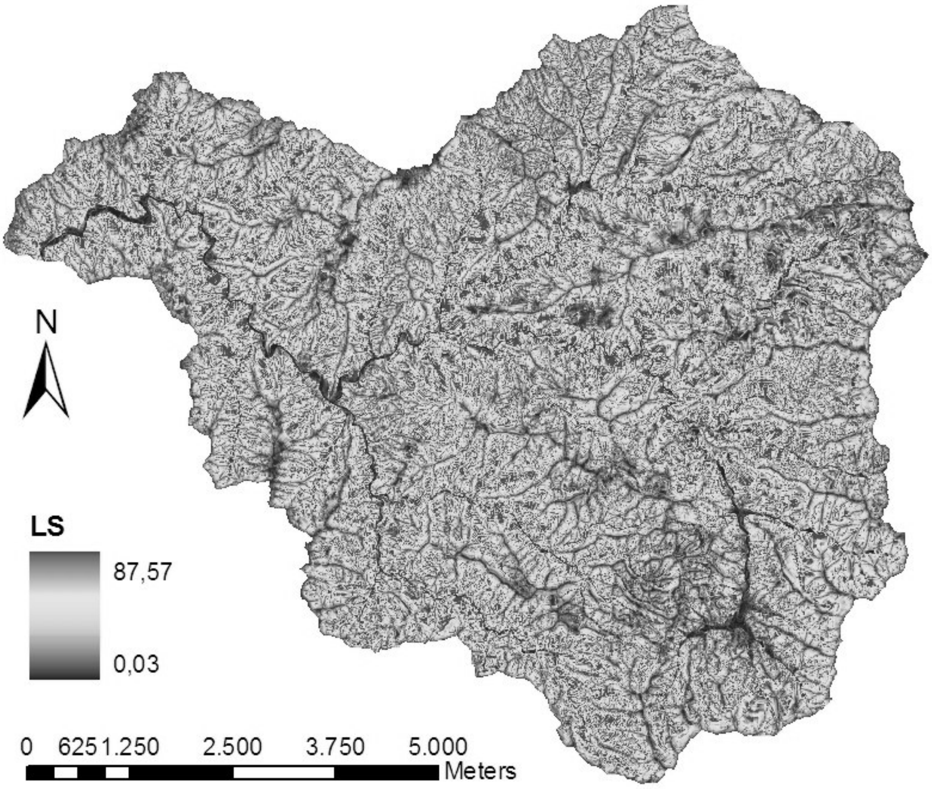


Figure 4.6 LS factor derived from Hickey's Algorithm.

Previously described different LS algorithms are summarized in Table 4.3. Mitasova's (1996) algorithm does not appear to fit into the study area. Results of Moore and Burch's (1986) algorithm are similar to Hickey's (2000) algorithm. Hickey's algorithm is more complex and sophisticated than Moore and Burch's algorithm. Hickey defines slope lengths by using cut off slope angles but Moore and Burch uses constant slope length value, 22.13 m, given by Wischmeier and Smith (1978). This is not an appropriate approach for complex terrains, for this reason, Hickey's algorithm is used for deriving LS factor.

Table 4.3 Comparison table for different LS algorithms.

Algorithm	*m*	*n*	*min*	*max*	*mean*	*Std. dev*
Mitasova	0.4	1.0	0	1241.62	8.93	13.47
Mitasova	0.4	1.3	0	2377.88	13.81	19.53
Mitasova	0.4	1.4	0	2952.96	16.03	22.44
Mitasova	0.6	1.0	0	19367.79	20.22	126.92
Moore&Burch	0.4	1.3	0	4598.73	25.12	113.93
Hickey	-	-	0.03	87.57	8.66	6.60

4.3. USLE Results

Average annual soil losses were calculated by multiplying five factors: R; the erosivity factor, K; the soil erodibility factor; LS, the topographic factor; C, the crop and crop management factor. This multiplication was performed for both C factors derived from Landsat TM (1987) and Landsat ETM+ (2000) NDVI maps. The resulting maps can be seen in Figures 4.7 and 4.8. In these calculations P, the conservation support practice factor was not considered, because there is no conservation work in the region. In the western side of the watershed there is a medium sized area that has no erosion rate. Because, there are some no attribute values (missing data) in the soil data set that was obtained from KHGM. The highest value for map of 1987 that is shown in Figure 4.7 is 2471.9 t/ha/year. This rate increases to 2724.35 t/ha/year for map of 2000 and shown in Figure 4.8. Highest rate (A) values in both maps generally matches with the areas having highest LS values.

USLE results were classified into three zones as low, moderate and high erosion risk classes. Threshold values that were used to classify USLE result of 1987 were used as for 2000 results as well. These constant threshold values helped us to define soil loss change from 1987 to 2000. Histograms of USLE results for 1987 and 2000 are shown in Figure 4.9 and 4.10. As seen in these histograms, selected threshold value for low is between 0 and 14, moderate is between 14 and 200 and the high is over 200. Classified maps are also given in Figure 4.11 and 4.12. Areal values of classes and relative change percentages are summarized in Table 4.4.

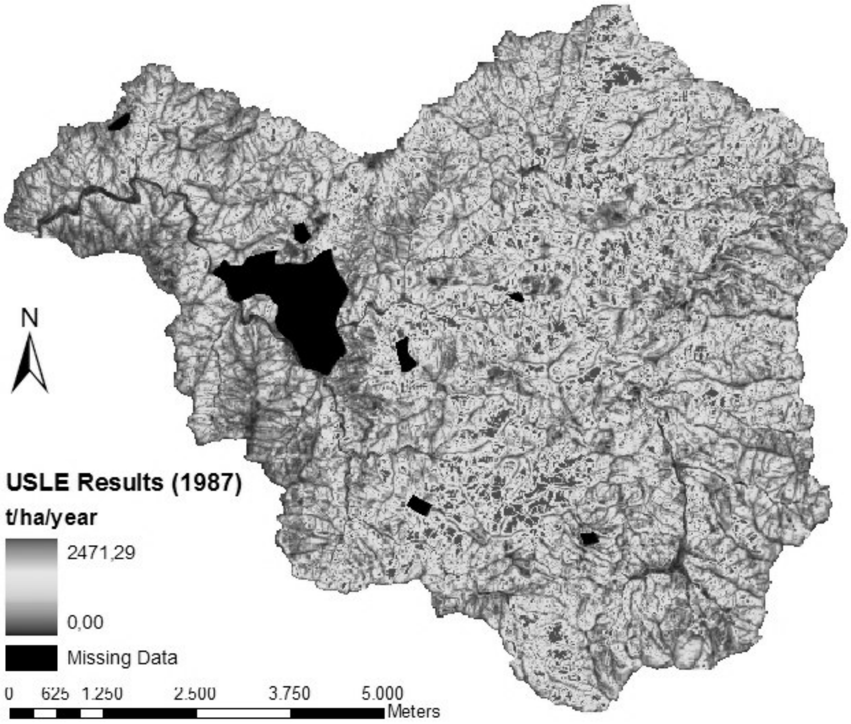


Figure 4.7 USLE results for 1987.

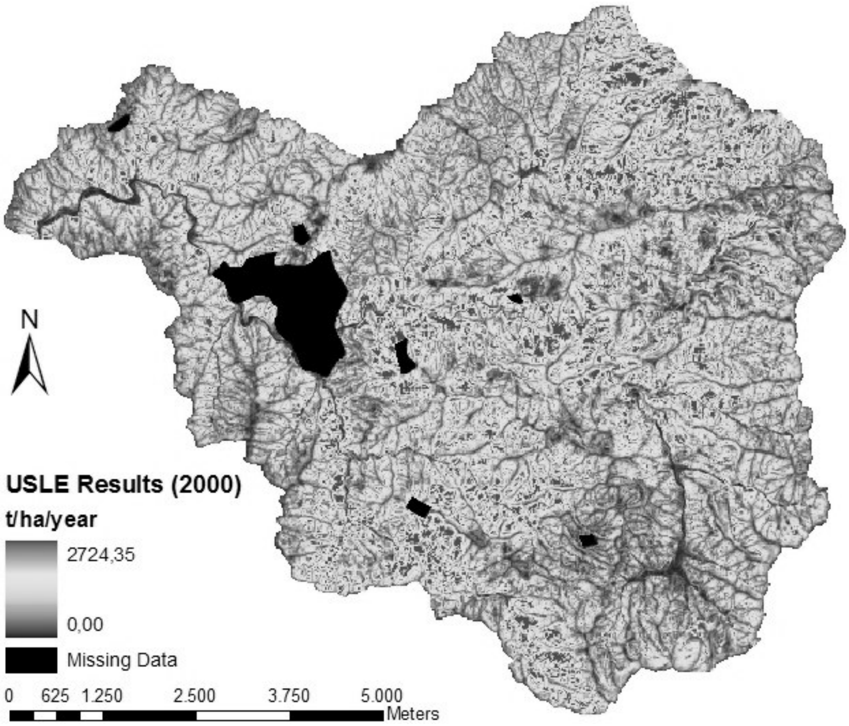


Figure 4.8 USLE results for 2000.

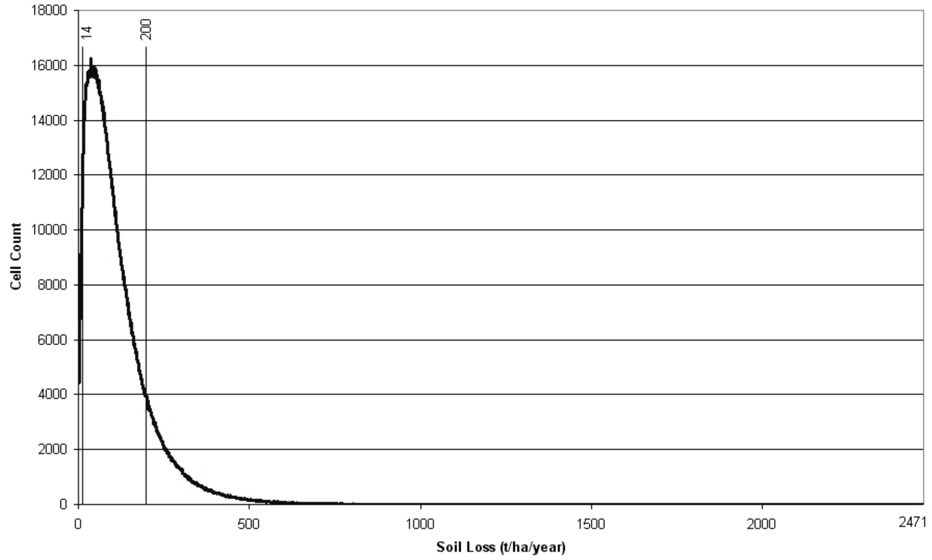


Figure 4.9 USLE results' histogram of 1987.

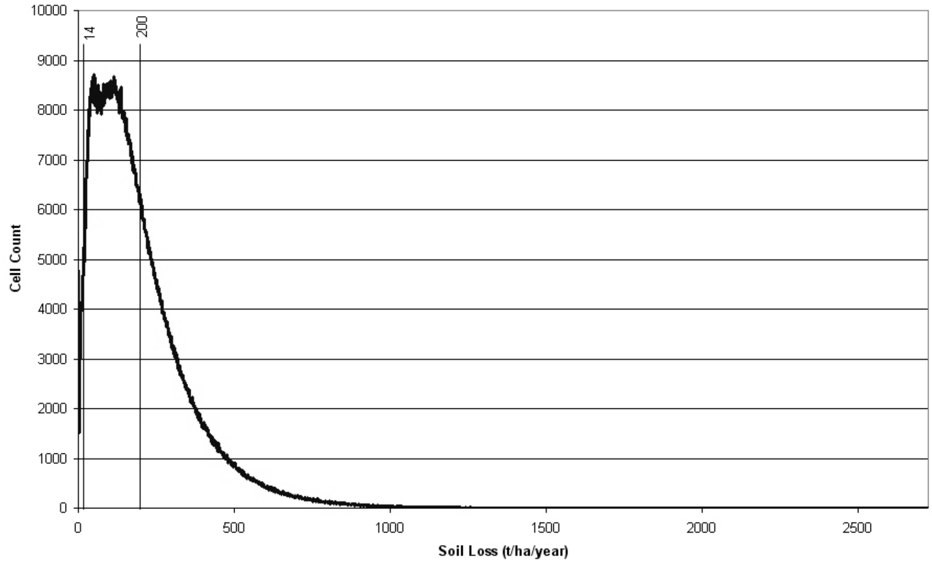


Figure 4.10 USLE results' histogram of 2000.

Table 4.4 Comparison table for USLE results.

Risk Class	***1987***		***2000***		***Change***	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
Low	304.17	5.19	121.89	2.01	-192.74	-61.26
Moderate	4877.86	80.47	3571.93	58.92	-1305.93	-26.77
High	869.35	14.34	2368.02	39.06	1498.67	172.39

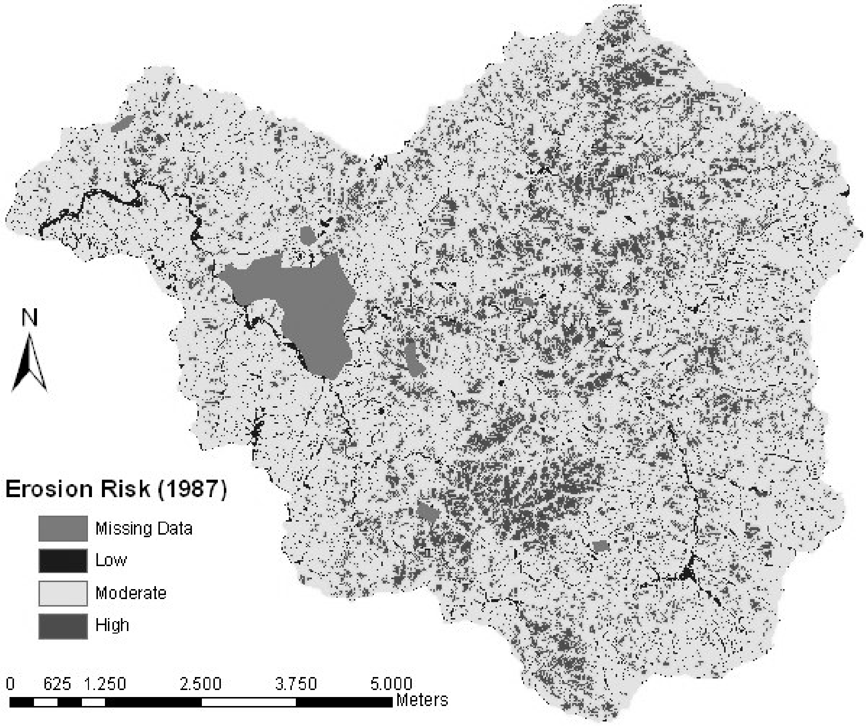


Figure 4.11 Classified USLE results of 1987.

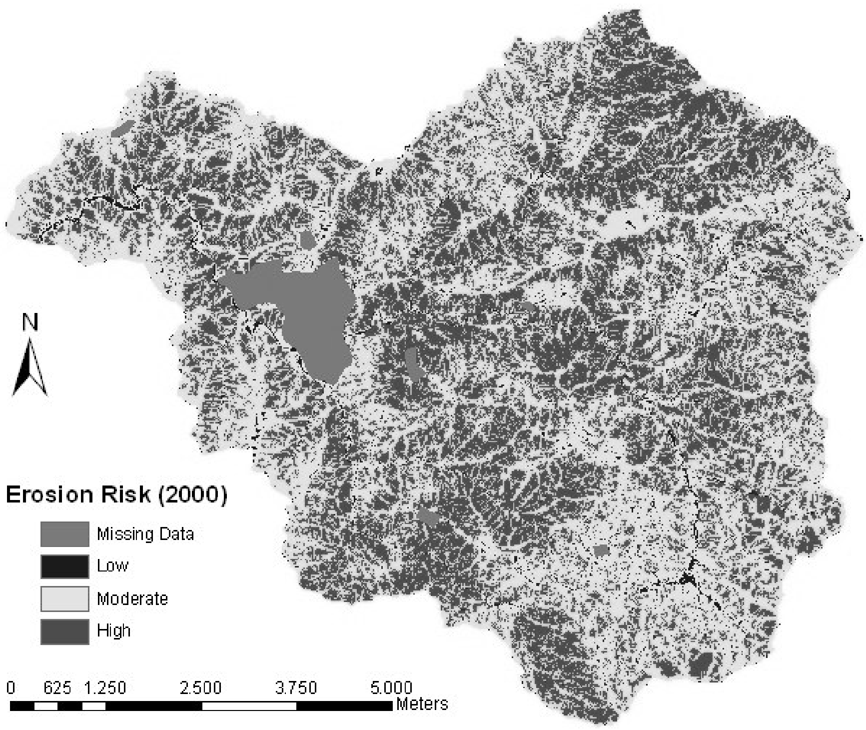


Figure 4.12 Classified USLE results of 2000.

4.4. Fuzzy Classification within GIS

Fuzzy logic provides a powerful and convenient formalism for classifying environmental conditions and for describing nature. Whereas traditional indices are based either on crisp sets with discontinuous boundaries between them, or on continuous variables whose values are only meaningful to experts. Fuzzy sets make it possible to combine these approaches. Conceptually the use of fuzzy logic is simple, but the real power of the methodology comes from the ability to integrate different kinds of observations in a way that permits a good balance between favourable and unfavourable observations. In addition, fuzzy logic can be used to classify and quantify environmental effects of a subjective nature, such as erosion, and it even provides formalism for dealing with missing data. The fuzzy memberships can be used as environmental indices, but it is also possible to "defuzzify" them and obtain a more traditional type of index.

One aspect of the problem of applying fuzzy indices to complex situations is the need to combine different indices representing different impacts. Perhaps the strongest positive feature of fuzzy logic in developing environmental indices is the ability to combine such indices much more flexibly than one can combine discrete measures, which are often simply binary indices corresponding to ordinary ("crisp") sets, such as "acceptable vs. unacceptable" (Zadeh, 1965). For this reason it is important to discuss how to combine different fuzzy indices.

The different fuzzy sets used in classifying environmental effects can be classified as complementary or independent. Complementary sets are ones which describe different ranges of the same properties; examples are pristine vs. polluted, or the sets nil/moderate/serious/extreme impact used in the preceding example from Angel et al. (1998). Independent sets are ones that address different properties, such as "very little seaweed, a few crabs, and thick patchy bacterial mats". A common example is that in describing humans, the sets of "short people" and "tall people" are complementary, but the sets of "short people" and "fat people" are independent. As a special case, any set and its complement are "complementary".

