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TC.
DOKUZ EYLUL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

THE USE OF GEOGRAPHIC
INFORMATION SYSTEMS (GIS)
IN WATER RESOURCES
RESEARCH AND MANAGEMENT

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İZMİR

PREFACE

With in the last decade, the use of geographic information systems (GIS) for spatial hydrologic data analysis has provided many benefits for water resources planning and management. A well-designed GIS can help the planners to assess and accomplish the best management decisions and practices.

The study herein is an introduction to GIS and its applications in water resources research. The study also demonstrates the use of GIS in identification of erosion and erosion-based pollution. For that purpose, the USLE model and GIS are integrated to arrive at spatial distributions of model parameters, to define critical regions with respect to erosion, and finally to estimate gross erosion and organic N transport from a small watershed.

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ÖZET

Su kaynakları yönetiminde mevcut etkenlerin karmaşıklığı, bu etkenlerin içerdiği belirsizlik ve amaçların çeşitliliği, planlama ve yönetim kararlarının oluşturulmasında planlamacıları yoğun bir biçimde model kurma yoluna itmiştir. Kurulan bu modeller, hidrolojik süreçlere etki eden parametrelerin alansal değişkenlikleri nedeniyle yetersiz kalmakta; ancak son yıllarda bu sorun Coğrafi Bilgi Sistemleri (CBS) adı verilen yeni teknolojiler sayesinde bir ölçüde giderilebilmiştir.

Sunulan çalışma CBS'nin temel özelliklerini tanıtmının yanı sıra bu sistemlerin su kaynaklarında kullanılabilirliklerini irdelemektedir. Çalışmada, su kaynaklarındaki mevcut CBS uygulamaları tanıtılmış, örnek bir uygulama üzerinde sistem ihtiyaçları, teknik avantajları ve veri gereksinimleri açıklanmaya çalışılmıştır.

Örnek uygulamada, erozyon ve erozyon kaynaklı kirlilik kaynaklarının CBS destekli bir yöntemle tesbitine çalışılmıştır. Bunun için su erozyonunun tahmin edilmesinde yaygın bir biçimde kullanılan Üniversal Toprak Kaybı Eşitliği (USLE) denkleminin CBS ile entegrasyonu sağlanmış; örnek bir havza üzerinde erozyon, sediment yükleri ve buna bağlı organik N yükleri tesbit edilmeye çalışılmıştır.

Ülkemizde USLE denkleminin parametrelerine ilişkin yeterli alansal verilerin bulunmaması nedeniyle çalışma fiktif bir havza üzerinde gerçekleştirilmiştir. Dolayısıyla çalışma, CBS katkısıyla model çalışmalarında hızlı ve etkin bir yöntem geliştirmeyi ve yeterli verilerin mevcut olması halinde gerçek bir havzada çalışmaların hangi aşamaları içermesi gerektiğini belirlemeyi amaçlamaktadır.

Çalışmada, USLE denklem parametreleri ilgili haritaların sayısallaştırılmasıyla elde edilmiş ve bu parametreler CBS ortamında USLE modeline girdi olarak sokulmuştur. USLE modelinden elde edilen alt havzaların erozyon ve sediment yükleri, sedimentle birlikte taşınan organik N miktarlarının hesaplanması için geliştirilen azot taşınım modelinde kullanılmıştır. Bu hesaplamaların tümü CBS ortamında gerçekleştirilmiş dolayısıyla parametrelerin alansal dağılımları göz önüne alınabilmektedir.

Sonuç olarak havzanın toplam erozyon, sediment yükleri ve buna bağlı organik N yüklerinin alansal dağılımları elde edilmiştir.

Uygulama CBS'nin, su kaynaklarının planlanmasında yeterli alansal verilerin mevcut olması halinde etkin bir kullanım alanı bulabileceğini ve CBS'nin alansal analizlerde ne derece önemli rol oynadığını göstermektedir.

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ABSTRACT

The complexity and uncertainty of management objectives and parameters involved in water resources management have led planners to consult intensively to mathematical models in the description of natural phenomena. However, such models are often found to be deficient due to the spatial variation of model parameters and inputs. Recently, a new technology called "the Geographic Information Systems" or GIS has been developed to effectively solve this problem. The technique has found a wide area of application in water resources planning and management as well as in various other fields where the spatial distribution of effective parameters is significant.

The study presented introduces various characteristics of GIS and discusses its applicability in water resources engineering. Current GIS applications are presented together with the case of erosion and erosion based pollution identification, pointing out to advantages of the technique, requirements for its application, and various types of information that GIS can process.

For the case of erosion and erosion based pollution identification, GIS and USLE (Universal Soil Loss Equation) are integrated. USLE is a method which is used widely to determine soil loss in a small watershed. Due to the lack of sufficient spatial information in Turkey, the case study is carried out on a demonstrative basin. Basically, it is aimed in the study to develop a methodology which can be applied to a real basin if sufficient data are available. The parameters (R, K, LS, C, P) that USLE requires for soil loss estimation are derived in digital format by digitizing associate paper maps. The soil losses are computed by the USLE model where the manipulations of each digital-parameter-layer are realized in the GIS domain. Organic N pollution, which is transported by clay particles in sediment, is estimated by applying the enrichment concept of contaminants to sediment yield computed by USLE.

As a result spatial distributions of erosion and organic N in the demonstration basin are obtained by using GIS functions.

The case study has shown that GIS is a very powerful tool for analyzing the spatial properties of basin management components so that the best management decisions and practices can be obtained.

On the other hand, the presented work has also delineated the fact that the use of GIS at the most efficient level requires sufficient and suitable databases and an understanding of GIS system capabilities.

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I. INTRODUCTION

In recent times, river basin management has become highly complicated as an understanding is required, not only of the physical processes involved, but also of the man-made interferences such as land use, discharge and control of pollutants, construction of complex water structures, etc. Thus, problems encountered in management are no longer point events but spatially distributed occurrences. Accordingly, effective solutions can only be realized by investigating the phenomena and parameters underlying these problems on a spatially distributed basis. Furthermore, efficient management decisions often require development of scenarios to be tested and assessed in the regional or basin-wide scale.

The complexity in the analysis of spatial events has recently been facilitated by the introduction of a new technology called the geographical information systems (GIS). GIS are computer based systems which permit the representation of various types of spatially distributed inputs and outputs to and from physical system. They help not only to investigate the distribution of physical and demographic processes and parameters, but also to develop their interrelations. Furthermore, GIS can be effectively integrated with basin simulation models so that they perform as effective management tools. This is due to the fact that different management scenarios may be evaluated via model-GIS integration to arrive at optimum decisions. As such, GIS have been extensively used within the last decade in the analysis of water resources problems such as flood control, basin simulation and management, assessment of water pollution due to point and nonpoint sources, erosion control, and the similar. The application of the GIS in Turkey is fairly new; at present, researchers and planners are at the stage of learning the system rather than applying it to real cases.

The presented study is intended as an introduction to the application of GIS in water resources research. Within this respect, system characteristics, capabilities and requirements are analyzed to first identify the basis of a GIS application. Next the system is applied to the solution of a particular problem to demonstrate its applicability to basin management problems. The problem selected is the identification of rainfall-based erosion and the transport of nonpoint source pollution loads to water courses. Such an application is realized by the integration of GIS and the wellknown USLE (Universal Soil Loss Equation) approach.

An effective investigation of soil loss within a watershed by using GIS - USLE integration requires spatially distributed data on several parameters describing the basin. Such parameters include topography, rainfall characteristics, soil types, vegetation, land use, and the similar. In Turkey, data on most of these parameters are collected often on a local basis and therefore, a well-organized regional or basin-wide database is not available. Considering this lack of information, the case study is carried out by assumed values of regional parameters although a topographically known basin is selected. The results have shown that GIS can be effectively used to investigate critical regions within a basin with respect to erosion and to estimate nonpoint source pollution carried by sediment loads.

Some limitations encountered in the application stem from the limitations of the specific GIS software used. The study has shown that the use of GIS at the most efficient level requires sufficient databases and an understanding of GIS system capabilities.

In the following sections, an introduction is presented to characteristics of GIS systems and their use in water resources research. Next, the USLE method is presented to identify the nature of underlying parameters to be evaluated by GIS. In the application, GIS and USLE are integrated to identify the gross erosion, sediment loads, and organic N loads within a demonstration basin. It is foreseen that the study can be modified and revised in the future when sufficient data become available and when access can be made to a more advanced GIS software system.