The idea of using fuzzy logic in erosion mapping is to consider the spatial objects on a map as members of a set. For example, the spatial objects could be areas on an evidence map and the set defined as areas susceptible to be eroded. Fuzzy membership values must lie in the range (0,1), but there are no practical constraints on the choice of fuzzy membership values. Values are simply chosen to reflect the degree of membership of a set, based on subjective judgment.

In this stage of the study two sets of fuzzy rule bases with either one or two input variables that dominate soil loss rate in the watershed were used to classify soil erosion prediction. One variable model consisted of LS factor and two variable model consisted of LS and C factors. *"The membership function of a fuzzy set, usually expressed as* $f_A(x)$*, defines how the grade of membership of* x *in* A *is determined"* (Metternicht and Gonzales, 2005). In fuzzy based erosion risk classification studies, it is common to apply membership functions with trapezoidal and gaussian shapes (Sasikala et al., 1996; Mitra et al., 1998), as these shapes seem reasonable, although there is no formal theory that supports these shapes. The most of the mail-lists on fuzzy logic and environment modeling with fuzzy were visited in order to determine how to select the appropriate membership function for a specific phenomenon, one reply is maybe the summary of this web search, *"There is simply no escaping the need for common sense in science"* (Silvert, 2005).

4.4.1. One Variable Fuzzy Classification

Input membership function for LS factor was selected as trapezoidal that consists of three classes; low, moderate, and high. Parameters for these classes were derived from histogram of Hickey's LS algorithm results. Input membership function and parameters are both given in Table 4.5 and Figure 4.13. ArcGIS extension, namely FuzzyCell (Yanar and Akyürek, 2005) was used to implement fuzzy approach in the study.

Table 4.5 Input fuzzy membership function parameters for LS factor.

MF Name	*MF Type*	*Param.1*	*Param.2*	*Param.3*	*Param.4*
Low	Trapezoidal	-1	0	3	4
Medium	Trapezoidal	3	4	13	15
High	Trapezoidal	13	15	100	101

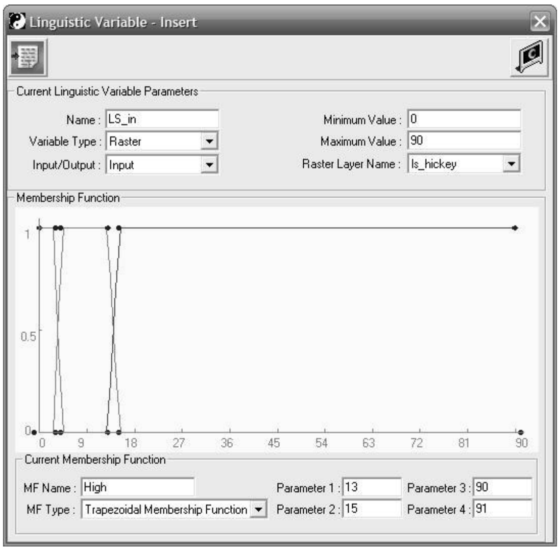


Figure 4.13 Input fuzzy membership function for LS factor.

The fuzzy set for output was defined by a gaussian type membership function, denoting slight, low or severe output values. These classes and the parameters are given in Table 4.6 and Figure 4.14. In all fuzzy implementations fuzzy model was selected as “Mamdani”, implication method was “minimum”, aggregation method was “maximum” and defuzzification type was “smallest of defuzzification”.

Table 4.6 Output fuzzy membership function parameters for LS factor.

MF Name	*MF Type*	*Parameter 1*	*Parameter 2*
Slight	Gaussian	0	20
Moderate	Gaussian	50	20
Severe	Gaussian	100	20

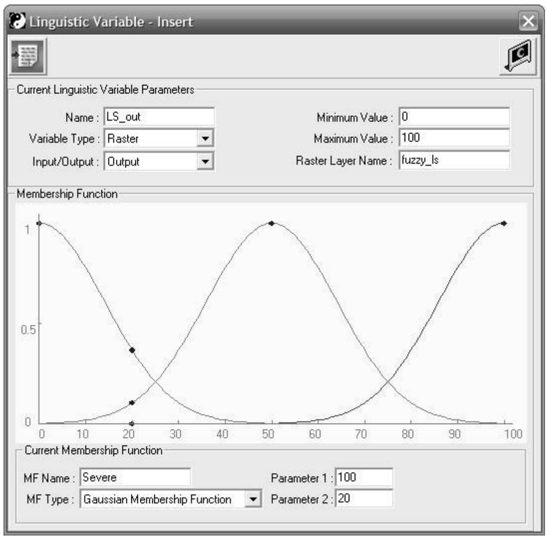


Figure 4.14 Output fuzzy membership function for LS factor.

Threshold values selected for FUZZY-LS for low is between 0 and 30, moderate is between 30 and 70 and the high is over 70. Classified map is given in Figure 4.15.

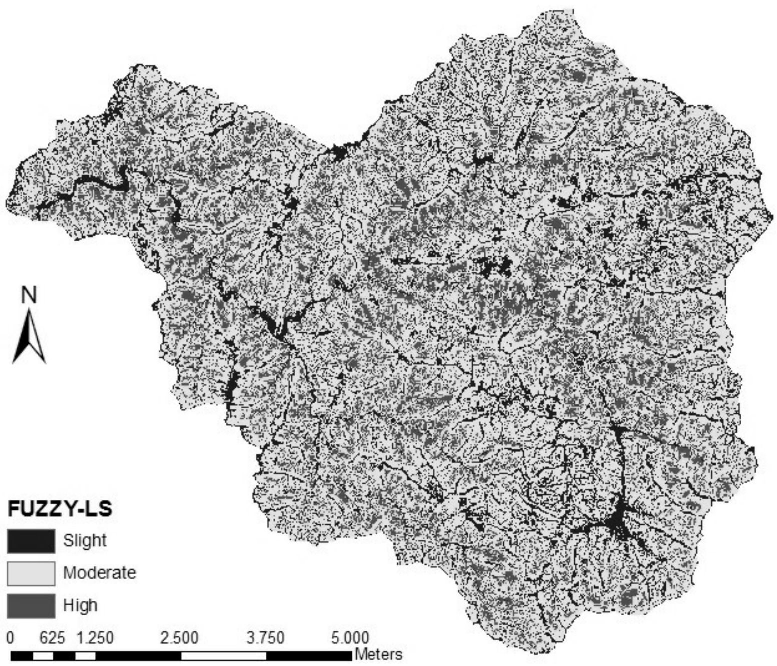


Figure 4.15 Classified FUZZY-LS outputs.

4.4.2. Two Variable Fuzzy Classification

Input membership functions for both C_{TM} and C_{ETM+} were selected as gaussian that consists of three classes; low, moderate and high. Input membership function and parameters are both given in Table 4.7 and Figure 4.16. Also, output membership function for both C_{TM} and C_{ETM+} is selected as gaussian consists of three classes. Output membership function and parameters are both given in Table 4.8 and Figure 4.17.

Table 4.7 Input fuzzy membership function parameters for C factors.

MF Name	*MF Type*	*Parameter 1*	*Parameter 2*
Low	Gaussian	0	0.2
Moderate	Gaussian	0.5	0.2
High	Gaussian	1	0.2

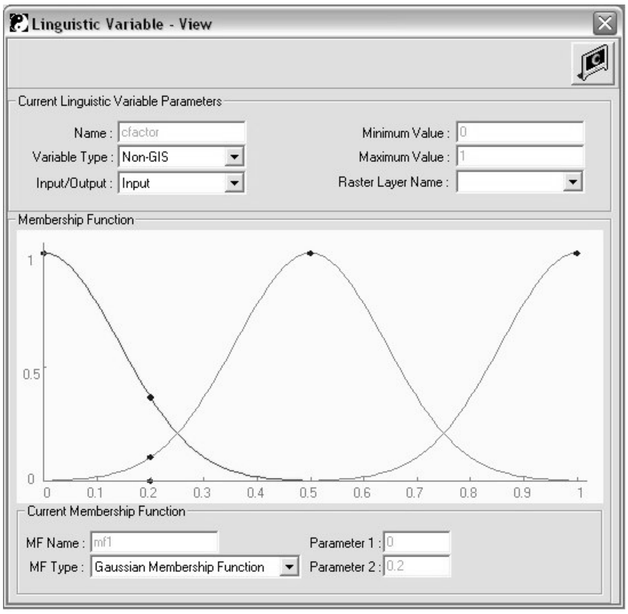


Figure 4.16: Input fuzzy membership function for C factors.

Table 4.8 Output fuzzy membership function parameters for C factors.

MF Name	*MF Type*	*Parameter 1*	*Parameter 2*
Slight	Gaussian	0	20
Moderate	Gaussian	50	20
Severe	Gaussian	100	20

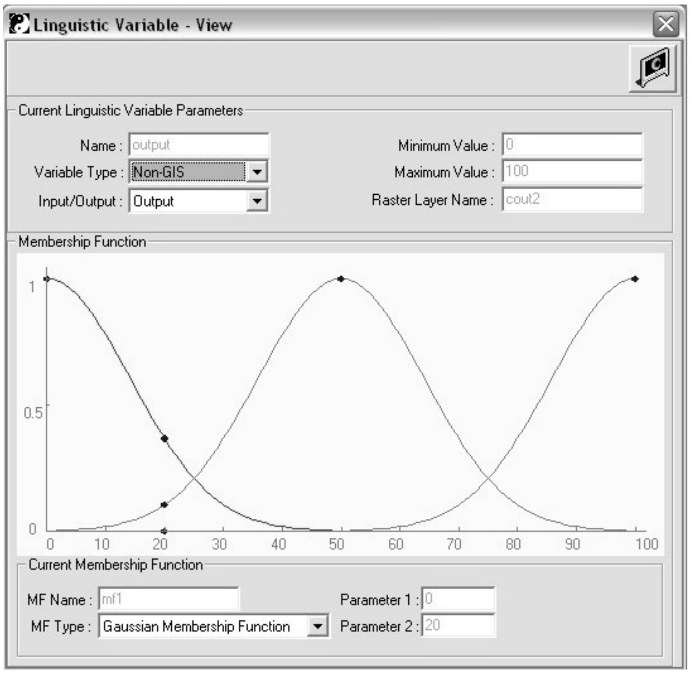


Figure 4.17 Output fuzzy membership function for C factors.

These fuzzy output layers were merged linearly into one layer by using two input membership functions, one is for LS and the other is for C_{TM}, the other case was for C_{ETM+}. Input and output functions have the same parameters and function types. Functions and the parameters are given in Table 4.9 and Figures 4.18.

Table 4.9 Fuzzy membership function parameters for the results.

MF Name	*MF Type*	*Input/Output*	*Parameter 1*	*Parameter 2*
LS	Triangular	Input	0	100
C_{TM}, C_{ETM+}	Triangular	Input	0	100
Result	Triangular	Output	0	100

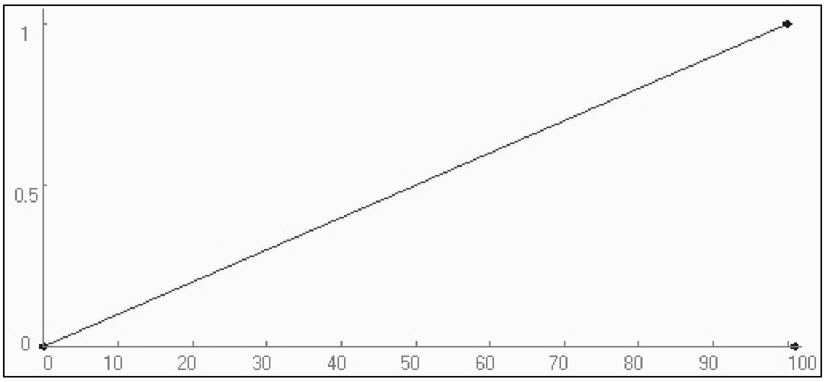


Figure 4.18 Input/Output fuzzy membership function for LS and C types.

Threshold values for FUZZY-LS-C_{TM} were selected by using natural break classification. Selected threshold values for low is between 0 and 20, moderate is between 20 and 60 and the high is over 60. Classified map is also given in Figure 4.19.

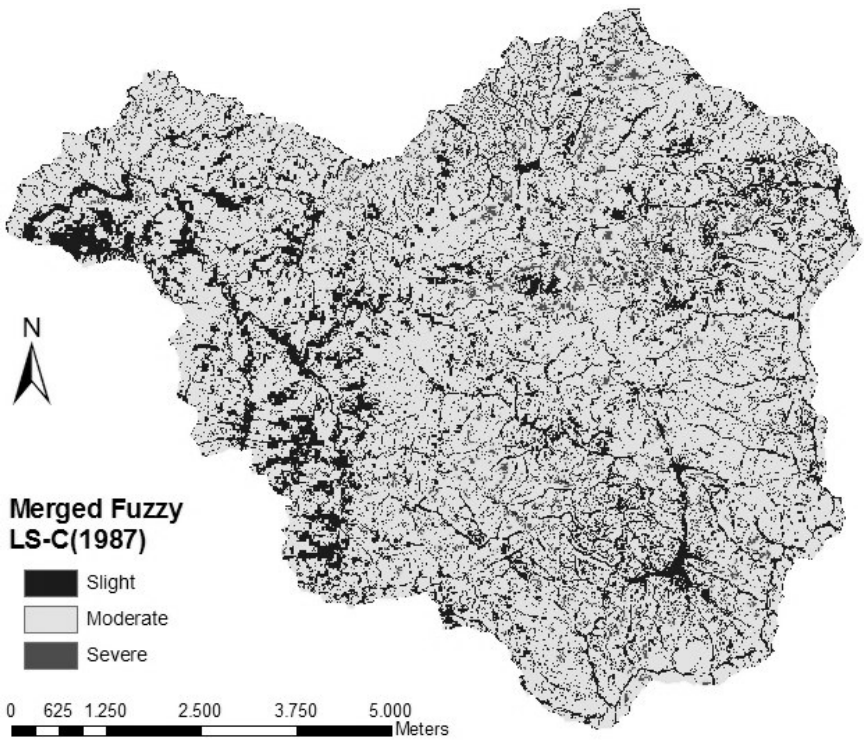


Figure 4.19 Merged fuzzy LS and fuzzy C_{TM} layers.

Threshold values for FUZZY-LS-C_{ETM+} were selected the same as the threshold values of FUZZY-LS-C_{TM}. Classified map is also given in Figure 4.20.

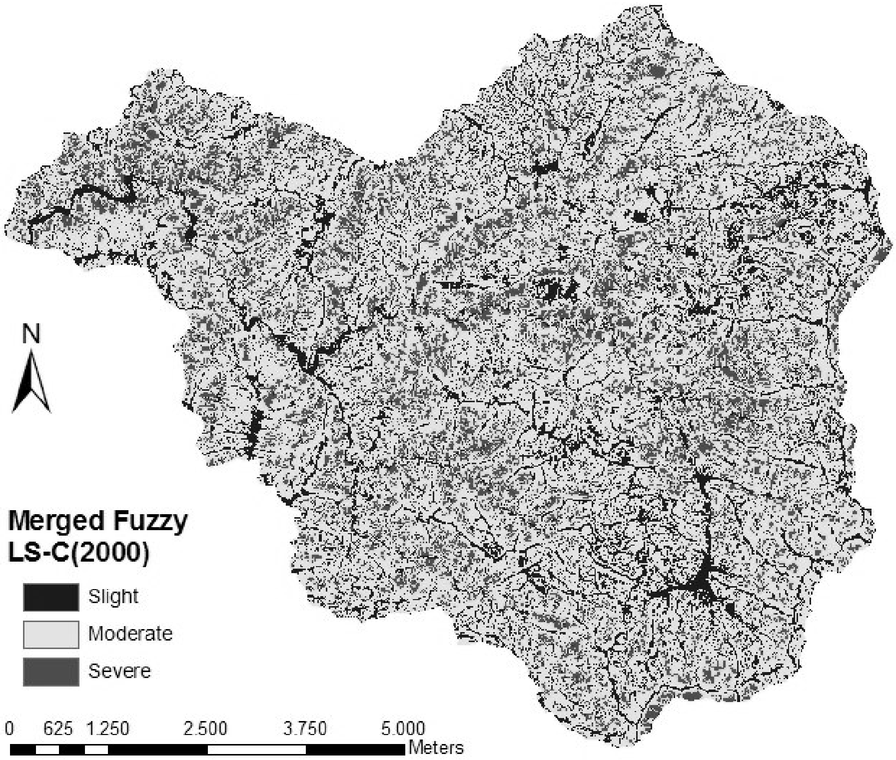


Figure 4.20 Merged fuzzy LS and fuzzy C_{ETM+} layers.

CHAPTER 5

DISCUSSION OF THE RESULTS

FUZZY-LS and merged fuzzy layers are compared with the USLE result. The comparison table, which contains areal values, is given in Table 5.1.

Table 5.1 Comparison table for USLE and FUZZY classifications.

Class		*1987*		*2000*		*Fuz.LS*
		USLE	*Fuz.LS-C_{TM}*	*USLE*	*Fuz.LS-C_{ETM+}*	
Slight	Area (ha)	304.17	1483.53	121.89	1195.63	1274.48
	%	5.19%	23.68%	2.01%	19.09%	20.35%
Moderate	Area (ha)	4877.86	4654.14	3571.93	4239.63	4002.51
	%	80.47%	74.30%	58.92%	67.68%	63.90%
Severe	Area (ha)	869.35	126.47	2368.02	828.87	987.14
	%	14.34%	2.02%	39.06%	13.23%	15.76%

5.1. Comparisons with USLE Model

Erosion risk map of the watershed classified by the two fuzzy logic based models were compared with those predicted by USLE model.

The one variable fuzzy logic model, which used input data from Hickey's LS algorithm result for the watershed has no similarity with areal values of USLE in any category. This shows that topographic factor is not the only factor that dominates erosion risk in the watershed. Another point, fuzzy classification was performed on only the topographic factor that was directly put into USLE equation;

it is clear that standalone FUZZY-LS approach does not clarify erosion risk in the watershed.

The two variable fuzzy logic models, which used input data from LS factor and C factors, give reasonable results compared to standalone FUZZY-LS approach. In the slight category that is shown in Figure 5.1, two variable fuzzy model predicted larger areas compared to USLE model, whereas smaller areas of the watershed was predicted in moderate and severe category compared to USLE results.