II. INTRODUCTION TO GIS

2.1. The Identification of Geography in Earth Sciences

Geography is highly significant in our lives such that any part of the geography describing our environment affects almost every decision we make. Spatial features of geography often appear as a constraint or become an input for our decision systems by which we manage or plan several natural resources.

The collection of data about the spatial distribution of significant properties of the earth's surface has long been an important activity of organized societies. From the earliest civilizations to modern times, spatial data have been collected by navigators, geographers, and surveyors, and developed into pictorial forms by map makers or cartographers. The collection and compilation of data and the publication of a printed map is costly and time-consuming. Therefore, the extraction of single themes from a general purpose map can be highly expensive if the map must be redrawn by hand. In earlier times, the initially high cost of mapping were acceptable as maps were considered to be relevant for long periods such as 20 years or more. Recently, however, information is needed on the changing conditions of the earth's surface. In particular, most of the problems to be analyzed by earth sciences are no longer point events but spatially distributed occurrences. For such cases, conventional mapping techniques fail to produce adequate information. For example, some kinds of mapping, such as weather charts, there can be a daily or even hourly need for the spatial database to be updated, which is not possible by hand (Burrough, 1990).

Essentially, the hand-drawn map is an image of the situation seen through the particular filter of a given surveyor in a given discipline at a certain point in time. More recently, the aerial photograph, and particularly the satellite image have made it possible to see how landscapes change over time and to follow the slow development of desertification or erosion, or the fast progress of forest fires, floods, and other weather systems. However, the products of airborne and space sensors are not actually maps, but photographic images or streams of data on magnetic tapes. The digital data are not in the familiar form of points, lines and areas representing the known and classified features of the earth's surface, but are coded in the picture elements (pixels

or cells in two-dimensional matrix) that contain simply a number indicating the strength of the reflected electromagnetic radiation in a given band. Thus, new tools were needed to convert these series of numbers into pictures and to identify meaningful patterns. The cartographers initially did not possess the skills to use these new tools; therefore, the new sciences of remote sensing, image analysis and pattern recognition were developed, not by the traditional collectors of spatial data, but by mathematicians, physicists and computer scientists with significant support from military authorities. The approach of practitioners in these fields to imaging the earth is highly different from that of the conventional field scientists, surveyors and cartographers. In the beginning, they often exaggerated the abilities of remote sensing and image analysis to recognize and map the properties of the earth's surface without extensive ground surveys. It has been gradually realized that the striking images produced from remotely sensed data only have a real value if they can be linked to the situation on ground; that is, a certain amount of field survey is essential for proper interpretation. Furthermore, to facilitate calibration, the images have to be located properly with respect to a proper geodetic grid; otherwise, the information cannot be related to a definite place. The need arose for a linkage between remote sensing data, earth surveys and cartography which has been made possible by the class of mapping tools known as Geographic Information Systems, or GIS.

2.2. Historical Background of Computer Aided Mapping

During the 1960s and 1970s, new trends emerged in the use of mapped data for resource assessment, land evaluation and planning. The basic feature of those new approaches was the realization of the need for an integrated and multidisciplinary assessment of the earth's surface since it was observed that different aspects of this surface did not function independently of each other.

Cartographers had begun to use computer techniques in the 1960s, but these were often limited to aids for the automated drafting and preparation of masters for printed maps. For traditional cartography, the new computer technology did not change the basic approaches to map making.

By 1977, however, the experience of using computers in map making had advanced significantly. Rhind (1977) presented the following list of reasons for using computers in cartography:

1. to make existing maps more quickly and more cheaply;
2. to make maps for specific user needs;
3. to make map production possible in situations where skilled staff are not available;
4. to experiment with different graphical representations of the same data;
5. to facilitate map making and updating when the data are already in digital form;
6. to facilitate analyses of data that demand interaction between statistical analyses and mapping;
7. to minimize the use of the printed map as a data store and thereby to minimize the effects of classification and generalization on the quality of the data;
8. to create maps that are difficult to make by hand, e.g. 3-D maps or stereoscopic maps;
9. to create maps in which selection and generalization procedures are explicitly defined and consistently executed;
10. to make possible a review of the whole mapmaking process, which can also lead to savings and improvements.

The introduction of computer-assisted cartography did not always immediately lead to direct savings in costs as expected. The acquisition and development of the new tools was often extremely expensive, and there was (and there still is) a shortage of trained staff. Many purchasers of expensive systems had to hire programming staff to adapt a particular system to their needs. There were many uncertainties in many mapping organizations about what the new tools were supposed to do were they only for doing existing work more quickly, or were they for providing the users of spatial data with a much wider range of products? In some organizations, the new computer-assisted mapping tools were introduced into the system without the necessary structural changes in work flow and practices that would permit the new technology work efficiently. Consequently, in map production organizations, automation was usually applied in areas that were "safe", like accurate drafting, scanning contours, and preparing films for printing. Many cartographers did not realize that having mapped data in digital form presented them with powerful database that could be used for the analysis of many important spatial problems.

Consequently, during the 1960s and 1970s, there were two main trends in the application of the computer methods to mapping: one was the automation of existing tasks, with an emphasis on cartographic accuracy and visual quality, and the other with the emphasis on spatial analysis often without care for good graphical results. Further progress has been realized by new developments in computer technology within the last few years (Burrough, 1990).

2.3. Development of Geographic Information Systems

The history of using computers for mapping and spatial analysis shows that there have been parallel developments in automated data capture, data analysis, and presentation in several related fields. These fields are cadastral and topographical mapping, thematic cartography, civil engineering, geography, mathematical studies of spatial variation, soil science, surveying and photogrammetry, rural and urban planning, utility networks, and remote sensing and image analysis. Consequently, there has been significant duplication of effort for different applications in different areas. This multiplicity of effort in related fields has led to the possibility of linking many kinds of spatial data processing together into general-purpose geographical information systems, as technical and conceptual problems are overcome. (Fig.2.1.)

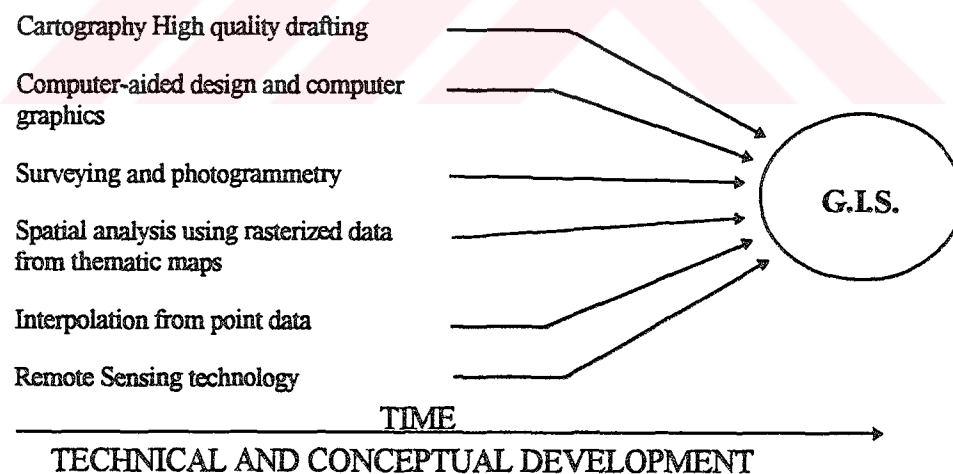


Figure 2.1. Geographical information systems as produced by linking parallel developments in many separate spatial data processing (Burrough, 1990).

Essentially, all the above disciplines are attempting the same kind of operation; namely, to develop a powerful set of tools for collecting, storing, retrieving, transforming, and displaying

spatial data from the real world. This particular set of tools constitutes a "Geographical Information System".

Geographical data describe objects from the real world in terms of;

- (a) their position with respect to a known coordinate system;
- (b) their attributes that are unrelated to position (such as color, cost, pH, etc.) and,
- (c) their spatial interrelations with each other (topological relations), which describe how they are linked together or how one can travel between them.

Geographical information systems differ from computer graphics because the latter are mostly concerned with the display and the manipulation of visible material. Computer graphics systems do not pay much attention to the non-graphic attributes that the visible material may have and which may be useful data for analysis. Good computer graphics are essential for a modern geographical information system but a graphics package is by itself not sufficient for performing the tasks expected, nor are such drawing packages necessarily a good basis for developing such a system (Burrough, 1990).

Geographical information systems have a lot in common with computer-aided-design (CAD) systems used for drafting several technical objects ranging from aeroplanes to the layout of a microchip. Both GIS and CAD systems must be able to relate objects to a frame of reference, and to describe topological relations. The major differences between GIS and CAD systems are the much greater volume and diversity of the data input to GIS systems and the special nature of the analysis methods used. These differences can be so large that an efficient system for CAD may be quite unsuitable for GIS, and vice versa.

Geographical information systems are much more than means of coding, storing, and retrieving data about the earth's surface. In essence, the data in a geographical information system, whether they are coded on a piece of paper or as invisible marks on the surface of magnetic tape, represent a model of the real world (Bouille, 1978). Because these data can be accessed, transformed, and manipulated interactively in a geographical information system, they can serve as a test material for studying environmental processes or for analyzing the results of trends, or of evaluating the possible results of planning decisions. By using the GIS, it is possible for planners

and decision-makers to investigate a range of possible scenarios and to obtain an idea of the consequences of a decision before action is taken in the landscape itself.

2.4. Components of a Geographical Information System

Geographical information systems have three important components—computer hardware, sets of application software modules, and a proper organizational context. These three components must be in balance if the system is to function satisfactorily.

2.4.1. Computer hardware

The general hardware components of a geographical information system are expressed as digitizer, plotter, screen (VDU), magnetic tape drive and the main unit, a CPU. The computer or central processing unit (CPU) is linked to a disk drive storage unit, which provides space for storing data and programs. A digitizer or a similar device is used to convert data from maps and documents into digital form and send them to the computer. A plotter or another kind of display device is used to present the results of data processing, and a tape drive is used for storing data or programs on magnetic tape, or for communicating with other systems. Inter-computer communication can also take place via a networking system over special data lines, or over telephone lines using a device known as a "modem". The user controls the computer and peripherals (i.e., plotters, printers, digitizers, and other apparatus linked to the computer) via a visual display unit (VDU), or a terminal. The user's terminal may be a microcomputer, or it may incorporate special hardware to allow maps to be displayed quickly. Fig. 2.2. shows the major hardware components of geographical information systems.

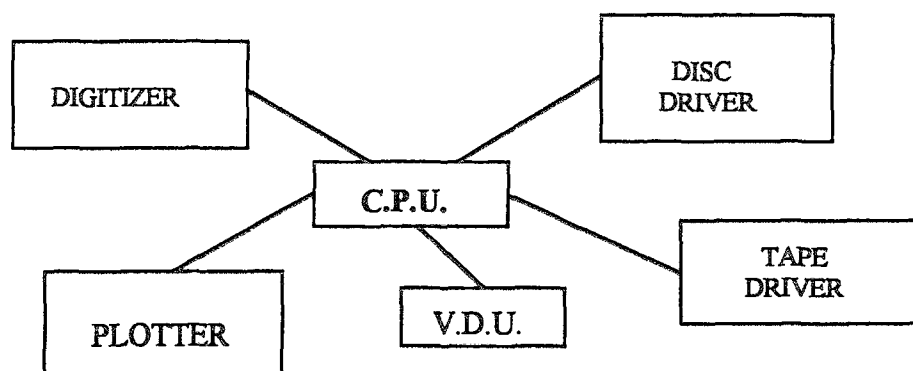


Figure 2.2. The major hardware components of a geographical information systems (Burrough, 1990).

2.4.2. GIS software modules

The software package for geographical information system consists of five basic technical modules. Fig. 2.3. shows the software modules of a geographic information system. These basic modules are sub-systems for:

- a) Data input and verification;
- b) Data storage and database management;
- c) Data output and presentation;
- d) Data transformation;
- e) Interaction with the user.

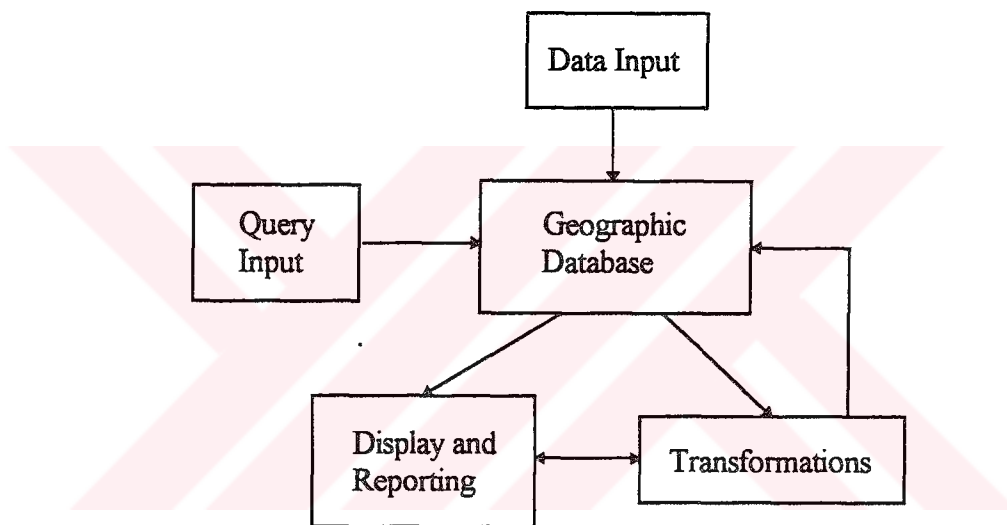


Figure 2.3. The main software components of a geographical information system.

Data input module covers all aspects of transforming data in the form of existing maps, field observations, and sensors (including aerial photography, satellites, and recording instruments) into a compatible digital form. A wide range of computer tools is available for this purpose, including the interactive terminal or visual display device (VDU), the digitizer, lists of data in text files, scanners (in satellites or aeroplanes for direct recording of data or for converting maps and photographic images) and the devices necessary for recording data already written on magnetic media such as tapes, drums, and disks. Fig. 2.4. shows a GIS data input module.

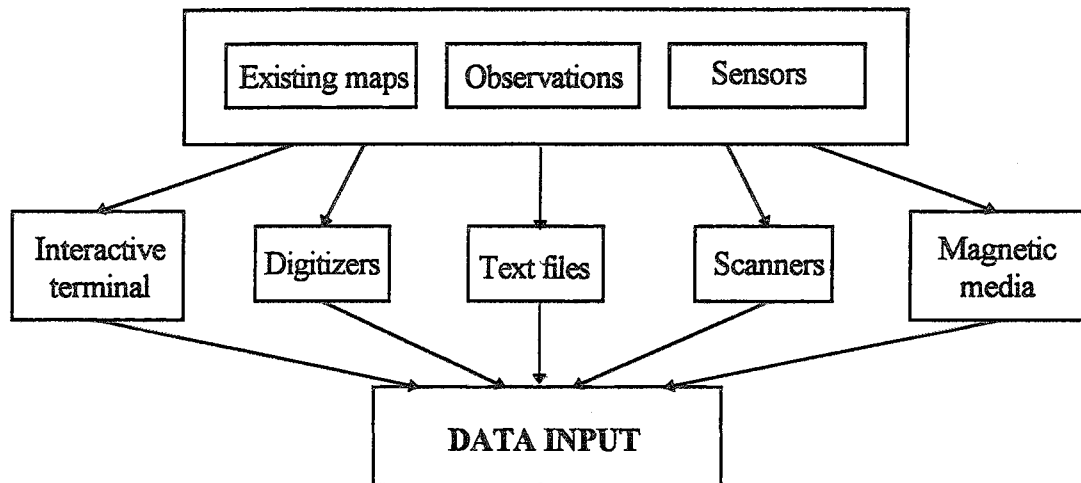


Figure 2.4. General representation of a GIS data input module.

Data storage and database management concerns the way in which the data about the position, linkages (topology), and attributes of geographical elements (points, lines, and areas representing objects on the earth's surface) are structured and organized, both with respect to the way they must be handled in the computer and to the way they are perceived by the users. The computer program used to organize the database is known a Database Management System (DBMS). Fig. 2.5. shows the components of a geographical database.