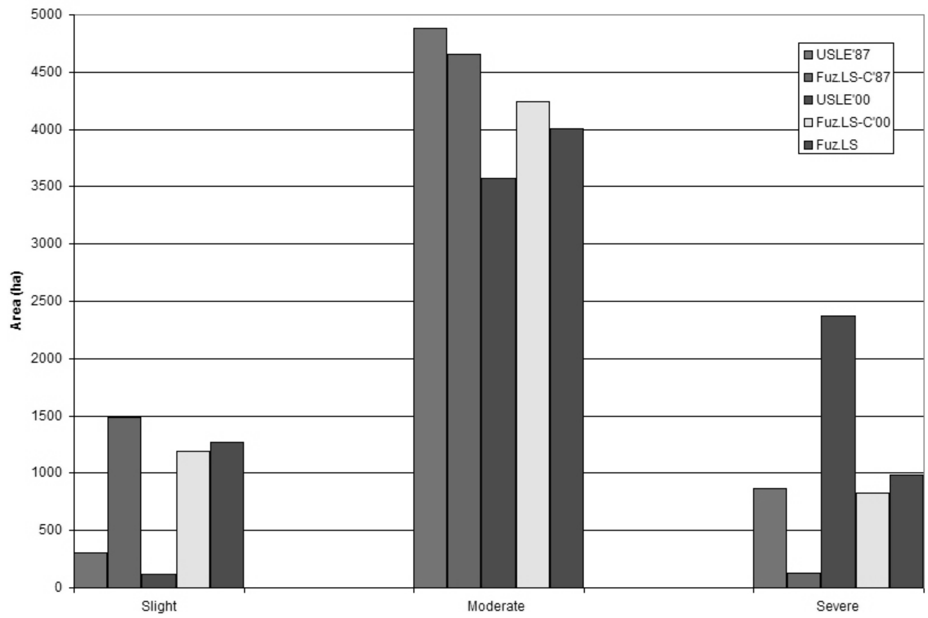


Figure 5.1 Comparison of traditional and fuzzy based USLE results.

The traditional USLE overestimated the areas prone to moderate and severe soil erosion. This result matched with the results of other researches on this topic (Mitra et al., 1998). Increase in fuzzy variables would improve the performance of USLE and would make the model more flexible and more realistic by describing the relationship between soil loss and rainfall erosivity.

In both of classification methods P factor was not considered, because no data for the watershed were available. This parameter would decrease soil loss rates of traditional USLE and also would make the model more realistic as well. Each parameter of USLE should be classified in fuzzy approach and merged together in order to find best comparison results between USLE and fuzzy approaches, one or two variable fuzzy models are not sufficient to compare these classification methods.

- Both Mitasova and Moore&Burch's algorithms give extreme values for stream bed. Hickey's algorithm considers and overcomes this problem; shortly gives more reliable results than the other algorithms. Cross sections from the same location for Mitasova's and Hickey's algorithm are shown in Figure 5.2.

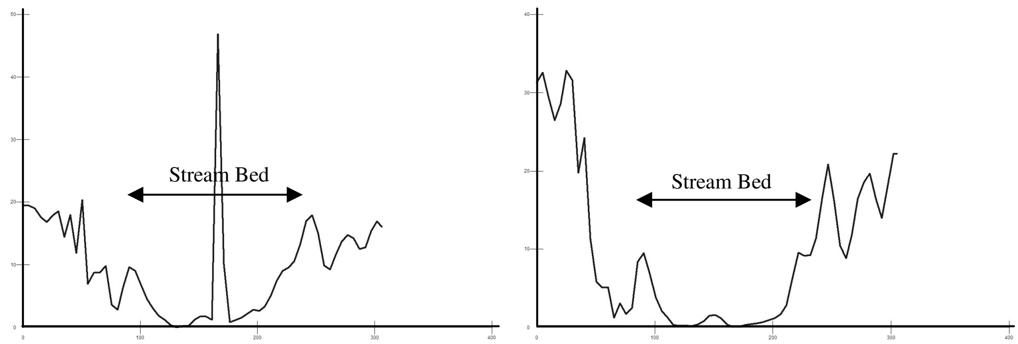


Figure 5.2 Cross sections for Mitasova's (left) and Hickey's (right) algorithms.

- Determining C factor of USLE is nearly impossible. C factors should be calculated and published by the agencies, unless users can calculate different C factors for the same area. In order to overcome this situation satellite driven, NDVI based C factor determination was performed for the watershed. In some areas, C values exceed the value of 1.0 that is the maximum value of C-factor. The reason of this exceeding was NDVI values below 0 that represent water bodies, bare soil and built-up areas. Negative values of NDVI was masked as 0 and then put into European Soil Bureau's formula.

- Damaged tree zones were clipped out from the forest map in order to determine the effect of degradation through the time. Forest map was published in 1996. It was observed that erosion risk increases from 1987 to 2000. This finding overlaps with the fuzzy outputs when the same process was applied. Comparison tables are given in Tables 5.2 and 5.3. Figures 5.3 and 5.4 show clearly that how erosion risk rises for traditional USLE implementation; also Figures 5.5 and 5.6 show the same trend for fuzzy implementation.

Table 5.2 Comparison table of USLE results for damaged forest areas.

Risk Class	***1987***		***2000***		***Change***	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
Low	23.53	4.01	6.47	1.10	-17.06	-72.52
Moderate	487.63	83.17	351.57	59.97	-136.07	-27.90
High	75.12	12.81	228.25	38.93	153.13	203.83

Table 5.3 Comparison table of FUZZY results for damaged forest areas.

Risk Class	***1987***		***2000***		***Change***	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
Low	159.71	27.07	105.93	17.96	-53.79	-33.68
Moderate	419.17	71.05	407.72	69.11	-11.45	-2.73
High	11.06	1.88	76.30	12.93	65.24	589.72

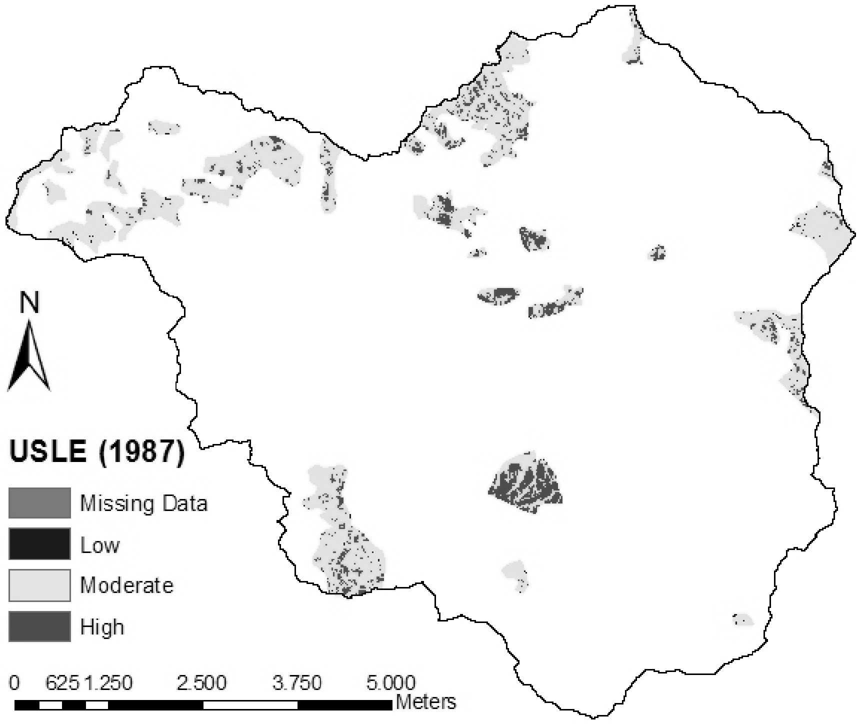


Figure 5.3 Clipped USLE results (1987) for damaged forest areas.

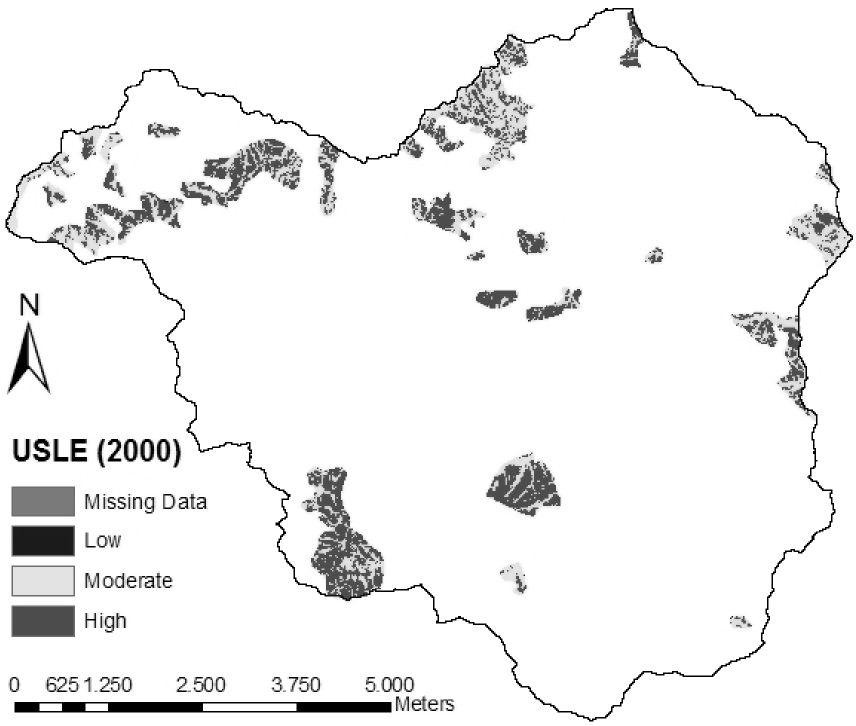


Figure 5.4 Clipped USLE results (2000) for damaged forest areas.

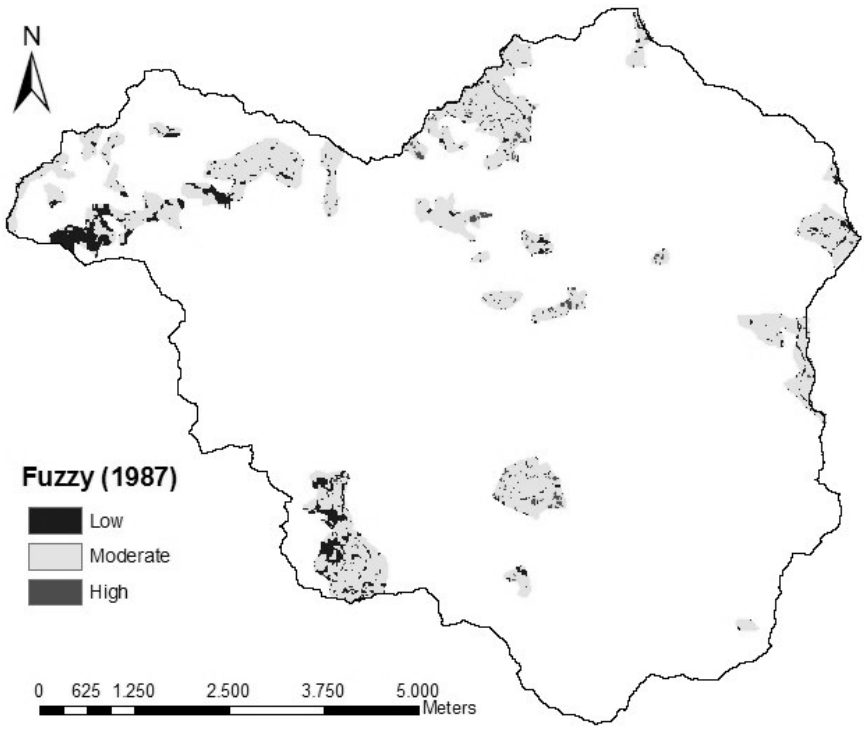


Figure 5.5 Clipped FUZZY results (1987) for damaged forest areas.

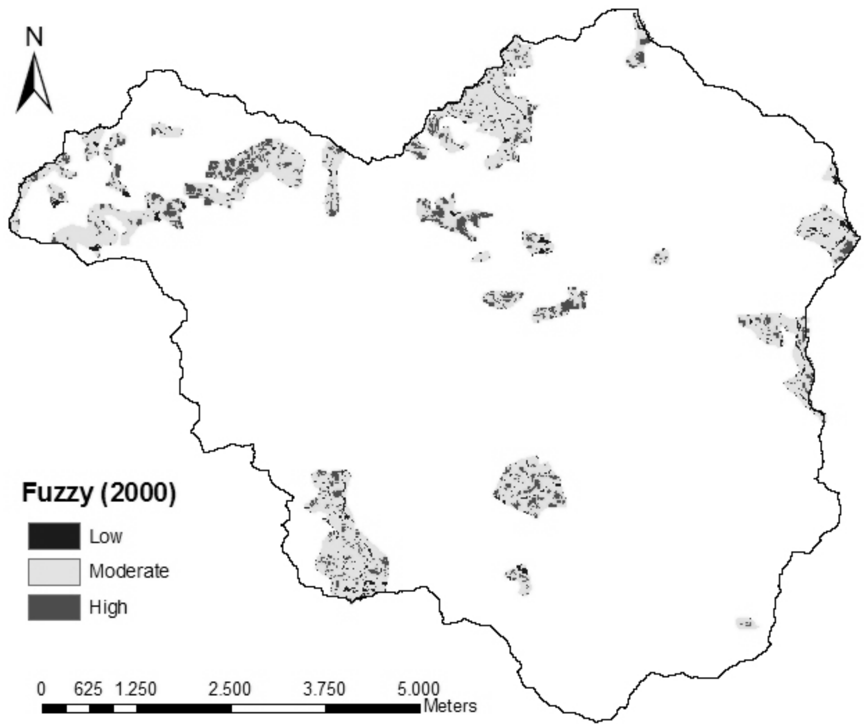


Figure 5.6 Clipped FUZZY results (2000) for damaged forest areas.

- Study area consists of 77 different land use areas having 11 different land use types. These areas (polygons) are shown in Figure 5.7 with their polygon IDs. The frequency of occurrence of cells of each category (slight, moderate, severe) in the thematic raster layers of classified two variable fuzzy implementations were summarized for these 77 polygons. The summaries were tabulated in Table 5.4. It is clear that erosion risk increases in most of these polygons. It can be found that areas of red pine (both damaged and undamaged), damaged mixed coppice and especially arable lands have more increase of erosion risk.

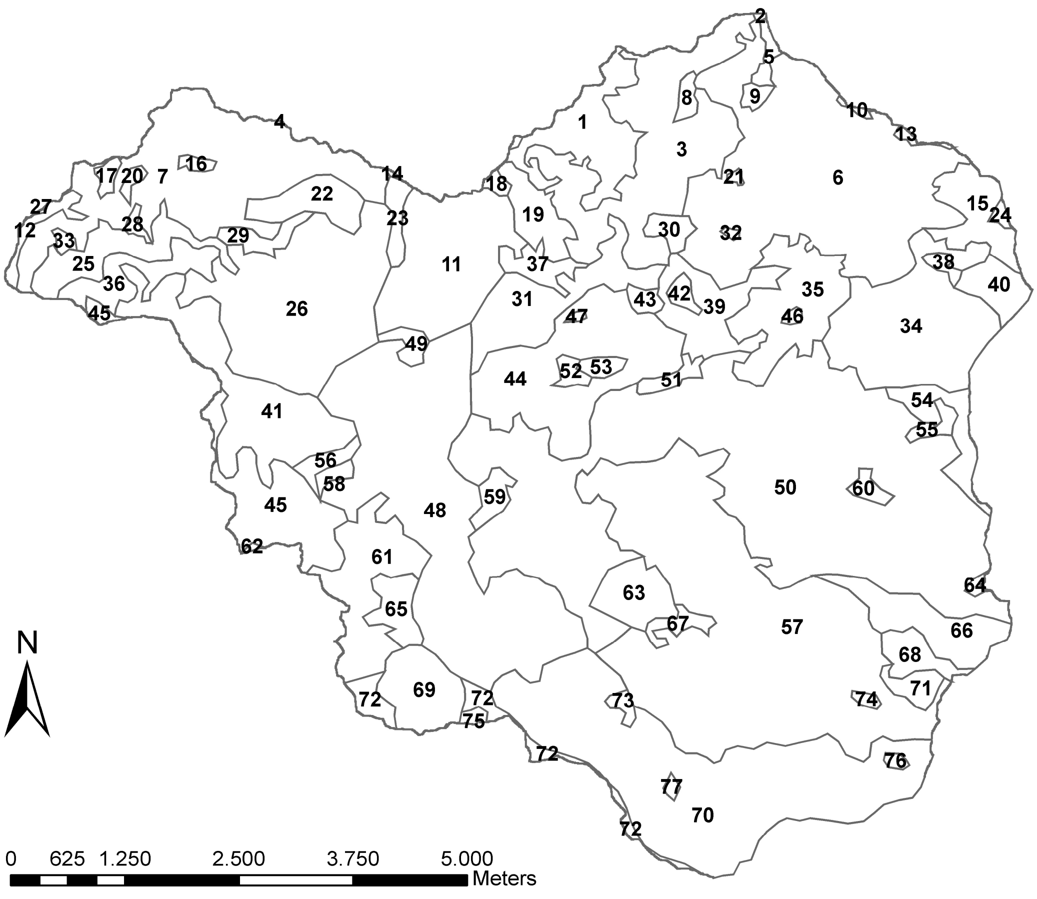


Figure 5.7 Land use polygons with IDs.

Table 5.4 Land use based category percentages of two variable fuzzy approach for the polygons.

ID	Definition	1987			2000		
		Slight	***Moderate***	***Severe***	***Slight***	***Moderate***	***Severe***
1	Damaged red pine	23.29%	73.72%	2.98%	22.32%	69.25%	8.42%
2	Forest soil without any tree	40.06%	59.94%	0.00%	40.06%	59.66%	0.28%
3	Arable land	22.42%	73.37%	4.21%	21.63%	67.82%	10.55%
4	Damaged mixed coppice	60.76%	39.24%	0.00%	60.76%	39.24%	0.00%
5	Damaged red pine	23.32%	75.11%	1.57%	18.79%	66.14%	15.07%
6	Red pine, "d" age class	21.00%	76.64%	2.36%	17.72%	71.04%	11.24%
7	Arable land	18.89%	80.19%	0.92%	15.92%	63.20%	20.88%
8	Red pine, "d" age class	33.02%	62.30%	4.69%	22.57%	63.19%	14.23%
9	Arable land	7.05%	69.41%	23.54%	6.24%	47.68%	46.08%
10	Settlement, cemetery	18.71%	80.20%	1.09%	18.61%	71.64%	9.75%
11	Arable land	19.04%	77.23%	3.73%	14.77%	67.12%	18.11%
12	Damaged mixed coppice	19.06%	80.56%	0.38%	18.39%	69.41%	12.20%
13	Settlement, cemetery	36.27%	56.08%	7.65%	36.27%	56.08%	7.65%
14	Red pine, "d" age class	45.23%	54.77%	0.00%	45.23%	46.29%	8.48%
15	Forest soil without any tree	29.94%	69.77%	0.28%	29.67%	68.70%	1.62%
16	Damaged mixed coppice	37.47%	62.53%	0.00%	20.12%	71.44%	8.43%
17	Damaged mixed coppice	24.23%	75.77%	0.00%	23.26%	70.65%	6.08%
18	Damaged red pine	11.38%	75.69%	12.93%	11.38%	63.89%	24.73%
19	Red pine, "d" age class	23.48%	75.06%	1.46%	13.02%	78.37%	8.60%
20	Damaged mixed coppice	20.21%	79.74%	0.05%	19.30%	68.49%	12.21%
21	Arable land	21.60%	78.03%	0.37%	21.60%	77.03%	1.37%
22	Damaged red pine	19.96%	79.98%	0.05%	10.49%	67.60%	21.91%
23	Damaged red pine	14.01%	82.91%	3.08%	14.01%	71.77%	14.22%
24	Damaged red pine	42.12%	57.75%	0.13%	42.12%	57.43%	0.45%
25	Water	39.50%	58.41%	2.09%	24.66%	52.66%	22.68%
26	Arable land	27.35%	72.11%	0.54%	18.32%	66.64%	15.04%
27	Arable land	35.57%	64.43%	0.00%	35.57%	51.68%	12.75%
28	Damaged mixed coppice	23.60%	76.40%	0.00%	20.93%	53.11%	25.96%
29	Damaged red pine	42.24%	57.76%	0.00%	10.13%	74.25%	15.63%
30	Arable land	16.04%	82.39%	1.57%	16.01%	72.45%	11.55%
31	Red pine, dominant "b" age class	20.62%	78.20%	1.18%	13.47%	66.08%	20.45%
32	Arable land	10.70%	85.63%	3.66%	18.03%	69.58%	12.39%
33	Damaged mixed coppice	18.90%	81.10%	0.00%	18.90%	63.41%	17.69%
34	Red pine, "d" age class	24.07%	74.93%	1.00%	23.98%	67.30%	8.73%
35	Arable land	25.28%	68.90%	5.82%	24.93%	64.90%	10.17%
36	Damaged mixed coppice	53.81%	46.19%	0.00%	14.07%	76.92%	9.01%
37	Damaged red pine	12.60%	83.80%	3.60%	10.38%	60.16%	29.46%
38	Forest soil without any tree	37.40%	62.27%	0.33%	37.40%	58.76%	3.84%
39	Red pine, dominant "c" age class	11.51%	77.41%	11.07%	10.88%	65.85%	23.27%
40	Damaged red pine	23.83%	75.37%	0.80%	23.92%	67.59%	8.49%
41	Red pine, dominant "c" age class	33.14%	66.85%	0.01%	18.06%	71.48%	10.46%
42	Forest soil without any tree	18.12%	73.99%	7.90%	18.12%	72.20%	9.69%
43	Damaged red pine	30.09%	65.84%	4.07%	30.09%	61.21%	8.69%

Table 5.4 Land use based category percentages of two variable fuzzy approach for the polygons (continued).

ID	Definition	1987			2000		
		Slight	***Moderate***	***Severe***	***Slight***	***Moderate***	***Severe***
44	Arable land	21,68%	74,22%	4,10%	17,86%	65,71%	16,44%
45	Forest soil without any tree	30,52%	69,41%	0,08%	21,31%	68,22%	10,47%
46	Damaged red pine	16,65%	72,03%	11,32%	16,65%	72,52%	10,83%
47	Damaged red pine	24,74%	75,26%	0,00%	24,10%	72,82%	3,08%
48	Arable land	27,51%	71,21%	1,28%	18,80%	66,87%	14,34%
49	Red pine, "d" age class	36,87%	63,13%	0,00%	17,67%	73,73%	8,60%
50	Red pine, "d" age class	16,89%	81,63%	1,48%	15,73%	66,82%	17,45%
51	Damaged red pine	16,88%	75,38%	7,74%	14,24%	55,17%	30,59%
52	Red pine, "d" age class	14,63%	78,60%	6,77%	8,95%	54,21%	36,84%
53	Damaged red pine	15,30%	82,20%	2,49%	15,30%	61,32%	23,37%
54	Damaged red pine	18,32%	80,71%	0,97%	18,32%	70,73%	10,95%
55	Red pine, "a" age class	15,71%	84,17%	0,12%	15,71%	75,87%	8,42%
56	Arable land	17,29%	82,71%	0,00%	14,88%	57,16%	27,96%
57	Arable land	28,17%	69,54%	2,30%	27,83%	67,31%	4,87%
58	Red pine, dominant "c" age class	45,37%	54,63%	0,00%	13,59%	77,08%	9,33%
59	Red pine, "a" age class	10,86%	88,24%	0,90%	9,50%	74,45%	16,05%
60	Rocky, stony	16,81%	82,68%	0,51%	15,96%	59,85%	24,19%
61	Arable land	44,34%	55,15%	0,50%	20,06%	69,65%	10,29%
62	Arable land	34,18%	65,82%	0,00%	27,81%	45,01%	27,18%
63	Damaged red pine	15,58%	79,25%	5,17%	15,58%	69,78%	14,64%
64	Forest soil without any tree	33,07%	66,93%	0,00%	33,07%	61,31%	5,62%
65	Damaged red pine	48,11%	51,17%	0,72%	20,29%	67,48%	12,23%
66	Red pine, "d" age class	16,52%	82,66%	0,82%	13,38%	75,96%	10,65%
67	Red pine, dominant "c" age class	25,91%	70,81%	3,28%	25,91%	69,75%	4,34%
68	Arable land	21,86%	73,68%	4,46%	20,10%	69,30%	10,60%
69	Damaged red pine	34,39%	65,22%	0,39%	19,76%	72,19%	8,05%
70	Red pine, "d" age class	19,87%	78,44%	1,69%	17,81%	69,95%	12,24%
71	Red pine, dominant "c" age class	22,30%	74,55%	3,15%	16,66%	75,92%	7,42%
72	Red pine, "d" age class	31,07%	67,35%	1,57%	22,01%	69,25%	8,74%
73	Damaged red pine	23,11%	74,79%	2,11%	23,11%	64,77%	12,13%
74	Red pine, "d" age class	29,17%	66,15%	4,68%	29,17%	66,79%	4,04%
75	Red pine, "d" age class	18,86%	80,91%	0,23%	18,86%	75,45%	5,69%
76	Damaged red pine	14,47%	84,98%	0,56%	12,16%	78,55%	9,29%
77	Arable land	12,79%	70,08%	17,14%	12,79%	64,54%	22,68%

- K factor values were assigned to the regions by using TURTEM’s soil database. Part of the K-factor map that elongates from south west to north east in the eastern part of the watershed has greater K values than the other zones in the region. This condition enhances soil loss rates for this zone.

This condition is also causes inconsistency between traditional USLE and fuzzy USLE results.

- There is no soil conservation study in the watershed; this makes it difficult to select the appropriate P factors. The value of 1.0, that is the maximum value of P factor, was selected as P factor for the worst case study. Soil conservation practice should be performed in arable lands by considering the erosion risk rising from 1987 to 2000 and that would increase in the near future for these lands.
- Rainfall erosivity index, R-factor was calculated for each year since 1966. Year of 1979 gave the highest results, in order to make the worst case study maximum values of different stations for years between 1966 and 2000 were selected and interpolated using IDW through the watershed.
- This study demonstrated a simple approach to build membership functions for USLE model. The membership functions for each linguistic value (e.g., slight, moderate, and severe) could be built based on statistics of the linguistic values. It was proved that the trapezoidal and the Gaussian membership functions derived using this approach could give reasonable results compared to USLE results.
- Researchers (Mitra et al., 1998; Ahamed et al., 2000; Metternicht and Gonzales, 2005) concluded that traditional USLE overestimates the areas prone to high level erosion risks. It is also found in this study that USLE over estimates the areas prone to moderate and severe soil erosion.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This study discussed USLE model, that is generally miscalculated, and its components -especially the topographic factor- for investigating the susceptibility of Kocadere Creek Watershed to soil erosion. Fuzzy based approach is used for erosion risk classification within GIS framework. The methods and the results of USLE model have been discussed in the previous chapters. The assessment results of USLE modeling have also been compared with the fuzzy based approach to ensure that the proposed methodology is reasonable. Based on the results and findings from this study, the following sections summarize some conclusions and recommendations.

6.1. Conclusions

The following conclusions provide answers to the research questions:

- USLE is not a “universal” equation. We cannot apply USLE to any topography. Topographic factor, which is the dominant factor in complex terrains, should be calculated carefully by using and comparing different LS algorithms. LS values should not exceed the value of 100 (GIS Based Tutorial, 2004).
- The reason for selecting USLE as a model is its simplicity. USLE was integrated within GIS framework in this study; sub-models were also applied for USLE-LS and USLE-C factors.

- Different algorithms for USLE-LS were implemented; Hickey's algorithm gives more reliable results than the others.
- Moore and Burch's algorithm uses flow accumulation in the equation, this makes the results unreliably high. Mitasova's algorithm gives more reliable results than Moore and Burch's. USLE does not work in stream bed; so algorithms should not calculate any value inside the stream bed.
- USLE-R factors were derived from the interpolation of 30 minute precipitation values observed in four different meteorological stations. None of these stations was in the watershed, and average altitude of these stations is approximately 15 m, but watershed's is 577 m. USLE-R results might not reflect the exact characteristics of the watershed.
- USLE-C factors were derived from NDVI images. In fact there is no global study in Turkey for determining C parameters for different type of vegetation.
- USLE-P factor was taken "1" as a worst case study because of no available data. USLE results would be lowered when P factor is considered.
- Boolean and fuzzy classification methods were used; boolean and two variable fuzzy approaches have similar results.
- One variable fuzzy approach did not give reliable result, this means that low parameter based fuzzy approach would fail on multi parameter models.

6.2. Recommendations

The following issues should be considered in future development of the present study:

- Land surveys and erosion loss observations should be performed in order to verify USLE and also the fuzzy based approaches.
- Geological map of the study region can be overlaid to see the effect of bare rocks. This approach generally does not give the appropriate results,

reflectance values of bare rock can be mixed with bare soil. In this case, in situ reflectance observations should be performed using electro-spectrometer.

- Areas having red pine, coppice and arable land are more susceptible to soil erosion. Soil loss rates would increase in these areas in the near future, and the upcoming studies should be located on these areas.
- Further study is required to find out a systematic approach in constructing membership functions based on expert knowledge and other relevant data.
- In any fuzzy based classification considering all parameters of USLE would give reliable results than one or two variable based fuzzy approaches.
- Development of a user-friendly decision support system (DSS) is required to support application of the USLE model in a real decision making process of conservation works.
- Researchers want to study on this region for erosion modeling, should determine soil erodibility parameter in the laboratories by analyzing soil samples; it is better to start the survey from the western part of the region.
- Volumetric values of the proposed dam for this watershed should be recalculated considering erosion risk.

REFERENCES

ACC, Ankara Chamber of Commerce, *http://www.atonet.org.tr,* visited on May 15^{th}, 2005.

Adinarayana, J., et al, *A site specific systems-approach model for soil erosion and silt yield studies for hilly watershed management,* In: Modelling Soil Erosion Sediment Transport and Closely Related Hydrological Processes, IAHS, Wallingford, 1998.

Ahamed, T.R.N., Rao, G.K., Murthy, J.S.R., *Fuzzy class membership approach to soil erosion modelling*, Agricultural Systems, 63, pp.97-110, 2000.

Akgül, S., Tekeli, Y.İ., Demirkıran, O., Cebel, H., Babayiğit, H.G., *Mogan ve Eymir Gölleri Havzası Erozyon Haritalama Projesi*, Köy Hizmetleri Ankara Araştırma Enstitüsü, 2003.

Angel, D., Krost, P. and Silvert, W., *Describing benthic impacts of fish farming with fuzzy sets: theoretical background and analytical methods,* J. Appl. Ichthyology 14, pp. 1-8, 1998.

Arkitera, *http://www.arkitera.com/v1/haberler/2004/11/22/*, visited on November 22^{nd}, 2004.

Bayramin, İ., Dengiz, O., Başkan, O., Parlak M., *Soil Erosion Risk Assessment with ICONA Model; Case Study: Beypazarı Area*, Turk J. Agric. For. 23, pp. 105-116, 2003.

Beasley, D.B., Huggins, L.F., Monke, E.J., *ANSWERS: A model for watershed planning*, Trans. of the ASAE 23 (4), pp. 938-944, 1980.

Beven, K., and Kirkby, M. J., *A physically based, variable contributing area model of basin hydrology,* Hydrological Science Bulletin, v. 24, p. 43-69, 1979.

Bottcher, A.B., Monke, E.J., Huggins, L.F., *Nutrient and sediment loading from a subsurface drainage system*, Trans. of ASAE 24 (5), pp. 1221-1226, 1981.

Bouraoui, F., and Dillaha, T.A., *ANSWERS-2000: Runoff and sediment transport model*, Journal of Environmental Engineering, ASCE 122 (6), pp. 493-502, 1996.

Britannica, *http://www.britannica.com*, visited on May 15th, 2005.

Burrough, P.A. and McDonnell, R.A., *Principles of Geographical Information Systems,* Oxford University Press, 1998.

Cambazoğlu, M.K.; Göğüş, M., *Sediment Yields of Basins in the Western Black Sea Region of Turkey,* Turkish J. Eng. Env. Sci. 28, pp. 355-367, 2004.

Clarke K.E., Bradley O.P. and Crane M.P., *Geographic Information Systems and Environmental Modeling,* Prentice Hall, 2001.

CLIGEN Weather Generator, *http://horizon.nserl.purdue.edu/Cligen*, visited on October 11th, 2004.

Cooley, K.R. and Williams, J.R., *Applicability of the Universal Soil Loss Equation (USLE) and modified USLE to Hawaii,* In: El-Swaify, S.A., Moldenhauer, W.C. and Lo, A. (eds.) Soil erosion and conservation, Soil Conservation Society of America, pp. 509-522, 1983.

Cowen, J., *A proposed method for calculating the LS factor for use with the USLE in a grid-based environment,* Proceedings of the thirteenth annual ESRI user conference, pp. 65 – 74, 1993.

Da Silva, A.M., *Rainfall erosivity map for Brazil*, Catena 57, pp. 251-259, 2004.

De Jong S. M., *Derivation of vegetative variables from a Landsat TM image for modeling soil-erosion,* Earth Surface Processes and Landforms. 19 (2), pp. 165-178, 1994.

Desmet, P.J.J. and Govers, G., *GIS-based simulation of erosion and deposition patterns in an agricultural landscape: a comparison of model results with soil map information,* Catena, 25, pp. 389-401, 1995.

Desmet, P.J.J. and Govers, G., *A GIS-procedure for automatically calculating the USLE LS-factor on topographically complex landscape units,* Journal of Soil and Water Conservation, 51 (5), pp. 427-433, 1996.

Dillaha, T.A. and Beasley, D.B., *Sediment transport from disturbed upland watersheds*. Trans. of the ASAE 26 (6), pp.1766-1777, 1983.

Dillaha, T.A., Beasley, D.B., Huggins, L.F., *Using the ANSWERS model to estimate sediment yields on construction sites*, J. Soil and Water Conservation 37 (2), pp. 117-120, 1982.

Doğan, O., *Türkiye yağışlarının erosive potansiyelleri,* Tarım Orman ve Köyişleri Bakanlığı, Ankara, 1987.

Doğan, O., Küçükçakar, N., Özel, M.E., Yıldırım, H., *Erosion Risk Mapping of Dalaman Basin Located in West Mediterranean Region Using CORINE Method*, TUBITAK, 1996.

EPIC, *http://www.brc.tamus.edu/epic*, visited on October 12nd, 2004.

Esengin, E., *Integration of Geographic Information Systems with Environmental Impact Assessment: A Case Study on Çamlı Dam,* MSc Thesis, METU, 2002.

FAO, UN Food and Agriculture Organization, *http://www.fao.org,* visited on December 4th, 2001.

Flanagan, D.C. and Nearing, M.A., *USDA-Water Erosion Prediction Project: Technical documentation,* NSERL Report No. 10, National Soil Erosion Research Laboratory, USA, 1995.

Folly, A., Bronsveld, M.C. and Clavaux, M., *A knowledge-based approach for C-factor mapping in Spain using Landsat TM and GIS,* International Journal of Remote Sensing, 12, pp. 2401-2415, 1996.

Foster, G.R., and Wischmeier, W.H., *Evaluating irregular slopes for soil loss prediction*, Transactions of the American Society of Agricultural Engineers 17 (2), pp. 305-309, 1974.

GDREC, General Directorate of Reforestation and Erosion Control, *http://www.agm.gov.tr,* visited on December 6th, 2001.

GeoWEPP Software, *http://www.geog.buffalo.edu/~rensch/geowepp*, visited on October 11th, 2004.

GLCF, Global Land Cover Facility, *http://* glcfapp.umiacs.umd.edu, visited on September 15th, 2003.

GIS Based Tutorial, The U.S. Army Corps of Engineers, Engineering Research and Development Center, Construction Engineering Research Laboratory, *http://skagit.meas.ncsu.edu/~helena/gmslab/reports/CerlErosionTutorial/denix/denixstart.html*, visited on April 17th, 2004.

Griffin, M.L., Beasley, D.B., Fletcher, J.J., and Foster, G.R., *Estimating soil loss on topographically nonuniform field and farm units,* Journal of Soil and Water Conservation 43, pp. 326-331, 1988.

Hatipoğlu M.A., *Hydrological Modelling of Soil Erosion and Runoff Using Remote Sensing and Geographical Information Systems (GIS),* PhD Thesis, METU, 1999.

Hession, W.C., and Shanholtz, V.O., *A geographic information system for targeting nonpoint- source agricultural pollution,* Journal of Soil and Water Conservation 43 (3), pp. 264-266, 1988.

Hickey, R, A. Smith, and P. Jankowski, *Slope length calculations from a DEM within ARC/INFO GRID*, Computers, Environment and Urban Systems, v. 18, no. 5, pp. 365 – 380, 1994.

Hickey, R., *Slope Angle and Slope Length Solutions for GIS,* Cartography, v. 29, no. 1, pp. 1-8, 2000.

Isaaks, E. H., and Srivastava R.M., *An introduction to applied geostatistics,* Oxford University Press, New York, 1989.

İrvem, A., *Coğrafi Bilgi Sistemi ile Toprak Kaybı ve Sediment Verimi Tahmini Modelinin (EST) Oluşturulması ve Seyhan Körkün Alt Havzasına Uygulanması*, PhD Thesis, Çukurova University, 2003.

ICC, İzmir Chamber of Commerce, *http://www.izto.org.tr/IZTO/TC/IZTO+Bilgi/izmir/sorunlar/sorun4.htm*, visited on April 7th, 2005.