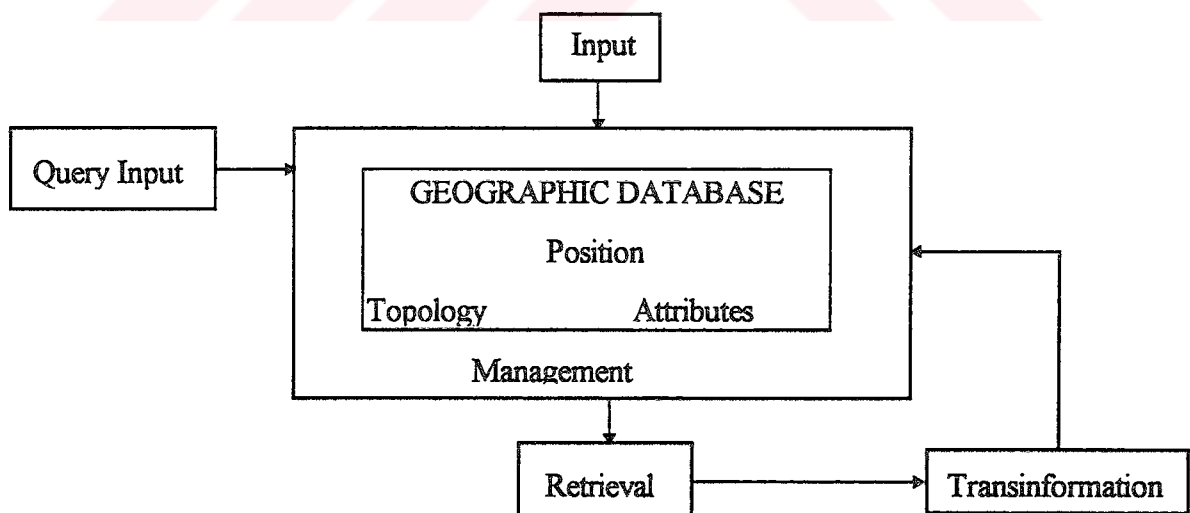


Figure 2.5. The components of the geographical database.

Data output and presentation concerns the ways by which data are displayed and by which results of analyses are reported to the users. Data may presented as maps, tables, and figures (graphs and charts) in different ways, ranging from the ephemeral image on a cathode ray tube (CRT) through hard-copy output drawn on printer or plotter to information recorded on magnetic media in digital form. Fig. 2.6. shows the general representation of a GIS output module.

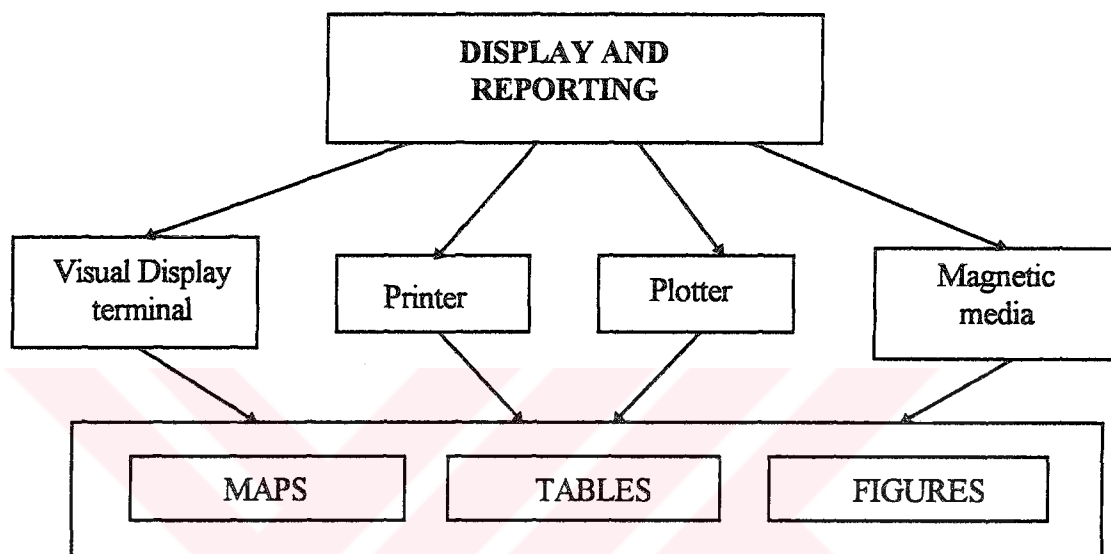


Figure 2.6. The general representation of a GIS output module.

Data transformation covers two classes of operation, namely: (a) transformations needed to remove errors from data, or update data or to match them to other data sets; and (b) numerous analysis methods that can be applied to the data in order to achieve answers to the questions asked of the GIS. Transformations can operate on the spatial and non-spatial aspects of the data, either separately or jointly. Many of these transformations, such as those associated with scale-changing, fitting data to new projections, logical retrieval of data, and calculation of areas and perimeters, are of such a general nature that one finds them in every kind of GIS in one form or another. Other kinds of operation may be extremely application-specific, and their incorporation into a particular GIS may be only to satisfy the particular users of that system. Fig.2.7. shows a schematic representation of GIS.

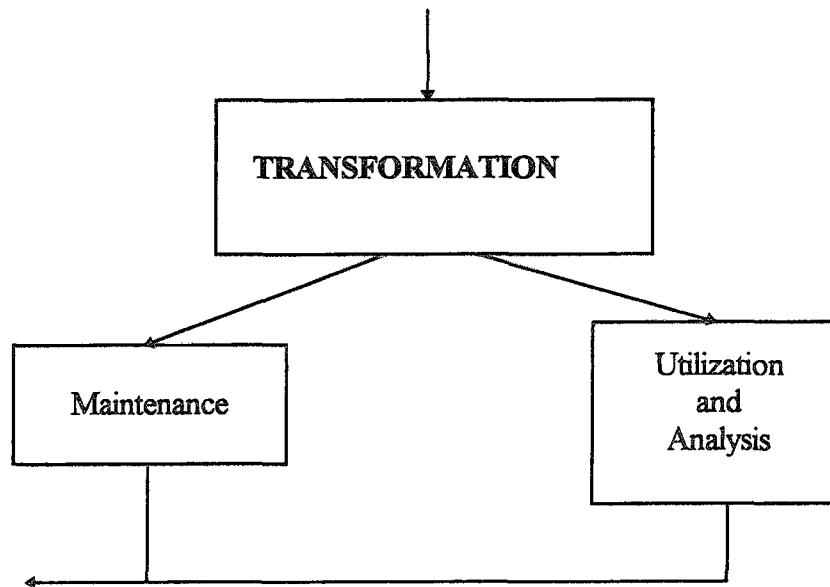


Figure 2.7. Schematic representation of GIS data transformations.

The designer of a GIS should expect that a user will want to ask an almost unlimited number of questions that will need to be answered by using certain combinations of data retrieval and transformation options. Although the range of actual questions can be unlimited, there are several broad types of questions that need to be considered. Some of these general questions are following:

- a) Where is object A?
- b) Where is A in relation to place B?
- c) How many occurrences of type A are there within distance D of B?
- d) What is the value of function Z at position X?
- e) How large is B (area, perimeter, count of inclusions)?
- f) What is the result of intersecting various kinds of spatial data?
- g) What is the path of least cost, resistance, or distance along the ground from X to Y along path way P?
- h) What is at points $X_1, X_2, \dots$?
- i) What objects are next to objects having certain combinations of attributes?
- j) Reclassify objects having certain combinations of attributes.

- k) Using the digital database as a model of the real world, simulate the effect of process P over time T for a given scenario S.

Many of these general questions are difficult to answer using conventional methods (for example, calculating the proportion of different kinds of soil mapped requires either extensive work with a planimeter or that the map units drawn on paper should be cut out individually and weighed!), and some are still difficult and time consuming using computer-aided methods.

The last module in the list for geographical information systems mentioned above, or the interaction with the user (query input) is absolutely essential for the acceptance and use of any information system. It is only in the last few years that the average user has been able to make direct contact with the computer other than via the media of punched paper tapes and cards handed into the computing center.