James, D.E., and Hewitt, M.J., *To save a river: Building a resource decision support system for the Blackfoot River drainage,* GeoInfo Systems 2 (10), pp. 36-49, 1992.

Kinnell, P.I.A., *Alternative approaches for determining the USLE-M slope length factor for grid cells*, Soil Science Society of America Journal 69, pp. 674-680.

Lufafa, A., Tenywa, M.M., Isabirye, M., Majaliwa, M.J.G., Woomer, P.L., *Prediction of soil erosion in a Lake Victoria basin catchment using a GIS-based Universal Soill Loss model*, Agricultural System 76, pp. 883-894, 2003.

Metternicht, G., Gonzales, S., *FUERO: foundation of a fuzzy exploratory model for soil erosion hazard predict*, Environmental Modelling&Software 20, pp. 715-728, 2005.

Mitasova, H., *Surfaces and Modeling.* Grassclippings, 7(1), pp. 18 – 19, 1993.

Mitasova, H., Hofierka, J., Zlocha, M. and Iverson, L.R., *Modeling topographic potential for erosion and deposition using GIS,* International Journal of GIS, v. 10, no. 5, pp. 629-641, 1996.

Mitra, B., Scott, H.D., Dixon, J.C. and McKimmey, J.M., *Applications of fuzzy logic to the prediction of soil erosion in a large watershed,* Geoderma, v. 86, pp. 183-209, 1998.

Moore, I. D. and G. J. Burch, *Physical Basis of the Length-Slope Factor in the Universal Soil Loss Equation,* Soil Science Society of America Journal, 50 (5), pp. 1294-1298, 1986.

Moore, I.D., and Wilson, J.P., *Length-slope factors for the Revised Universal Soil Loss Equation: Simplified method of estimation,* Journal of Soil and Water Conservation 47 (5), pp. 423-428, 1992.

Moore, I.D., and Wilson, J.P., *Reply to "Comment on Length-slope factors for the Revised Universal Loss Equation: Simplified method of estimation" by George R. Foster,* Journal of Soil and Water Conservation 49 (2),pp. 174-180, 1994.

Morgan, R.P.C., *Soil Erosion and Conservation, 2nd Ed.,* Longman Group Limited, New York, 1995.

Okalp, K., *Gediz Havzası'nın CORINE Programına Dayalı Olarak Erozyon Risk Sınıflaması: Gediz Erozyon Risk Sınıflaması*, BSc Thesis, Dokuz Eylül University, 2002.

Özden, Ş., Özden, D.M., *Türkiye Toprak Erozyon Modeli (TURTEM),* Toprak ve Gübre Araştırma Enstitüsü Araştırma Programı, Proje No: 95120A01, Ankara, 1997.

Questions: a User-friendly Interface to ANSWERS-2000, *http://dillaha.bse.vt.edu/answers/Questions&Answers.html*, visited on October 12nd, 2004.

Renard, K.G., Foster, G.R., Weesies, G.A. and Porter, J.P., *RUSLE, Revised Universal Soil Loss Equation,* Journal of Soil and Water Conservation 46 (1), pp. 30-33, 1991.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C., *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the*

Revised Universal Soil Loss Equation, U.S. Department of Agriculture, Agriculture Handbook No. 703, 1993.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C., (coordinators), *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE),* U.S. Department of Agriculture, Agricultural Handbook No.703, 1997.

Rewerts, C.C., and Engel, B.A., *ANSWERS on GRASS: Integrating a watershed simulation with a GIS*, ASAE Paper No. 91-2621, ASAE, 1991.

Römkens, M.J.M., Prasad, S.N., and Poesen J.W.A., *Soil erodibility and properties,* In Proc. 13th Congr. Int. Soil Sci. Soc., vol.5, pp. 492-504, Hamburg, Germany, 1986.

Sasikala, K.R., Petrou, M. and Kittler, J., *Fuzzy classification with a GIS as an aid to decision making,* EARSeL Advances in Remote Sensing, vol.4, pp. 97-105, 1996.

Schwab, G.O. and Frevert, R.K., *Elementary Soil and Water Engineering, 3rd Ed.,* John Wiley & Sons, Inc., Canada, 1985.

Sharpley, A.N. and Williams, J.R., *EPIC-Erosion/productivity impact calculator; 1. Model Documentation*, Technical Bulletin No. 1768, U.S. Department of Agriculture, 1990.

Silvert, B., Personal communication, 2005.

Skidmore, E.L., *Soil and water management and conservation: wind erosion,* In Victor J. Kilmer, Handbook of soils and climate in agriculture, Florida, 1982.

Storm, D.E., Dillaha, T.A., Mostaghimi, S., Shanholtz, V.O., *Modeling phosphorus transport in surface runoff*, Transactions of the ASAE 31 (1), pp. 117-127, 1988.

SWCS, Soil Water Conservation Society, *http://www.swcs.org,* visited on June 23rd, 2005.

TemelSu International Engineering Services Inc., *Çamlı Dam Environmental Impact Assessment Pre-study Report*, Ankara, 1997.

TFCSE, The Turkish Foundation for Combating Soil Erosion, for Reforestation and the Protection of Natural Habitats, *http://www.tema.org.tr,* visited on November 27th, 2001.

The University of Alabama, Department of Civil and Environmental Engineering, Class Material of Construction Site Erosion Control, Module 3: RUSLE, *http://unix.eng.ua.edu/~rpitt/Class/Erosioncontrol/Module3/MainECM3.html,* visited on May 17th, 2005.

Tıp Dünyası, *http://www.ttb.org.tr*, visited on March 24th, 2005.

Tomlin, C.D., *The Map Analysis Package*. New Haven: School of Forestry and Environmental Science, Yale University, 1980.

TSSA, Turkish Soil Science Association, *http://www.toprak.org.tr/isd/isd_20.htm,* visited on March 15th, 2005.

UN Conference on Environment and Development, *http://www.un.org/geninfo/bp/enviro.html,* visited on April 16th, 2004.

USDA, United States Department of Agriculture, *http://www.usda.gov,* visited on March 24th, 2005.

Van der Knijff, J.M., Jones, R.J.A., Montanarella, L., *Soil erosion risk assessment in Italy,* European Soil Bureau, EUR 19044 EN, 1999.

Van Remortel, R.D., Maichle, R.W., Hickey, R.J., *Computing the LS factor for the Revised Universal Soil Loss Equation through array-based slope processing of digital elevation data using a C++ executable*, Computers&Geosciences 30, pp. 1043-1053, 2004.

Ventura, S.J., Chrisman, N.R., Connors, K., Gurda, R.F., and Martin, R.W., *A land information system for soil erosion control planning,* Journal of Soil and Water Conservation 43 (3), pp. 230-233, 1988.

WEPP Software, *http://topsoil.nserl.purdue.edu/nserlweb/weppmain*, visited on October 11th, 2004.

Wijesekera, N.T.S. and Samarakoon, L., *Extraction of Parameters and Modelling Soil Erosion Using GIS in Grid Environment,* Proceedings of the Asian Conference on Remote Sensing, Singapore, November 2001.

Williams, J.R., *The EPIC model*, Grassland, Soil and Water Research Laboratory, U.S. Department of Agriculture, Agriculture Research Service, 1994.

Wilson, J.P., *Estimating the topographic factor in the Universal Soil Loss Equation for watershed,* J. Soil Water Conserv. 41 (3), pp. 179–184. 1986.

Wischmeier W.H., *Use and misuse of the universal soil loss equation,* Journal of Soil and Water Conservation 31 (1), pp. 5-9, 1976.

Wischmeier, W.H. and Smith, D.D., *Predicting rainfall erosion losses – a guide to conservation planning,* U.S. Department of Agriculture, Agricultural Handbook No. 537, 1978.

Yanar, T.A. and Akyürek, Z., *The enhancement of the cell-based GIS analyses with fuzzy processing capabilities,* Information Sciences (in press), 2005.

Zadeh, L.A., *Fuzzy sets*, Inf. Control 8, pp.338-353, 1965.

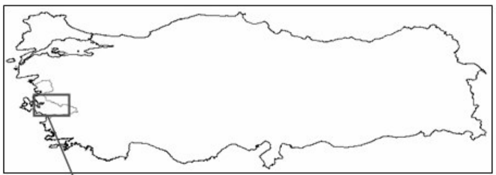
APPENDIX A

MAXIMUM 30 MINUTE PRECIPITATIONS, STATION LOCATIONS

Yıl	Güzelyalı	Bornova	Selçuk	Çeşme
2000	22.5	21.6	20.2	13.0
1999	12.3	12.7	19.9	16.2
1998	34.9	17.6	26.7	19.9
1997	16.0	13.9	25.7	29.2
1996	18.8	12.8	23.2	12.9
1995	37.5	23.4	12.8	4.2
1994	18.7	13.2	13.1	27.4
1993	7.2	17.2	27.4	22.9
1992	13.5	19.3	10.3	23.3
1991	22.4	13.3	21.3	10.7
1990	7.7	6.3	12.8	5.8
1989	26.4	7.6	12.3	12.9
1988	4.0	4.5	9.0	17.8
1987	19.2	13.5	8.2	39.5
1986	11.3	16.4	14.2	5.5
1985	16.0	**34.7**	10.9	8.5
1984	13.7	13.6	20.0	24.9
1983	12.3	15.2	15.7	19.4
1982	21.0	28.4	31.0	31.7
1981	21.8	18.1	9.2	9.8
1980	18.6	28.5	17.1	18.7
1979	**52.3**	27.8	12.2	26.1
1978	14.2	22.9	14.0	**45.1**
1977	6.0	16.5	30.9	10.1
1976	27.4	24.2	9.0	20.5
1975	23.0	18.9	31.3	16.1
1974	15.4	17.4	19.8	16.5
1973	18.6	10.1	16.7	7.6
1972	17.6	10.2	22.2	17.7
1971	12.7	15.6	13.0	26.6
1970	10.3	12.3	18.6	17.1
1969	13.6	12.6	19.2	20.4
1968	18.1	10.4	16.4	13.4
1967	16.5	14.8	14.7	14.3
1966	33.6	25.4	**39.4**	21.3
1965	17.7	21.6	25.0	
1964	15.0	21.5		
1963	11.9			
1962	15.5			
1961	13.9			
1960	11.2			
1959	12.5			
1958	13.8			
1957	16.2			
1956	8.0			
1955	11.5			
1954	14.9			
1953	15.6			
1952	14.4			
1951	9.0			
1950	19.7			
1949	8.7			
1948	12.1			
1947	12.5			
1946	15.8			
1945	16.8			
1944	14.1			
1943	27.3			
1942	25.6			
1941	14.0			
1940	11.3			
1939	12.1			
1938	14.5			

Station	Geographic		UTM35N	
	Longitude	Lattitude	Easting (X)	Northing (Y)
Güzelyalı	27°05'E	38°24'N	507324.38	4250379.49
Bornova	27°13'E	38°28'N	518949.52	4257795.84
Selçuk	27°22'E	37°57'N	532262.29	4200509.31
Çeşme	26°21'E	38°18'N	443212.12	4239480.07

Station	Height
Güzelyalı	29 m
Bornova	53 m
Selçuk	17 m
Çeşme	5 m



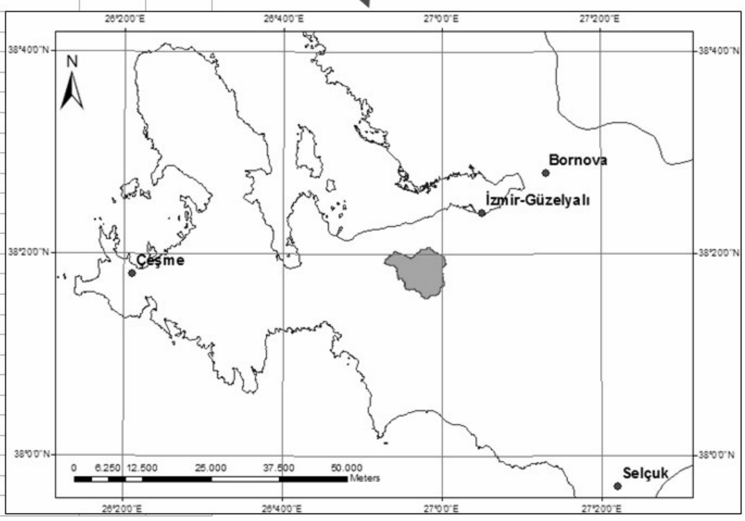


Figure A.1 Study region, meteorological stations and precipitations.

APPENDIX B

STATISTICAL VALUES OF INTERPOLATION RESULTS

Table B.1 Statistical values for interpolated precipitation and USLE-R values.

Year	Precipitation (mm)			USLE-R Factor (metric ton-m/ha)		
	Min	***Max***	***Mean***	***Min***	***Max***	***Mean***
1966	30.86	32.20	31.58	53.45	58.55	56.17
1967	15.76	16.12	15.93	12.66	13.29	12.94
1968	15.81	16.75	16.21	12.74	14.42	13.44
1969	13.81	14.55	14.16	9.52	10.65	10.05
1970	11.05	12.08	11.61	5.89	7.13	6.54
1971	13.53	14.92	14.15	9.11	11.24	10.03
1972	16.34	16.63	16.44	13.68	14.19	13.86
1973	15.41	16.95	16.15	12.05	14.79	13.34
1974	15.87	16.30	16.12	12.85	13.61	13.28
1975	21.92	22.46	22.27	25.69	27.06	26.58
1976	24.53	26.14	25.26	32.72	37.48	34.83
1977	8.50	10.78	9.77	3.33	5.58	4.53
1978	16.36	19.55	17.81	13.70	20.11	16.48
1979	41.28	46.59	43.53	99.46	128.72	111.50
1980	20.06	20.61	20.44	21.24	22.52	22.12
1981	18.77	20.51	19.59	18.43	22.28	20.19
1982	22.74	24.49	23.70	27.79	32.58	30.39
1983	13.04	13.96	13.51	8.42	9.74	9.08
1984	14.19	15.39	14.75	10.09	12.02	10.98
1985	18.47	19.08	18.86	17.79	19.09	18.62
1986	11.93	12.26	12.10	6.94	7.37	7.16
1987	18.31	19.53	18.71	17.45	20.07	18.29
1988	4.61	6.02	5.25	0.88	1.58	1.18
1989	19.89	22.73	21.07	20.85	27.77	23.64
1990	7.53	7.72	7.61	2.57	2.70	2.63
1991	19.06	20.66	19.84	19.03	22.64	20.75
1992	14.55	15.63	15.05	10.65	12.42	11.46
1993	9.79	12.52	11.32	4.53	7.70	6.23
1994	17.61	18.13	17.84	16.06	17.10	16.52
1995	29.00	33.66	31.22	46.79	64.37	54.87
1996	17.16	17.87	17.53	15.19	16.57	15.90
1997	16.35	17.73	16.99	13.69	16.30	14.88
1998	28.94	31.60	30.12	46.61	56.24	50.76
1999	12.71	13.39	13.07	7.96	8.90	8.46
2000	21.07	22.03	21.60	23.60	25.98	24.89
MEAN	18.26	18.42	18.32	17.37	17.68	17.48
WORST	46.80	49.02	47.67	129.99	143.46	135.18

APPENDIX C

CHART OF INTERPOLATED PRECIPITATIONS

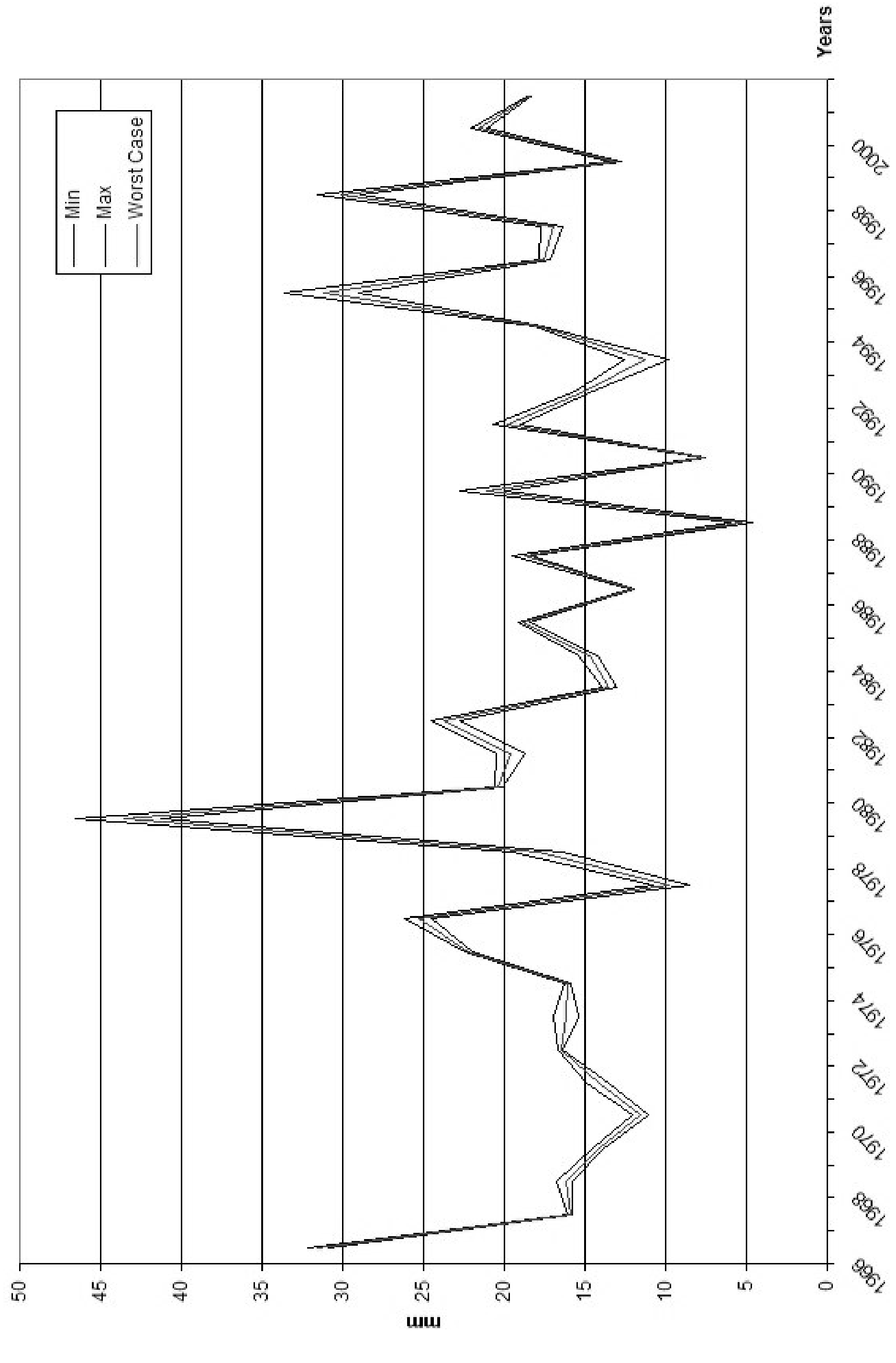


Figure C.1 Statistical values of interpolated precipitation values.