2.4.3. Organizational aspects of GIS

The five technical sub-systems of GIS, described in the previous section, govern the way in which geographical information can be processed, but they do not guarantee that any particular GIS will be used effectively. In order to be used effectively, the GIS needs to be placed in an appropriate organizational context as shown in Fig. 2.8. It is not sufficient for an organization to purchase a computer and some software and to hire or train one or two individuals and then to expect instant success. New tools can only be used effectively if they are properly integrated into the whole work process. This requires not only the necessary investments in hardware and software, but also in the retraining of personnel and managers to use the new technology in the proper organizational context. In the 1970's, the high price of many commercial systems sold for geographical information processing made managers cautious of making expensive investments in the then new and untried technology. In recent years the decreasing hardware prices have encouraged automation, yet skilled personnel and reasonably priced software have still remained scarce.

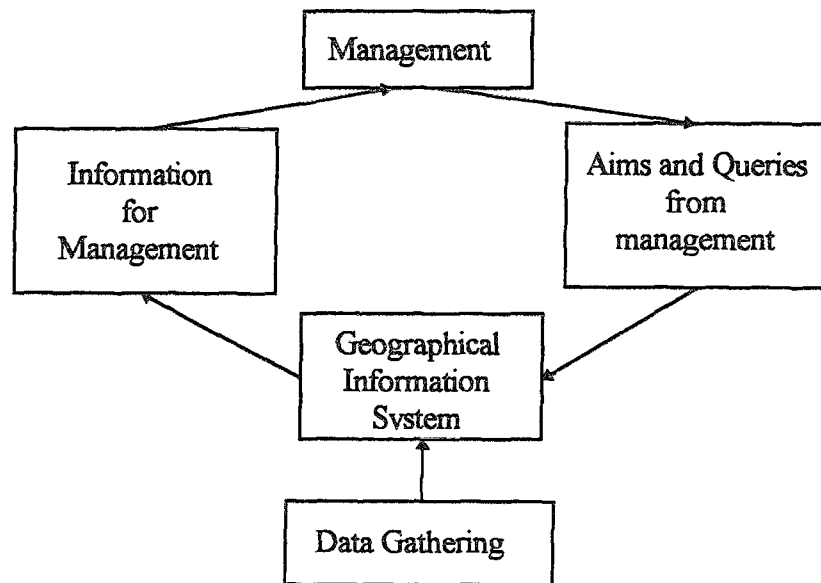


Figure 2.8. Organizational aspects of geographical information systems.

2.5. GIS Management and Analysis

2.5.1. The Concept of a GIS

The management of a GIS involves the control over the creation, manipulation and the representation of its information content, just like any other database management system. A clear understanding of the GIS structure depends on awareness and the knowledge of basic concepts and fundamentals. Many concepts applied to GIS management are common to other fields such as statistics, computer sciences and numerical cartography. A GIS can be seen as a tool to analyze information in a spatial context. The area under investigation - the study area - is characterized with several attributes - resources features - that can be interrelated on a common basis. The resource management of a region is performed either manually by map overlay method or with computer assistance using numerical spatial data sets or geo-based files as shown in Fig.2.9.

The manual approach is performed by overlaying transparent maps in order to visually merge the set of information and then to produce the output map. Limits of this method are the reduced number of maps that can be possibly overlaid simultaneously for visual analysis and the difficulties to obtain or produce transparent maps at a common scale.

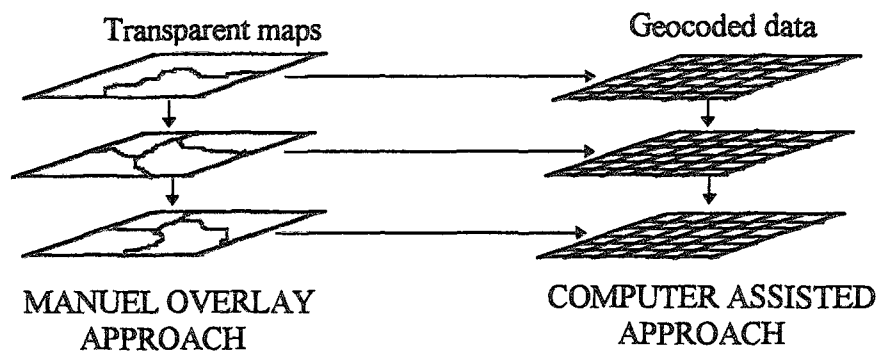


Figure 2.9. Manual and computer assisted approaches in resource management.

The computer assisted approach requires information in digital form. Resource management of numerically encoded data can be seen as an extension of multivariate analysis in a spatial context. Interrelation of resource features (attributes or factors) is performed through numerical transformations. Fig. 2.10. illustrates this approach in the study of erosion and sedimentation in a watershed. As it is observed in this figure, the major steps in analysis of spatial information by GIS are the following:

- Spatial data acquisition and storage,
- Creation of derived data sets,
- Analysis and management of data, and
- Data representation.

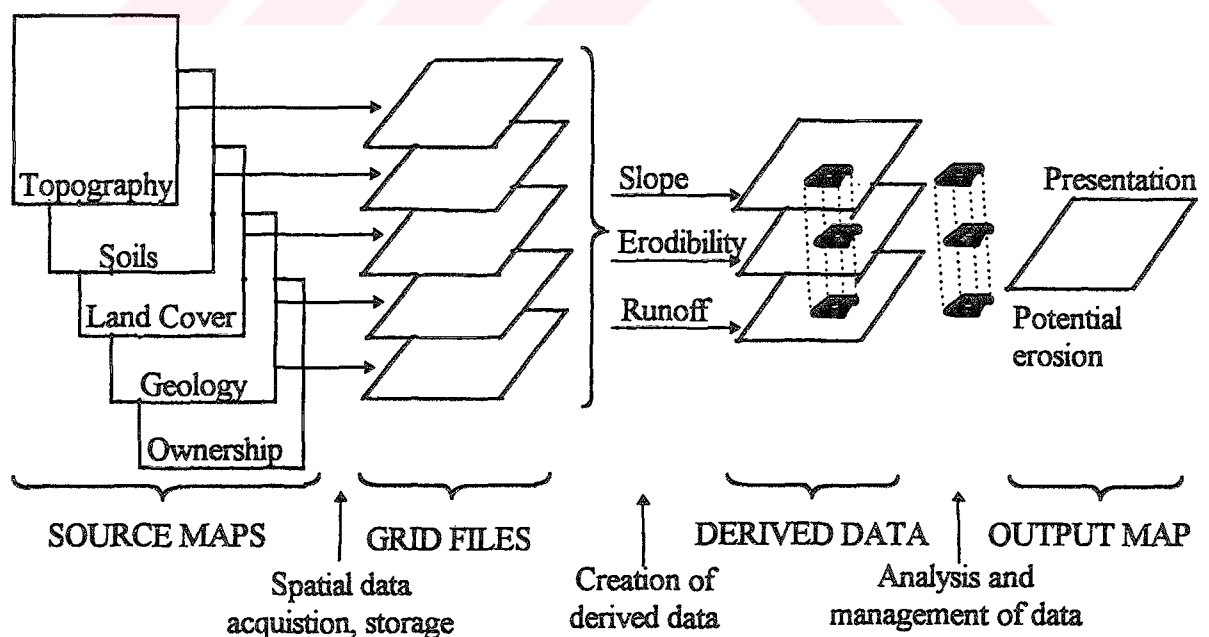


Figure 2.10. Major steps in a GIS environment.

2.5.2. The nature of GIS data

2.5.2.1. Types of GIS contents

Similar to maps or images, the GIS content is of two kinds. It gives information about features that are located within the region of interest as well as about the thematic content of those features. In order to fully understand and use information of a GIS, both spatial and attribute characteristics should be clearly defined as well as their interactions known as spatio-attribute characteristics. Natural spatial features are extremely complex both in their spatial and attribute contents; they have to be simplified or generalized in order to be understood.

2.5.2.2. Attribute characteristics

A variable expresses numerical measurements of a phenomenon. Measurements are acquired for a number of observations (sites or locations) during a limited period of time. A variable is called an attribute; an observation can be described with a single attribute (univariate description) or with several attributes (multivariate). Both the phenomenon and the attribute are of a different nature; they can be either continuous (terrain elevation, soil clay content, etc.) or discrete (number of inhabitants, land cover types, etc.)

Measurements can be made at three different levels: nominal, ordinal and interval-ratio, which form a hierarchical order with respect to information content:

- Nominal level has the poorest information content. Values are discrete and are used to identify observations.
- Ordinal level adds information about the ranking of observations. They can be compared to each other in order to determine whether they are smaller, equal or greater.
- Interval-ratio level defines how much an observation is greater or smaller than the others. It has the highest information content.

From an interval-ratio level, one can derive ordinal or nominal level content but going the other way is not permitted because of the lack in information content.

Table 2.1. summarizes characteristics and permissible operations that can be applied to each level. Again the interval-ratio level has the widest range of permissible operations and statistics (Collet, 1986).

Table 2.1. Hierarchy of levels of measurement (Collet, 1986).

	NOMINAL	ORDINAL	INTERVAL RATIO
Information content	Identification	Identification ranking	Identification ranking meaning of interval values
Permissible operations	$\neq, =$ some logical operations	$<, =, >, \neq$ logical operations	$<, =, >, +, -, *, /, \neq$ logical and arithmetical operations
Relevant statistics	mode, contingency coefficient	median, percentiles	mean, variance, coefficient of correlation
	discrete values		discrete or continuous values

2.5.2.3.Spatial characteristics

In spatial analysis, observations on which measurements are made are called spatial features. Spatial characteristics of a feature are its location, shape, size and its relationships with the neighborhood. Existing spatial features can be grouped into three different types: points, lines and areas (or surfaces). Basically, a point is spatially dimensionless; a line has a single spatial dimension -as it is made from an infinite succession of points- and an area has two spatial dimensions. These features are described further in the following:

- A point feature (a point) is fully described with its location. It has a size that can vary from none to a measurable value. Differences between a point and an areal feature are related to concepts of scale and resolution.

- A linear feature (a line or a segment of a line) can be of different types: a straight line, a broken line made of a finite number of consecutive straight segments, and a smooth curved line made of an infinite number of consecutive straight segments. The shape of a line describes the feature as a whole as the size expresses both its width and length. An observed linear feature such as a road or a river may have a changing width and an undefined length; but, in practice, significant simplifications are made. In the field of thematic cartography that includes most of GIS, a linear feature is described as a broken line with a unique width and a defined length .

- An areal feature (or surface) is generally described as a polygon by its limits or boundaries. There are three major types of areal features: a solid area that can be convex or concave and an area surrounding one more areas (area with a "hole"). The location of an area can be described either with a single point (its center of gravity, the center of its internal or enclosing circle, etc.) or more often as a polygon with its boundaries. There are several descriptors for the shape and the size of an area.

In GIS, the spatial dimension can be described with different levels of measurements. They are the same as the three levels described in the attribute characteristics: nominal, ordinal and interval-ratio level. However, the third is the most commonly used. Location and neighborhood relationship of a spatial feature use the concept of distance.

The location of a feature is a measure of its horizontal and vertical distance away from the axis system X and Y. This axis system is arbitrarily defined with an origin at the intersection of the two axes X and Y. These are commonly assumed as orthogonal and produce an orthogonal coordinate system.

Neighborhood relationships are principally described with the concept of proximity. The proximity concept uses distance to express how far is a feature away from other features. There are several different measures of distance such as the Euclidean distance, Manhattan distance, Chi square distance, etc. The distance commonly used is the Euclidean distance that can be summarized as the shortest line between two point locations. Assuming two point locations A and B, the distance between A and B is:

$$d_{AB} = \sqrt{[(X_A - X_B)^2 + (Y_A - Y_B)^2]} \quad (2.1.)$$

with X_A , X_B , Y_A , Y_B the location of A and B within the coordinate system.

2.5.2.4. Spatial distribution of attributes

Another fundamental consideration in spatial analysis are interactions between spatial and attribute dimensions. The spatial distribution is spatially continuous when the phenomenon occurs in any location inside the region. Attributes with discrete and continuous values can be spatially continuously distributed. For example, altitude is continuously distributed but its measure can either be expressed with a continuous measurement unit (meters, feet,...) or discrete unit (low, medium, high altitude).

The distribution is spatially discrete or continuous when the phenomenon occurs only in specific locations inside the region. Again attributes with discrete and continuous values can be spatially discontinuously distributed. The distribution of electric power consumption is an example of a spatially discrete distribution because it occurs only where human activities are located. But this consumption can be measured either with a continuous unit (kilowatt per month) or a discrete unit (low, medium, high consumption rate).

Practically, it is sometimes difficult to determine whether a phenomenon has a spatially continuous or discrete distribution but it should be noted that it has significant effects on interpolation results.

It is the spatial distribution of a phenomenon that produces spatial features. Considering a unique region, its pattern will be quite different when land cover types or administrative boundaries or topography are presented. Each attribute divides the region into spatial features of different size, shape and location. The difficult thing is that some phenomena are visible and some others are not. Most of them belong to the second category. Fig.2.11. shows interactions between attribute characteristics (level of measurement), spatial characteristics and spatial distribution of attributes.

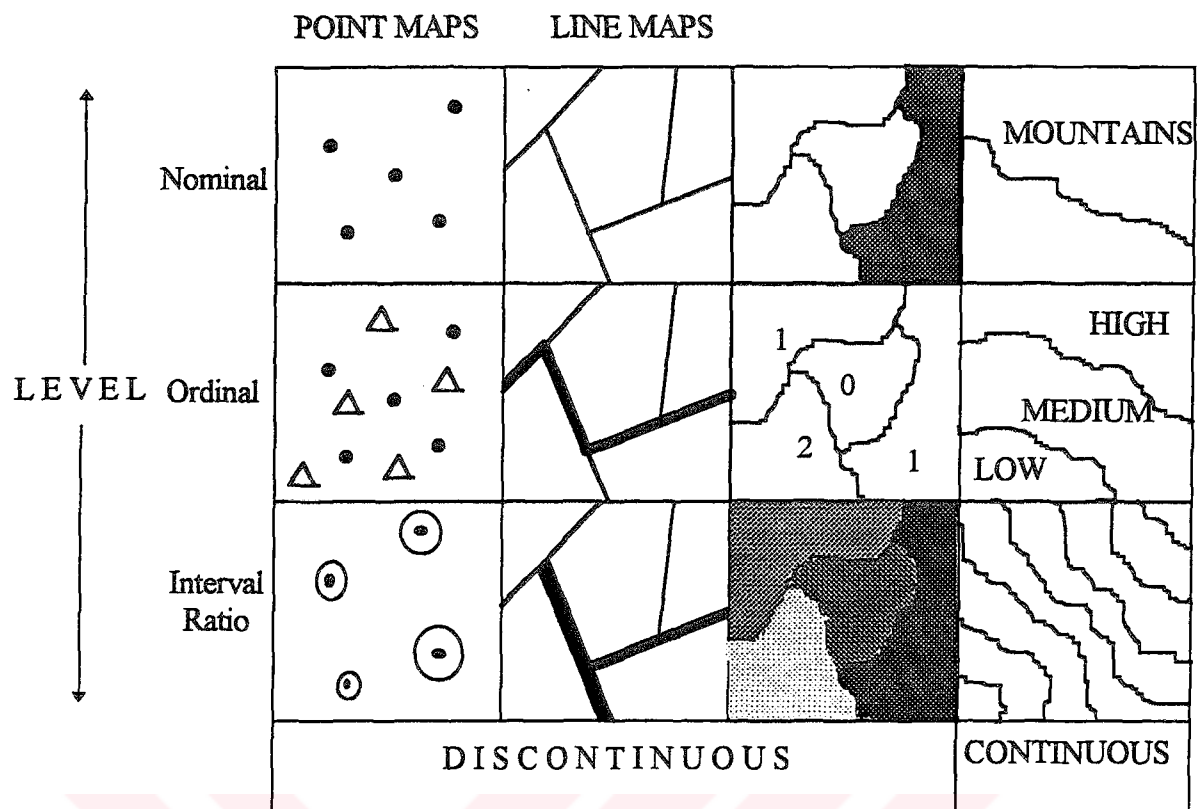
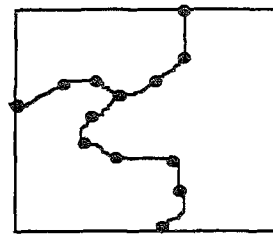


Figure 2.11. Graphical representation of continuous and discontinuous spatial distributions at different levels of measurement.