APPENDIX D

CHART OF INTERPOLATED USLE-R FACTORS

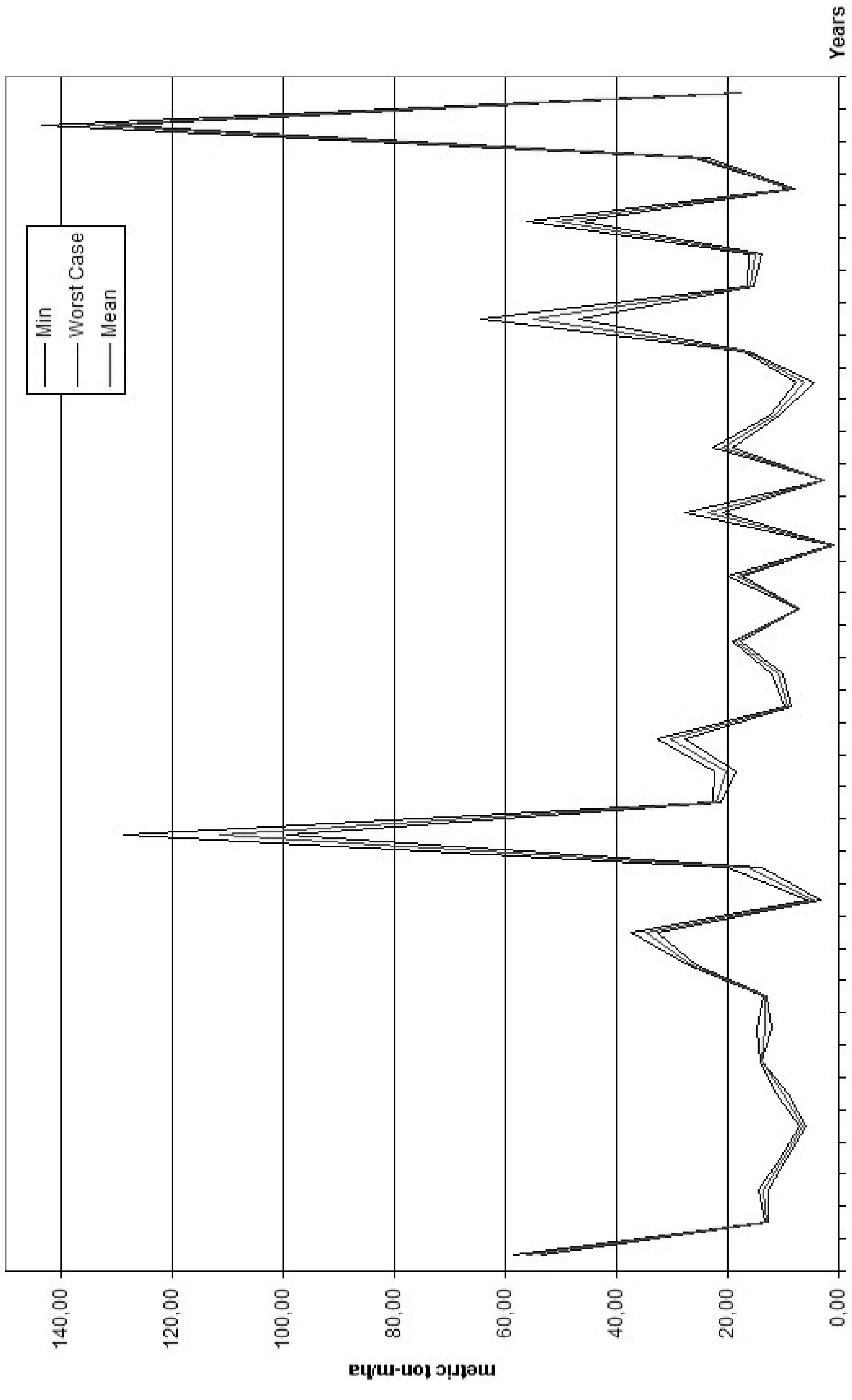


Figure D.1 Statistical values of interpolated USLE-R values.

APPENDIX E

INTERPOLATION RESULTS FOR PRECIPITATION AND USLE-R FACTORS

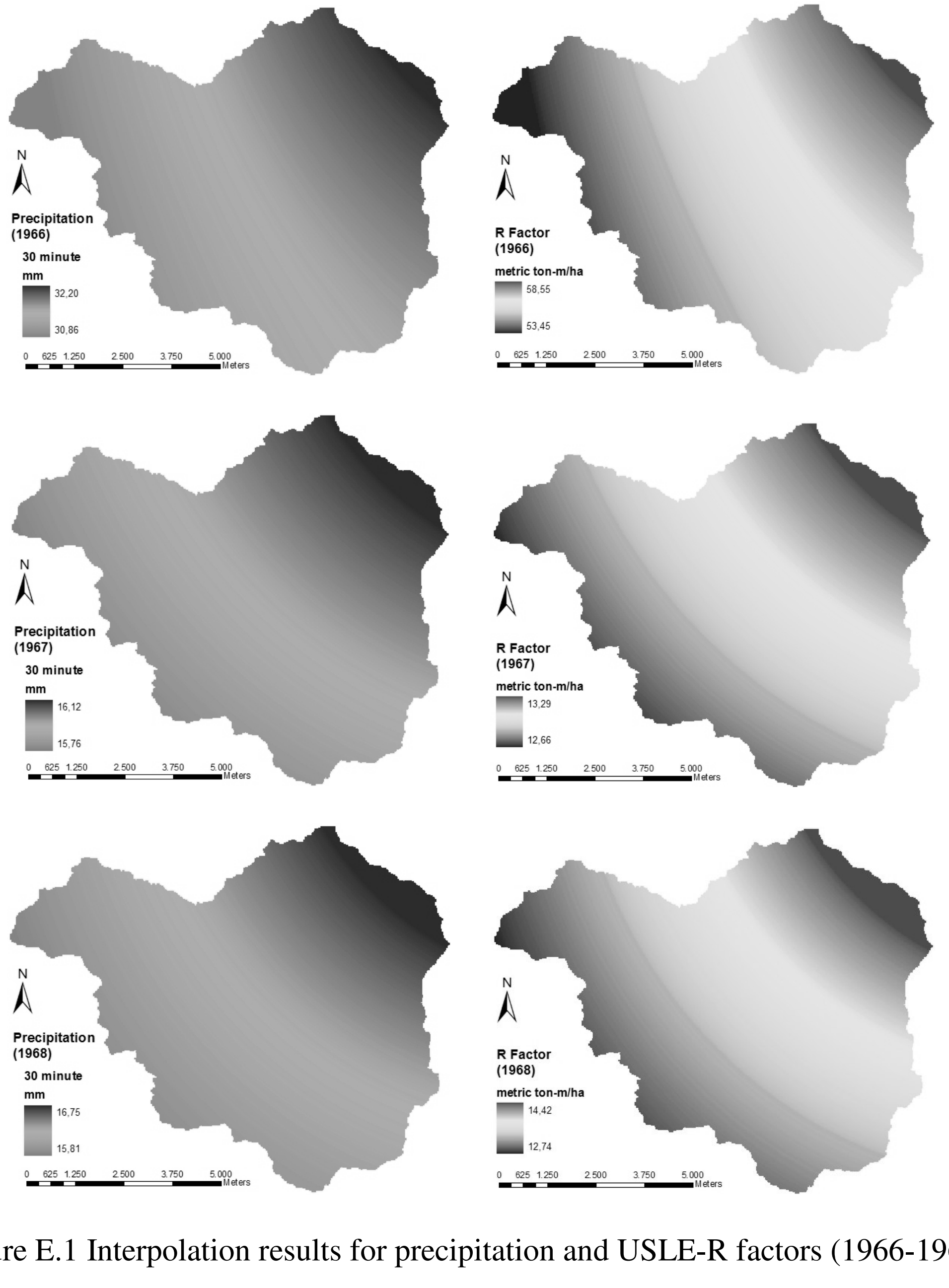


Figure E.1 Interpolation results for precipitation and USLE-R factors (1966-1968).

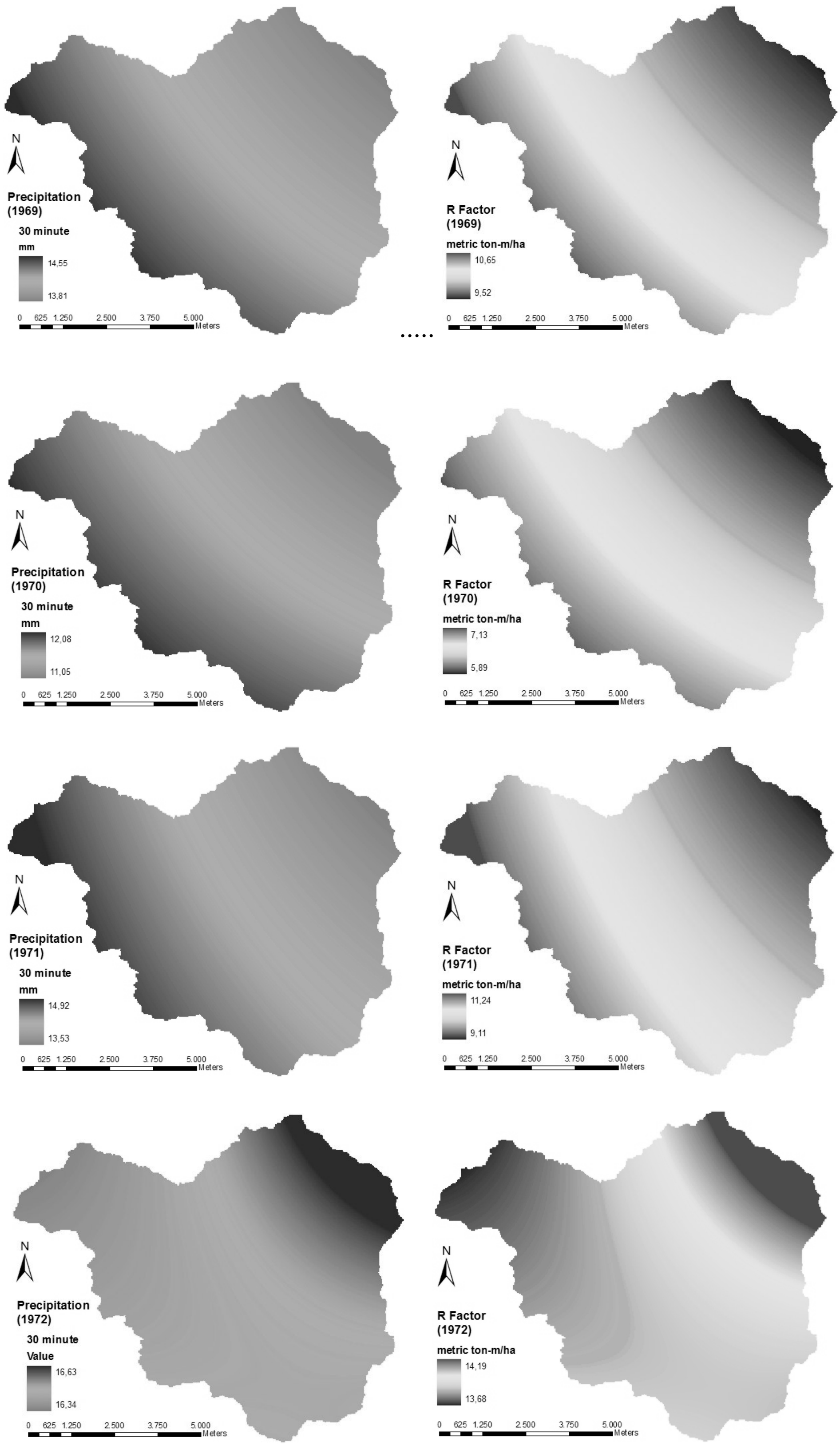


Figure E.2 Interpolation results for precipitation and USLE-R factors (1969-1972).

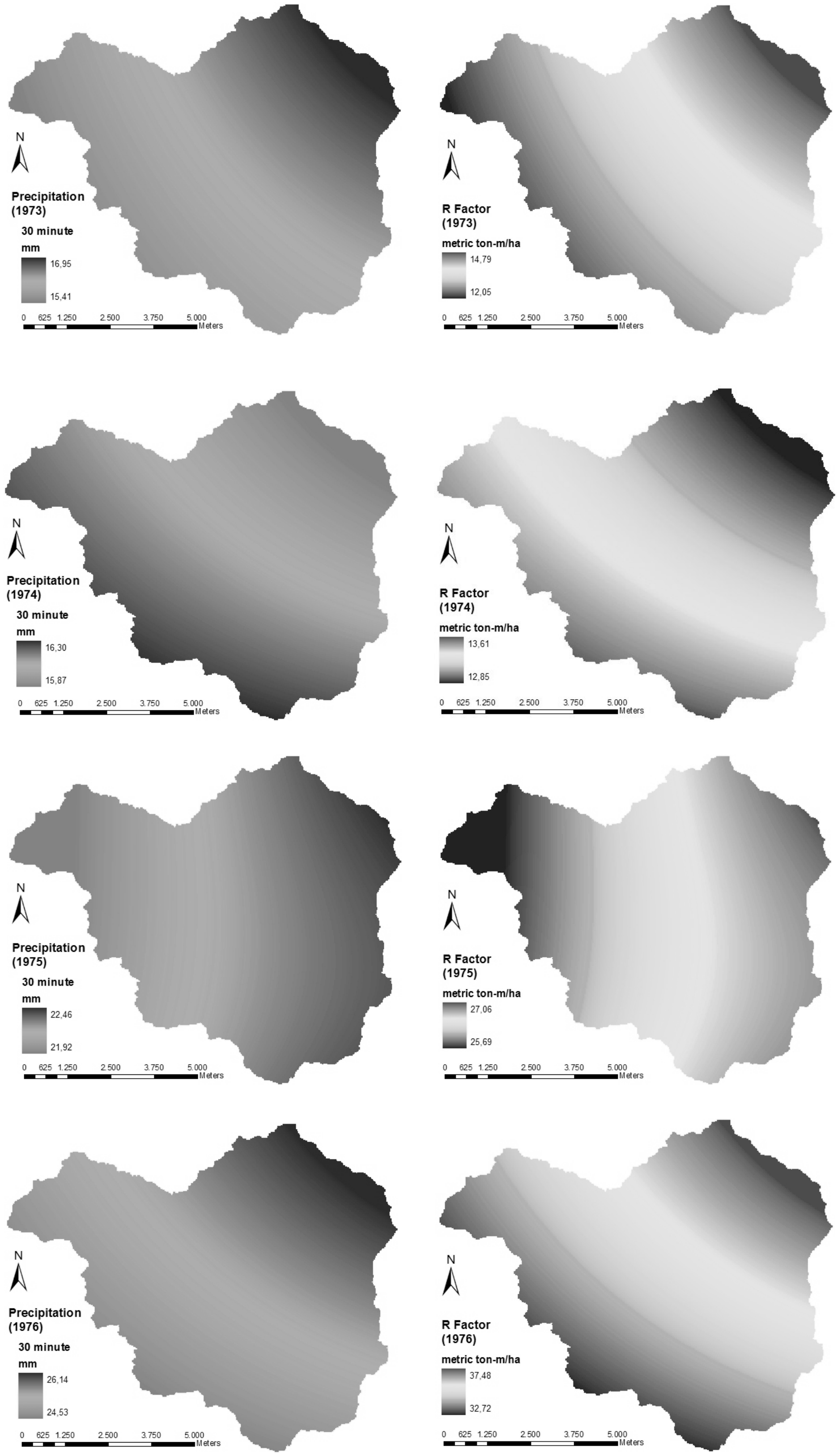


Figure E.3 Interpolation results for precipitation and USLE-R factors (1973-1976).

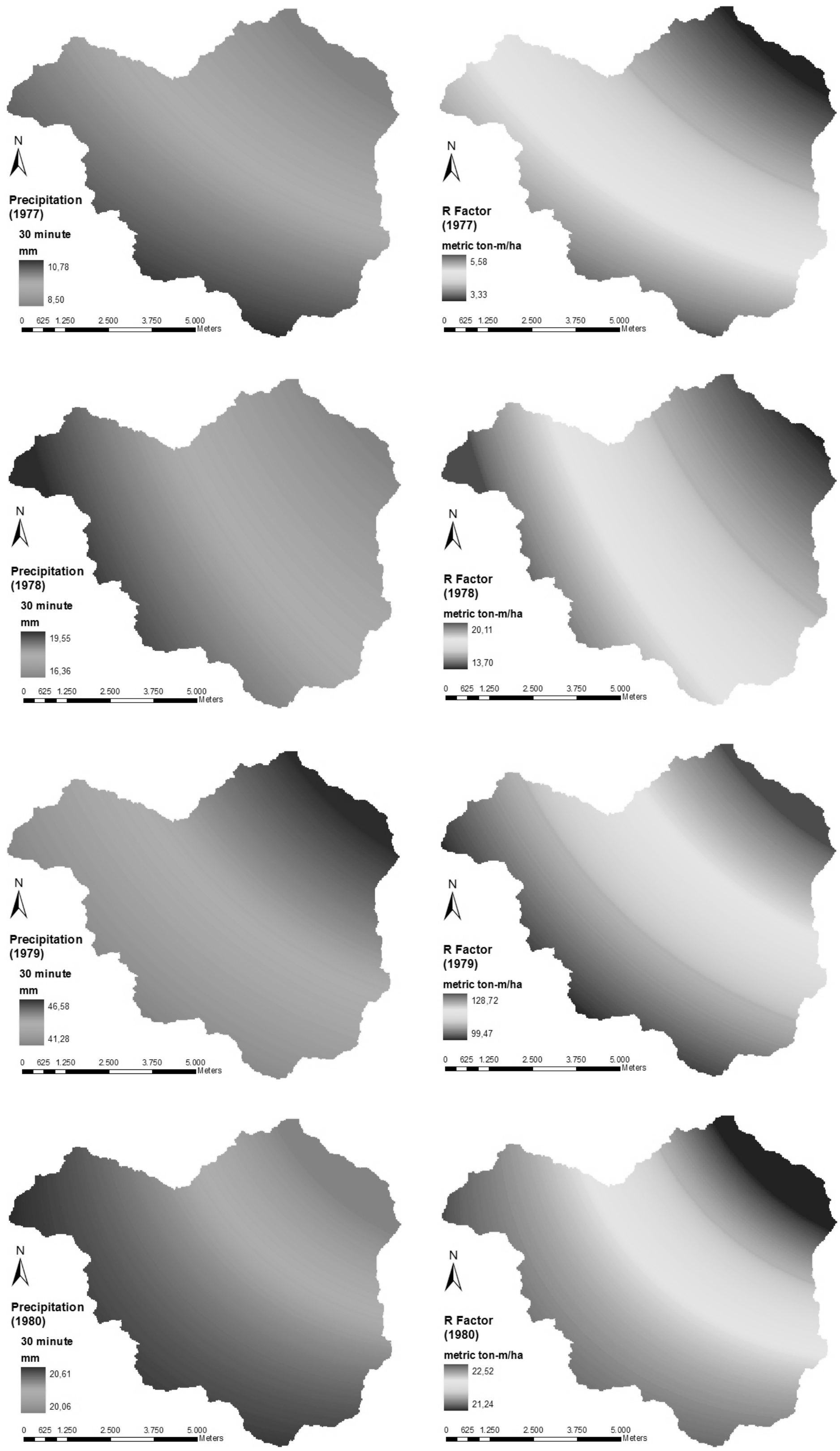


Figure E.4 Interpolation results for precipitation and USLE-R factors (1977-1980).

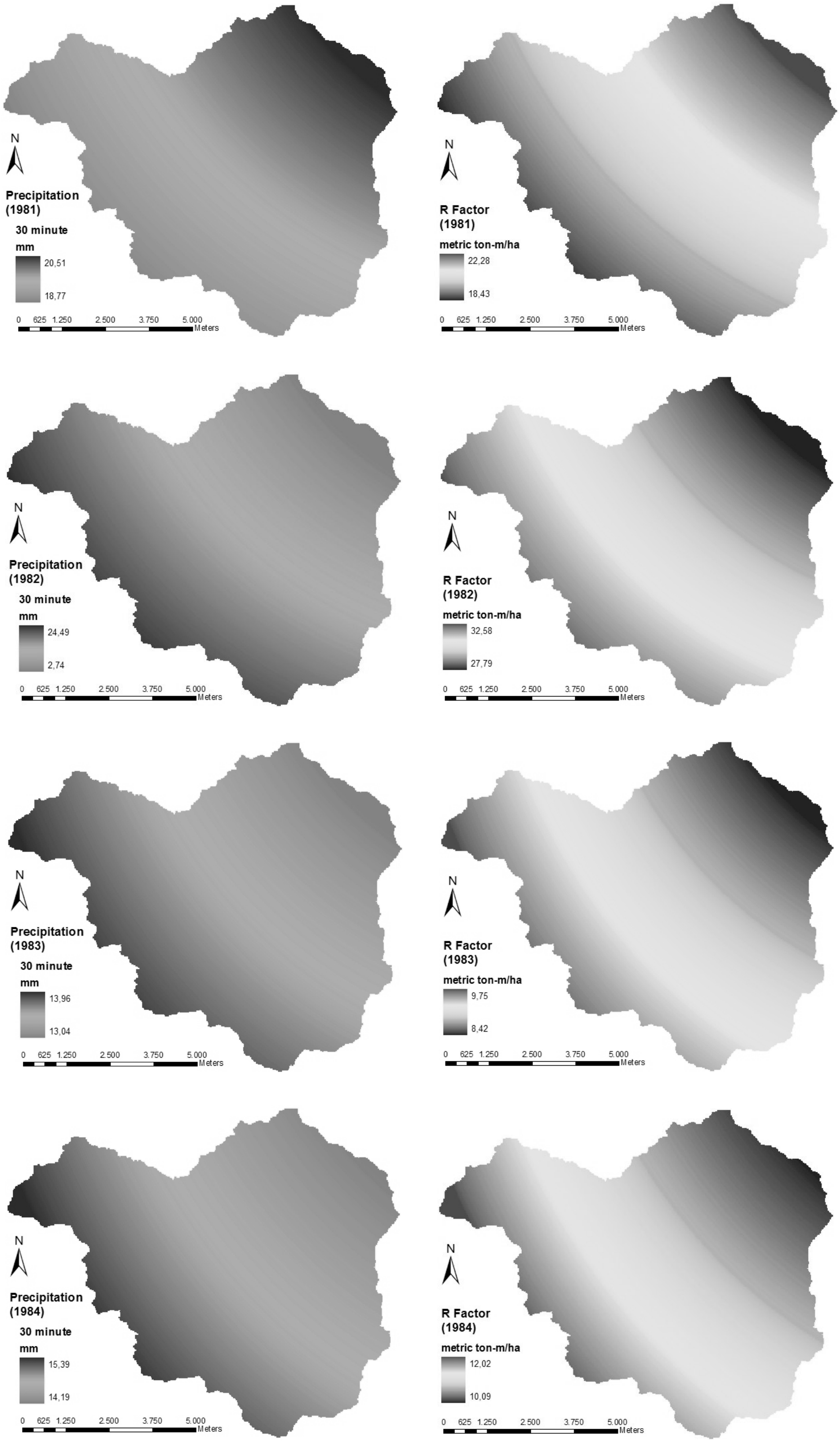


Figure E.5 Interpolation results for precipitation and USLE-R factors (1981-1984).

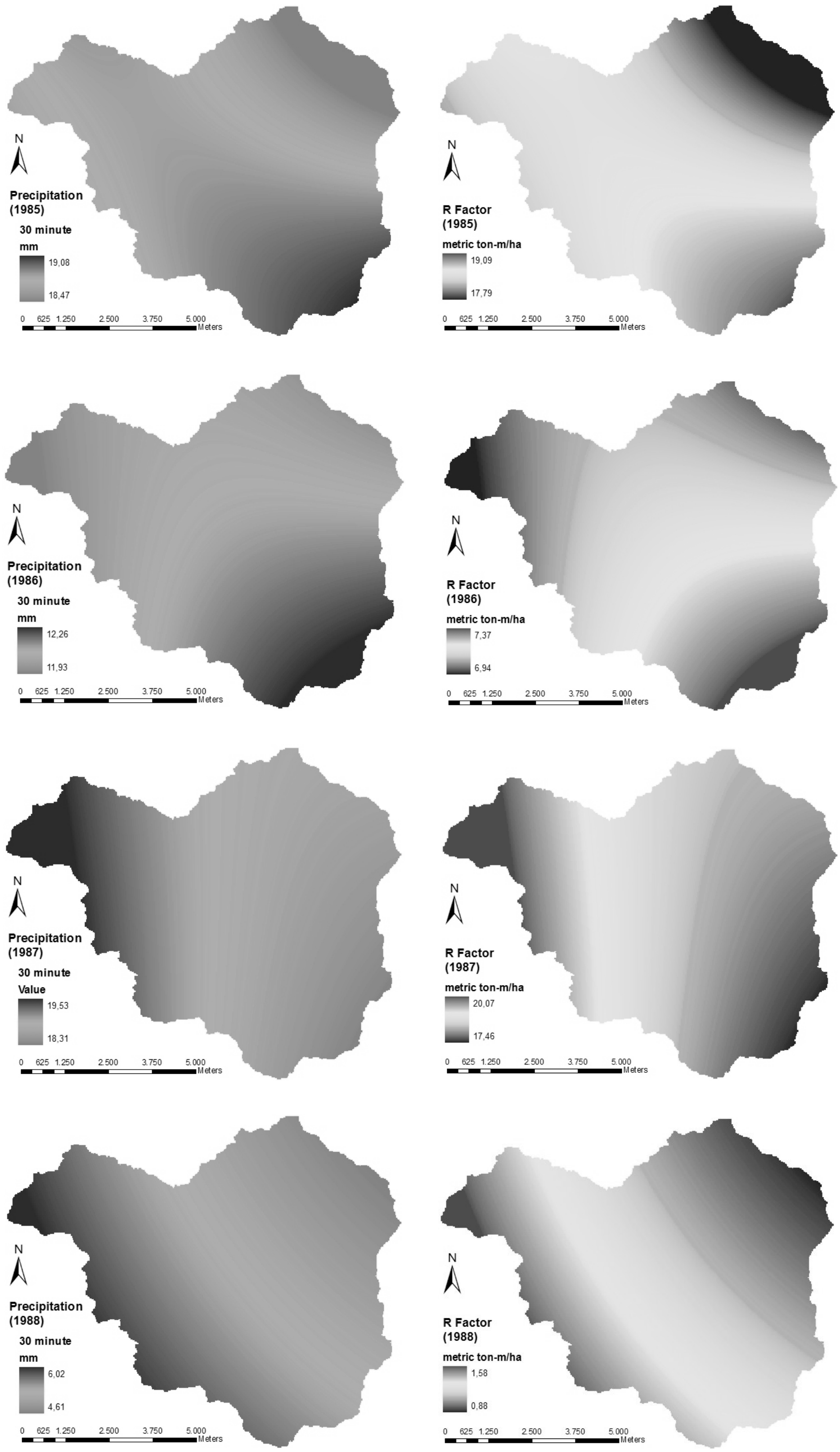


Figure E.6 Interpolation results for precipitation and USLE-R factors (1985-1988).

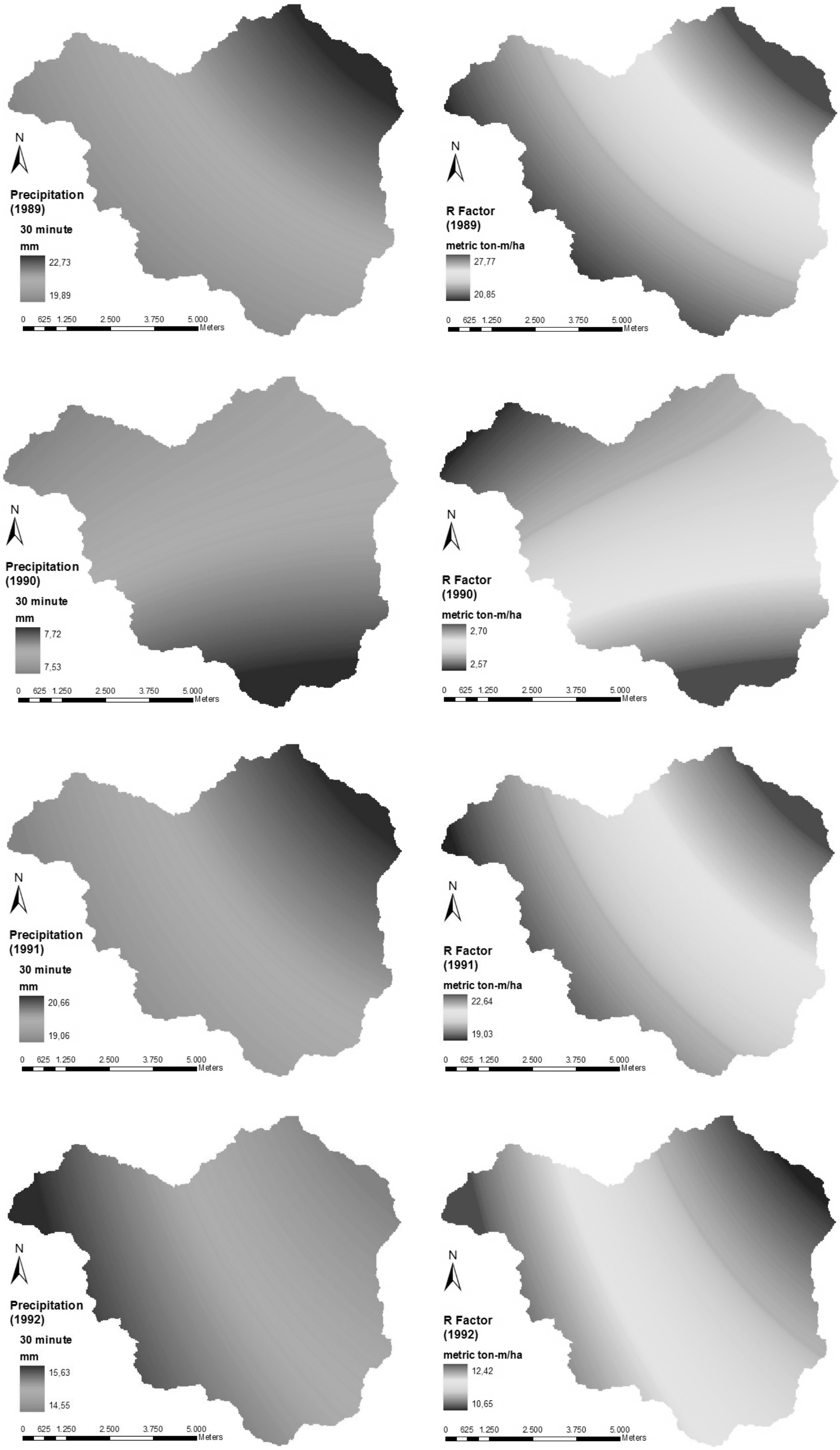


Figure E.7 Interpolation results for precipitation and USLE-R factors (1989-1992).

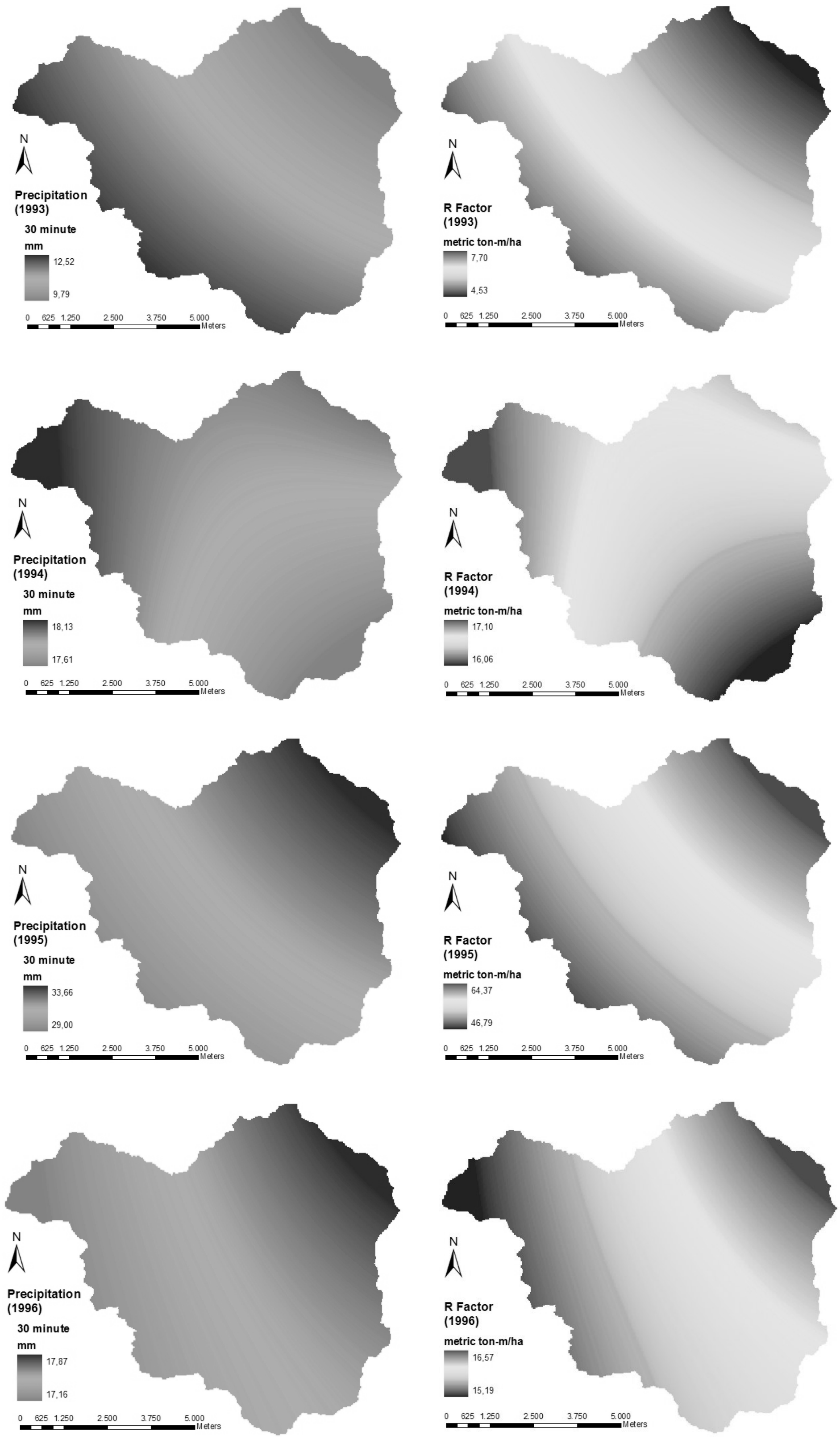


Figure E.8 Interpolation results for precipitation and USLE-R factors (1993-1996).