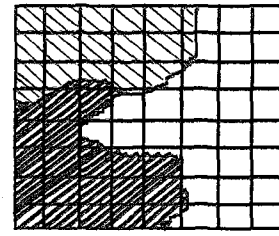
2.5.3. Types of GIS

2.5.3.1. Basic Structures

Analysis of attributes and their interactions within the region investigated can be performed using two different approaches. These two approaches determine the process of data collection, data manipulation and data structure, and consequently determine the structure of GIS. Accordingly, there are two types of GIS structures: (a) vector or polygon structure and (b) raster or grid structure. The first one divides the region into a set of spatial features specific to each attribute; the second structure divides the region into a set of regular cell arbitrarily defined and common to all attributes. Fig.2.12. shows the differences between vector and raster structure.



VECTOR



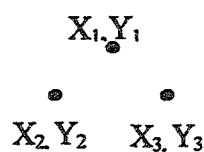
RASTER

Figure 2.12. Vector and raster structure.

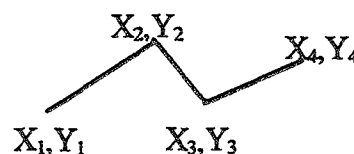
2.5.3.2. Vector structures

There are several ways of describing components of a region in vector mode, but they all have two elements in common: a description of spatial features and a list of their related attribute values. Differences occur in the structure of spatial descriptors.

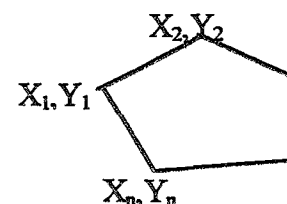
The fundamental element in vector mode is an (X, Y) coordinate pair used to define the location and spatial characteristics of features. As described in the previous section, a point is fully defined with a single pair of X and Y coordinates as it has no shape. A very accurate description of linear and areal features (or entities) would require an infinite number of coordinates. For practical purposes, lines are considered as simplified broken lines and spatially described with a sequence of coordinate pairs which locate each vertex of the line. As an area can be identified with its limits or boundary, this entity is treated as a polygon. Considering a polygon as a closed broken line, the line description technique can be extended to polygon description by repeating the first vertex at the end of the sequence. This assures that the line is closed. In summary, spatial entities are described as a sequence or an ordered list of coordinate pairs (a unique pair for a point). Their shape is simplified through a process of generalization which is related to the scale of the analysis. It must be noted that a greater generalization produces a shorter list of coordinate pairs (Fig.2.13.).



POINT



LINE



POLYGON

Figure 2.13. Point, line, and polygon in vector structure.

Different types of vector structures can be grouped as either topological or nontopological structures. Non-topological structures constitute the simplest way of storing polygon data as it is similar to the manual process. Each entity is defined as a sequence of points with an identifier to label it either as a point or a polygon. A point list structure is a sequential table containing coordinate pairs for each entity. It is a very simple structure to develop and to understand (Fig.2.14.). However, it has two majors limits: a great redundancy of coordinates as most points belong to more than one entity, and secondly, the great difficulty of polygon boundary modification. In order to improve both storage efficiency and point modification, this point list structure can be modified to produce a common point dictionary structure. It separates spatial information into two parts: a list of coordinate pairs identifying each observable vertex known as the common point dictionary and a list of vertex numbers which describe each entity (Fig.2.15.). Edition or modification of points simply involves a change of coordinate values in the common dictionary that will modify each of the relevant entities.

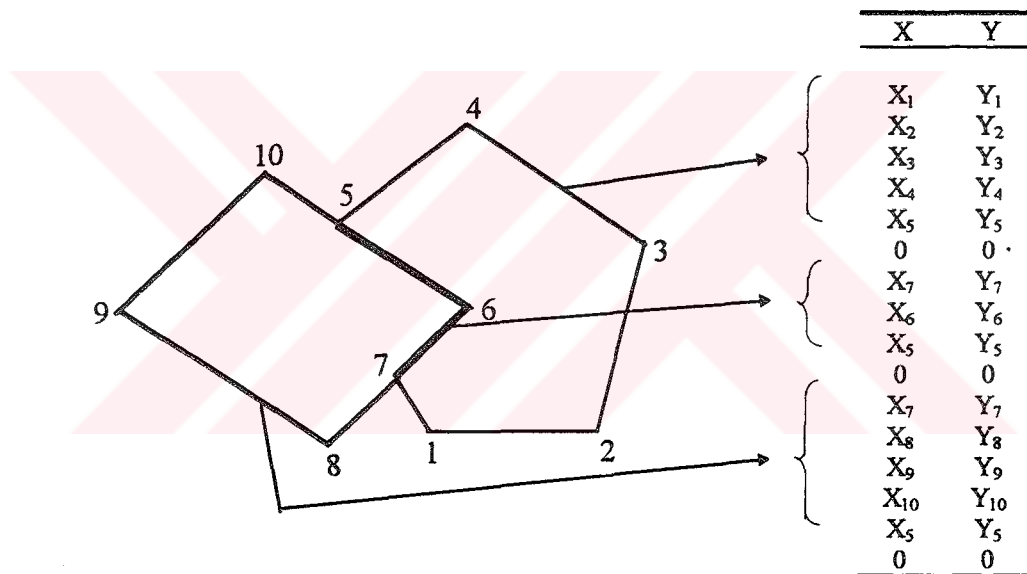


Figure 2.14. Point list structure.

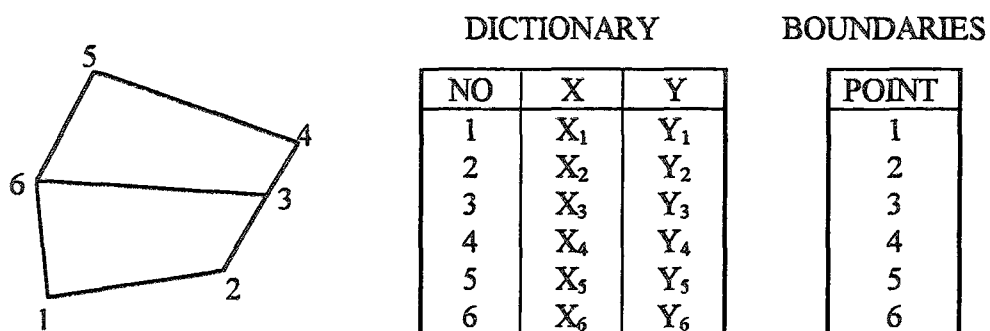


Figure 2.15. Common point dictionary structure.

Topological structures are more complex since they add explicit information about neighborhood relationships of features. In order to integrate topological information, the fundamental unit is no longer the vertex but the chain. Its associated concept is the node. A node is an intersection of more than two segments. Thus a chain is a broken line with two nodes as end points.

As an example chain 1 is the broken line that nodes N1 and N2 end in Fig.2.16. Associated to each chain are two attribute identifiers, one corresponding to the area to the left of the chain and the second to the area to its right. Because "left" and "right" are related to a specific direction, chains must be examined in a common direction: either clockwise or counter-clockwise. There are several variants of topological structures, but they all have in common concepts of chain, node and attribute or attribute identifier.

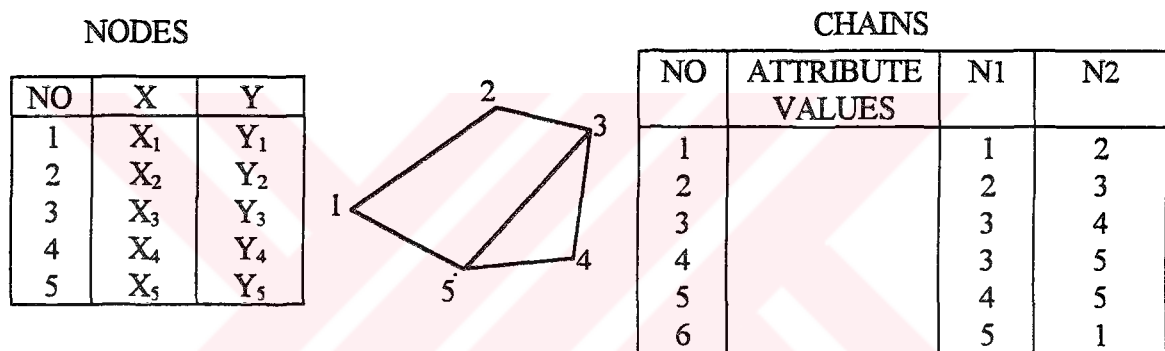


Figure 2.16. Topological structure using chains and nodes.