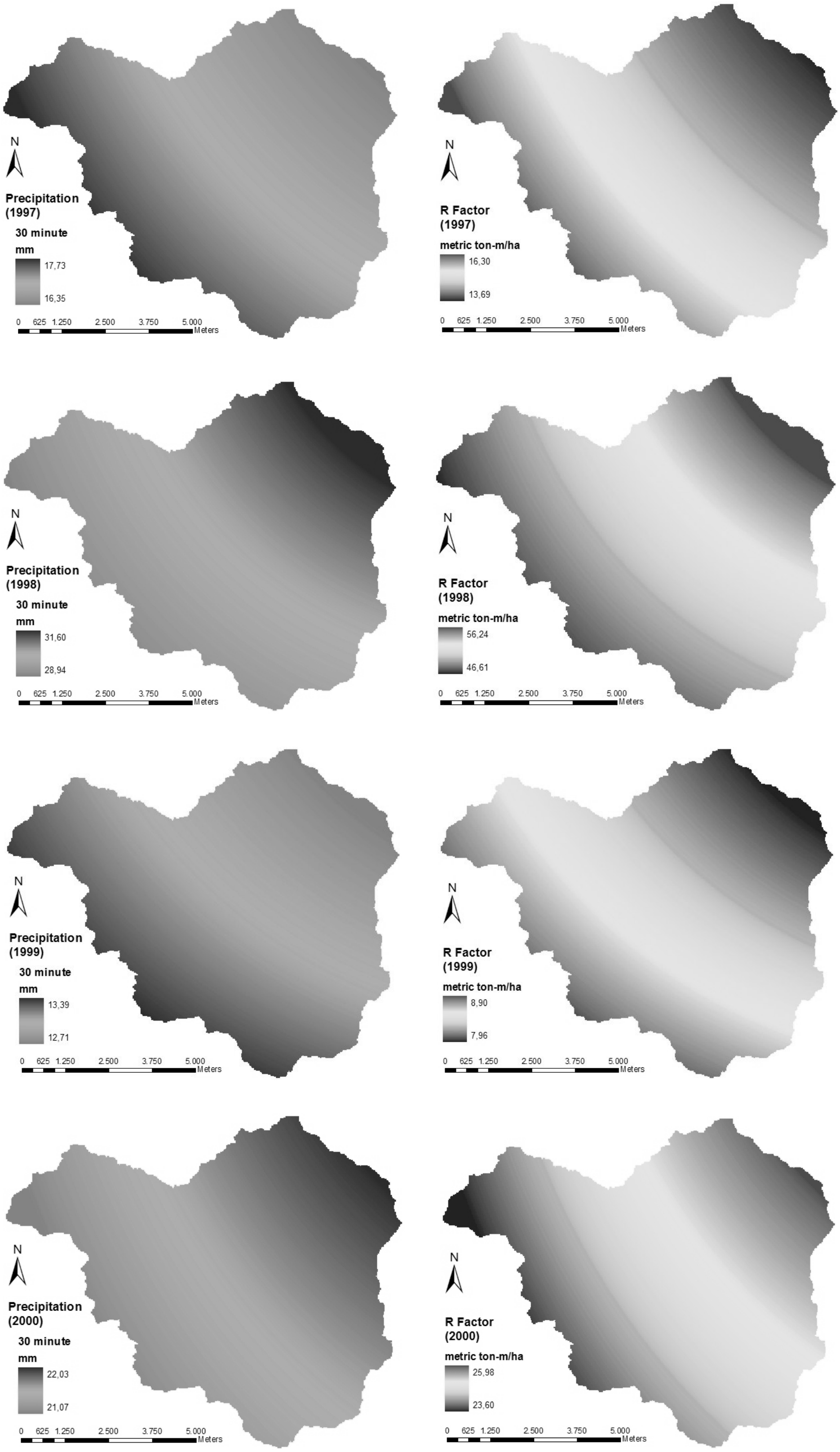


Figure E.9 Interpolation results for precipitation and USLE-R factors (1997-2000).

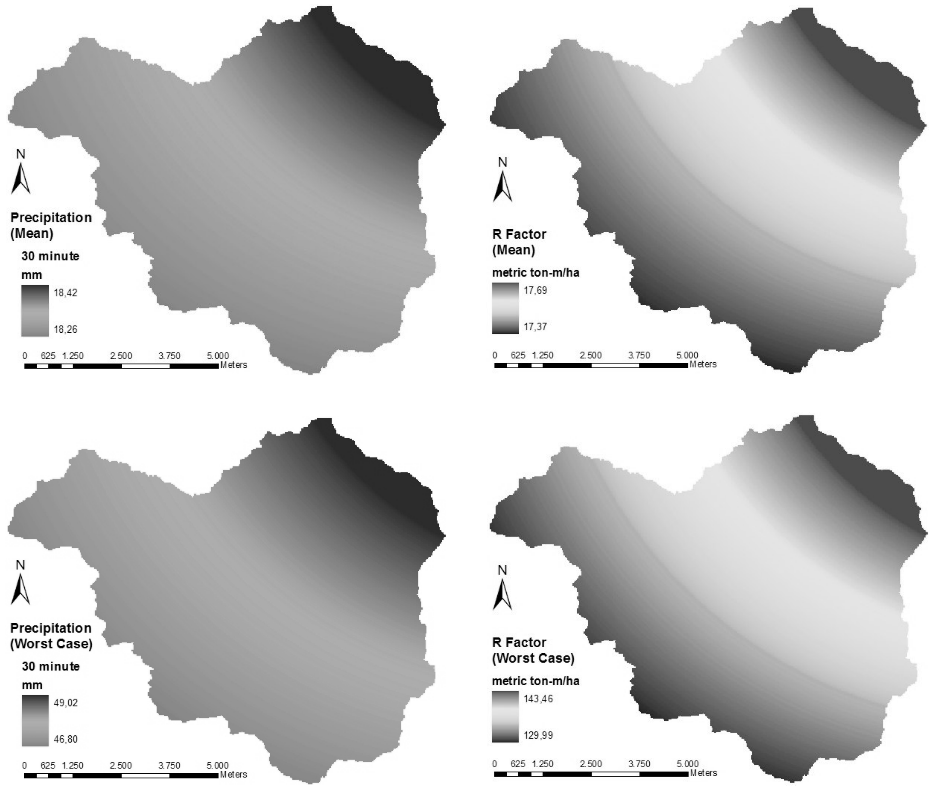


Figure E.10 Interpolation results for precipitation and USLE-R factors (mean, worst case).

APPENDIX F

HICKEY'S USLE-LS AML CODE

```
/* sl.aml *****************************************************************
/* The input : a grid of elevations.
   /* The elevations must be in the same units as the horizontal distance.
          /* The unit of measurement for the elevation grid.
          /* The change in slope(as a %) that will cause the slope length
          /* calculation to stop and start over.
/* The output: a grid of cumulative slope lengths,
         /*: a grid of LS values for the soil loss equation,
         /*: an optional grid of down hill slope angle.
/* Usage: sl <elevation grid> <slope length grid> <LS value grid>
        /* {FEET | METER} {cutoff value} {slope angle grid}

&args sl_elev sl_out LS_out grd_units cutoff_value sl_angle

/* Convert user input to capital letters ***********************************
&sv .grid_units = [translate %grd_units%]

/* Set default cutoff value if necessary **********************************
&if [null %cutoff_value%] or [index %cutoff_value% #] eq 1 &then

   &sv .slope_cutoff_value = .5
&else

   &sv .slope_cutoff_value = [calc [value cutoff_value] / 100]

/* Set the grid environment *********************************************
setcell   %sl_elev%
setwindow %sl_elev%
&describe %sl_elev%

/* Create a depressionless DEM ******************************************
&run fil.aml %sl_elev% sl_DEM

/* Create an outflow direction grid **************************************
sl_outflow = flowdirection(sl_DEM)

/* Create a possible inflow grid ******************************************
sl_inflow = focalflow(sl_DEM)

/* Calculate the degree of the down slope for each cell ******************
&run dn_slope.aml sl_DEM sl_slope

/* Calculate the slope length for each cell *******************************
&sv cell_size       = [show scalar $$cellsize]
&sv diagonal_length = 1.414216 * %cell_size%
```

```
   /* Convert to radians for cos--to calculate slope length
if (sl_outflow in {2, 8, 32, 128})
   sl_length = %diagonal_length%
else
   sl_length = %cell_size%
endif

/* Set the window with a one cell buffer to avoid NODATA around the edges **
setwindow [calc [show scalar $$wx0] - [show scalar $$cellsize]] ~
        [calc [show scalar $$wy0] - [show scalar $$cellsize]] ~
        [calc [show scalar $$wx1] + [show scalar $$cellsize]] ~
        [calc [show scalar $$wy1] + [show scalar $$cellsize]]

/* Create a new flow direction grid with a one cell buffer ***************
sl_flow = sl_outflow
kill sl_outflow
sl_outflow = con(isnull(sl_flow), 0, sl_flow)
kill sl_flow

/* Create a grid of the high points and NODATA *************************
   /* The high points will have 1/2 their cell slope length for VALUE ***
&run high_pts.aml

/* Create a grid of high points and 0's **********************************
   /* This will be added back in after the slope lengths for all other ****
   /* cells has been determined for each iteration ***********************
sl_high_pts = con(isnull(sl_cum_l), 0, sl_cum_l)

/* Calculate the cumulative slope length for every cell ******************
&run s_length.aml

/* Calculate the LS value for the soil loss equation *********************
&run ls.aml

/* Reset window and mask *********************************************
setwindow %sl_elev%
setmask   %sl_elev%
setmask   off

/* Kill temporary grids *************************************************
kill sl_(!DEM outflow inflow length high_pts!)

/* Set the output grid names to the user input **************************
rename sl_cum_l  %sl_out%
rename ls_amount %LS_out%
&if [null %sl_angle%] &then

   kill sl_slope
&else

   rename sl_slope %sl_angle%
&return
```

```
/* fil.aml ****************************************************************
/* The input : a grid of elevations
/* The output: a depressionless elevation grid.
/* Usage: fil

&args DEM_grid fil_DEM

/* Copy original elevation grid ******************************************
%fil_DEM% = %DEM_grid%

/* Create a depressionless DEM grid *************************************
finished = scalar(0)
&do &until [show scalar finished] eq 1
   finished = scalar(1)
   rename %fil_DEM% old_DEM
   if (focalflow(old_DEM) eq 255) {
      %fil_DEM% = focalmin(old_DEM, annulus, 1, 1)
      test_grid = 0
   }
   else {
      %fil_DEM% = old_DEM
      test_grid = 1
   }
   endif
   kill old_DEM
      /* Test for no more sinks filled ************************************
   docell
      finished {= test_grid
   end
   kill test_grid
&end

&return
```

```
/* dn_slope.aml ********************************************************
/* The input : a grid of elevations with no depressions

/* The output: a grid of down slopes in degrees.
/* Usage: dn_slope

&args DEM_grid down_slope

/* Compute the outflow direction for each cell ***************************
dn_outflow = flowdirection(%DEM_grid%)

/* Set the window with a one cell buffer ********************************
&describe %DEM_grid%
setwindow [calc [show scalar $$wx0] - [show scalar $$cellsize]] ~
        [calc [show scalar $$wy0] - [show scalar $$cellsize]] ~
        [calc [show scalar $$wx1] + [show scalar $$cellsize]] ~
        [calc [show scalar $$wy1] + [show scalar $$cellsize]]

/* Create a DEM with a one cell buffer ***********************************
   /* This prevents NODATA being assigned to the edge cells that flow
   /* off the DEM. Cells that flow off the DEM will get 0 slope ************
dn_buff_DEM = con(isnull(%DEM_grid%), focalmin(%DEM_grid%),
%DEM_grid%)

/* Calculate the down slope in degrees **********************************
&sv cell = [show scalar $$cellsize]
   /* The () pervent problems that occur with using whole numbers ****
&sv cell_size       = (1.00 * %cell%)
&sv diagonal_length = (1.414216 * %cell_size%)
   /* find down slope cell and calculate slope ***************************
if (dn_outflow eq 64)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(0, -1)) div ~
              %cell_size%)
else if (dn_outflow eq 128)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(1, -1)) div ~
              %diagonal_length%)
else if (dn_outflow eq 1)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(1, 0)) div ~
              %cell_size%)
else if (dn_outflow eq 2)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(1, 1)) div ~
              %diagonal_length%)
else if (dn_outflow eq 4)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(0, 1)) div ~
              %cell_size%)
else if (dn_outflow eq 8)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(-1, 1)) div ~
              %diagonal_length%)
else if (dn_outflow eq 16)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(-1, 0)) div ~
              %cell_size%)
else if (dn_outflow eq 32)
   %down_slope% = deg * atan((dn_buff_DEM - dn_buff_DEM(-1, -1)) div ~
              %diagonal_length%)
else
   %down_slope% = 0.00
endif
```

```
/* Reset old settings *****************************************************
setwindow %DEM_grid%

/* Clip the output grid ***************************************************
dn_slope = %down_slope%
kill %down_slope%
rename dn_slope %down_slope%

/* Kill the temporary grids **********************************************
kill dn_buff_DEM
kill dn_outflow

&return
```

```
/* high_pts.aml **********************************************************
/* This is not a stand alone AML ****************************************
   /* Grids used from sl.aml:
      /* sl_outflow
      /* sl_inflow
      /* sl_slope
   /* Grid produced for sl.aml:
      /* sl_cum_l

/* Find the high points and set value to half their own slope length *****
/* A high point is a cell that has no points flowing into it or if the only
/* cells flowing in to it are of equal elevation. ***************************
if ((sl_inflow && 64) and (sl_outflow(0, -1) eq 4))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 128) and (sl_outflow(1, -1) eq 8))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 1) and (sl_outflow(1, 0) eq 16))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 2) and (sl_outflow(1, 1) eq 32))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 4) and (sl_outflow(0, 1) eq 64))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 8) and (sl_outflow(-1, 1) eq 128))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 16) and (sl_outflow(-1, 0) eq 1))
   sl_cum_l = setnull(1 eq 1)
else if ((sl_inflow && 32) and (sl_outflow(-1, -1) eq 2))
   sl_cum_l = setnull(1 eq 1)
   /* Flat high points get 0 instead of 1/2 slope length ******************
else if (sl_slope eq 0)
   sl_cum_l = 0.0
else
   sl_cum_l = 0.5 * sl_length
endif

&return
```

```
/* s_length.aml ************************************************************
/* This is not a stand alone AML ****************************************
   /* Grids used from sl.aml:
      /* sl_inflow
      /* sl_outflow
      /* sl_slope
      /* sl_length
      /* sl_high_pts
      /* sl_DEM
   /* Grid produced for sl_aml:
      /* sl_cum_l

/* Pervents the testing of the buffer cells ********************************
setmask sl_DEM

/* Calculate the cumulative slope length for each cell *******************
nodata_cell  = scalar(1)
&sv finished = .FALSE.
&do &until %finished%
   rename sl_cum_l sl_out_old
   &sv counter = 0
   &do counter = 1 &to 8

      /* Set the varibles for the if that follows
   &select %counter%
      &when 1
         &do

         &sv from_cell_grid          = sl_north_cell
         &sv from_cell_direction     = 4
         &sv possible_cell_direction = 64
         &sv column                  = 0
         &sv row                     = -1
         &end

      &when 2
         &do

         &sv from_cell_grid          = sl_NE_cell
         &sv from_cell_direction     = 8
         &sv possible_cell_direction = 128
         &sv column                  = 1
         &sv row                     = -1
         &end

      &when 3
         &do

         &sv from_cell_grid          = sl_east_cell
         &sv from_cell_direction     = 16
         &sv possible_cell_direction = 1
         &sv column                  = 1
         &sv row                     = 0
         &end

      &when 4
         &do
```

```
    &sv from_cell_grid         = sl_SE_cell
    &sv from_cell_direction     = 32
    &sv possible_cell_direction = 2
    &sv column                 = 1
    &sv row                   = 1
    &end

  &when 5
    &do

    &sv from_cell_grid         = sl_south_cell
    &sv from_cell_direction     = 64
    &sv possible_cell_direction = 4
    &sv column                 = 0
    &sv row                   = 1
    &end

  &when 6
    &do

    &sv from_cell_grid         = sl_SW_cell
    &sv from_cell_direction     = 128
    &sv possible_cell_direction = 8
    &sv column                 = -1
    &sv row                   = 1
    &end

  &when 7
    &do

    &sv from_cell_grid         = sl_west_cell
    &sv from_cell_direction     = 1
    &sv possible_cell_direction = 16
    &sv column                 = -1
    &sv row                   = 0
    &end

  &when 8
    &do

    &sv from_cell_grid         = sl_NW_cell
    &sv from_cell_direction     = 2
    &sv possible_cell_direction = 32
    &sv column                 = -1
    &sv row                   = -1
    &end

&end


  /* Test for possible flow source cell
if (not(sl_inflow && %possible_cell_direction%))
  %from_cell_grid% = 0
  /* Test for flow source cell
else if (sl_outflow(%column%, %row%) <> %from_cell_direction%)
  %from_cell_grid% = 0
```

```
      /* Test flow source cell for nodata
   else if (isnull(sl_out_old(%column%, %row%)))
      %from_cell_grid% = setnull(1 eq 1)
      /* Test current cell slope against cutoff value
   else if (sl_slope >= (sl_slope(%column%, %row%) * %.slope_cutoff_value%))
      %from_cell_grid% = sl_out_old(%column%, %row%) + ~
                   sl_length(%column%, %row%)
   else
      %from_cell_grid% = 0
   endif
   &end


      /* Select the longest slope length
   sl_cum_l = max(sl_north_cell, sl_NE_cell, sl_east_cell, sl_SE_cell, ~
              sl_south_cell, sl_SW_cell, sl_west_cell, sl_NW_cell, ~
              sl_high_pts)

      /* Kill the temporary grids
   kill (!sl_north_cell sl_NE_cell sl_east_cell sl_SE_cell ~
        sl_south_cell sl_SW_cell sl_west_cell sl_NW_cell!)
   kill sl_out_old

      /* Test for the last iteration filling in all cells with data
   &sv no_data = [show scalar nodata_cell]
   &if %no_data% eq 0 &then

      &sv finished = .TRUE.

      /* Test for any nodata cells
   if (isnull(sl_cum_l) and not isnull(sl_outflow))
      sl_nodata = 1
   else
      sl_nodata = 0
   endif
   nodata_cell = scalar(0)
   docell
      nodata_cell }= sl_nodata
   end
   kill sl_nodata

&end


/* Reset original window and clip the cumulative slope length grid *****
setwindow sl_DEM
rename sl_cum_l sl_out_old
sl_cum_l = sl_out_old
kill sl_out_old
&return
```

```
/* ls.aml ***************************************************************
/* This is not a stand alone AML ***************************************
   /* Grids used from sl.aml:
      /* sl_cum_l
      /* sl_slope
   /* Grid produced for sl.aml:
      /* ls_amount
/* Convert meters to feet if necessary ***********************************
&if %.grid_units% eq METERS &then

   ls_length = sl_cum_l div 0.3048
&else
   ls_length = sl_cum_l
/* Calculate LS for the soil loss equation *******************************
   /* For cells of depostion
if (ls_length eq 0)
   ls_amount = 0
   /* For slopes 5% and over
else if (sl_slope >= 2.862405)
   ls_amount = pow((ls_length div 72.6), 0.5) * ~
         (65.41 * pow(sin(sl_slope div deg), 2) + ~
          4.56 * sin(sl_slope div deg) + 0.065)
   /* For slopes 3% to less than 5%
else if ((sl_slope >= 1.718358) and (sl_slope < 2.862405))
   ls_amount = pow((ls_length div 72.6), 0.4) * ~
         (65.41 * pow(sin(sl_slope div deg), 2) + ~
         4.56 * sin(sl_slope div deg) + 0.065)
   /* For slopes 1% to less than 3%
else if ((sl_slope >= 0.572939) and (sl_slope < 1.718358))
   ls_amount = pow((ls_length div 72.6), 0.3) * ~
         (65.41 * pow(sin(sl_slope div deg), 2) + ~
         4.56 * sin(sl_slope div deg) + 0.065)
   /* For slopes under 1%
else
   ls_amount = pow((ls_length div 72.6), 0.2) * ~
         (65.41 * pow(sin(sl_slope div deg), 2) + ~
         4.56 * sin(sl_slope div deg) + 0.065)
endif

/* kill temporary grids ***************************************************
kill ls_length
&return
```