2.5.3.3. Raster structure

The raster structure is unique and simple to understand due to its basic principle. The study area is subdivided into a regular pattern (grid or raster) of spatial units (cells) with the same shape (generally rectangular or square) and size. Thus, size of spatial units is defined with two descriptors: the length and width; consequently the shape will be either rectangular or square. Neighborhood relationships are implicit because of the regular arrangement of cells into a grid. The relative position of each cell is defined with its line and column number within the "matrix". One grid is generated for each attribute. In order to preserve this regular structure, each cell has an attribute value which can be different or similar to neighbor cells (Fig 2.17.). The cell size is

not related to the pattern complexity of the spatial distribution but is arbitrarily defined and has effect on the amount of spatial details the grid can provide. Cell size is generally determined to optimize both the size of the study area and the capacity of the processing system.

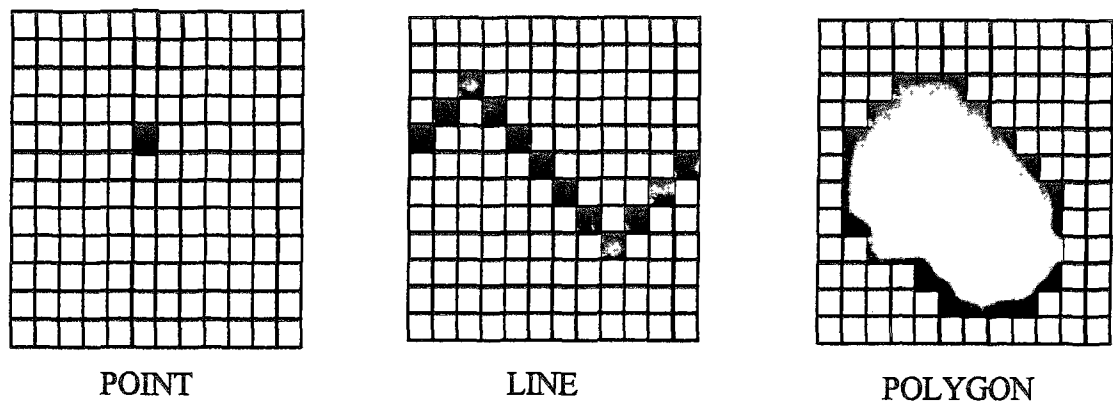


Figure 2.17. Point, line, polygon structure in raster format.

Description of a spatially continuous attribute can be performed very simply in raster form. Each cell value summarizes attribute of its whole area. There are several procedures that can produce cell values depending on the type of original information selected.

2.5.3.4. Vector structure versus raster structure

A comparison of the two geographical information structures shows that both have advantages and limits. In general, it can be pointed that vector structure is more oriented toward the uses of accurate spatial location -such as cadastral or network system management- while raster structure provides more detailed information on attribute content and its spatial distribution. The latter is used whenever complex combinations of attributes or modeling are required, such as in the analysis of many environmental factors and environmental management. Table 2.2. sketches major strengths and limits of the two structures: on one hand, the strength of vector structure is in storage efficiency and sampling flexibility; on the other hand, raster structure permits a complex spatial relationship study as well as multi-attribute analysis, and its format is easy to handle by computer.

Table 2.2. Some major strengths and limits of vector and raster structures.

	VECTOR	RASTER
Storage efficiency	good	poor
Storage data structure	complex	simple
Spatial sampling	varying across study area	regular across study area
Spatial measures	precise	approximate
Spatial relationships	complex to handle	easy to handle
Discrete spatial distributions	simple	simple
Continuous spatial distributions	requires attribute transform	simple
Multi-attribute analysis	complex	simple

2.6. Basic Procedures for a GIS Application

2.6.1. Methods of spatial data capture and encoding

Data capture for spatial data processing is usually referred to as "digitization" and the primary source of data is often existing maps. An analog (i.e., paper) map may be designed for visual assessment and, as a result, digitization must often be made by manual tablet means to allow the interaction of the human eye and mind to be incorporated in the process (Marble and Peuquet, 1990).

Other methods of data capture cover a wide range from the use of classified satellite data to man/computer cooperation in the analysis of stereo pairs of aerial photographs, and in the digitization of interpreted locations, lines and areas on visual images, usually aerial photographs.

In manual digitization, tablets are directly connected to computer systems, although the addition of micro-processor in the interface chain can assist some aspects of data checking and on-line transformations. The main problems in using a manual digitization tablet arise because digitization is inherently slow and manual digitization involves human labor.

The automatic digitization of existing map sheets is now being carried out by a number of methods. The two main approaches are usually referred to as automatic line following and scanning. Basic methodology in automatic digitization is to convert the images in raster to vector format.

Remotely sensed data such as satellite images or digital aerial photographs have effective usage fields in data capture for GIS. Recent developments in remote sensing technology enable the researchers to take spatial data of earth's surface in a very high resolution both in time and space. The general structure of remotely sensed images is raster format that can be read by numerous kind of GIS.

The data which are captured by any technique in suitable formats for the foreseen analyses are then transferred to the database of the system.

2.6.2. Data management and manipulation in the GIS

The volumes and the variety of data have been rapidly increasing through the use of modern data capture technologies at considerable costs in money and in effort. The data stored into an established database system are usually derived from many sources and are in many forms as mentioned in previous sections. The database management system of a particular GIS can be different from the others with respect to their purpose of use. A database is defined as "a collection of interrelated data stored together with controlled redundancy to serve one or more applications in an optimal fashion. A database management system consists of the combination of a database and the associated software to perform all needed data entry, storage, retrieval and

maintenance tasks. The database management system may also be the nucleus "subsystem" of a larger information system that provides analytical and other facilities beyond the scope of general file management (Marble and Peuquet, 1990).

Any given geographic information system must be capable of performing a series of manipulations on the spatial data held in its files. Each system contains a specific set of these procedures, determined by the requirements of the users of the system. A typical set of manipulation capabilities is listed below:

Data Manipulation Alternatives in GIS:

(a) Reclassify-attributes

(b) Generalization

Dissolving and merging

Line smoothing

Complex generalization

(c) Interpolation

Centroid allocation

Contouring

Scale change

Distortion elimination

Projection change

(d) Generation

Points

Lines

Polygons

Simple five-sided polygons

Circles

Latitude and longitude lattices

Corridors

Other

(e) Data extraction

Search and identification

Attributes

Shapes

Measurement

Number of items

Distances

Size of areas

Angle direction

Volume (cubic measure)

(f) Comparison

Intersection-overlay

Point in polygon

Polygon on polygon (grid cell on polygon)

Other

Juxtaposition (proximity)

Shortest route

Nearest neighbor

Line of sight

Contiguity

Connectivity

Complex space-attribute-time correlation

(g) Interpretation

Determination of optimum location

Determination of suitability

Determination of desirability

A major difference between the available geographic information systems exists between those, mainly the earlier systems, which are limited to recasting and reformatting operations (e.g., take in two sets of map data, carry out an overlay operation and then produce a map of results) as compared with the more modern systems, which are increasingly oriented toward support of analysis and formal modeling (e.g., large-scale, spatial mathematical programming or spatial simulations).

On a very basic level, each GIS consist of a data structure and a selection of algorithms that are matched to that data structure. The most operational GIS utilize vector and raster data structures and, hence, must make use of vector and raster based algorithms for all internal data manipulation.

2.6.3. Display of spatial data

An important feature of any information system is report generation. This feature, in a geographic information system, frequently involves the creation of a special thematic map display that may represent the distillations of a number of complex retrievals and manipulations of the original data. The field of computer graphics has provided the GIS developer and user with a wide variety of inexpensive and sophisticated tools for the creation of map displays, both interactively and in hardcopy. The cost of these displays has been dropping rapidly in the last few years, and their level of sophistication has significantly increased.

Graphic display represents an extremely powerful tool for both summarization and browse operations within the digital, spatial database. Its use will continue to increase as the sophistication of the displays and our knowledge of how to make the most effective use of them increases.

2.7. Future Directions and Trends in GIS

Until recent times, most geographical information systems were set up for local applications, or for work on a limited project area. However, there are now strong indications that many users, particularly major government agencies in developed countries, show the desire to set up comprehensive countrywide systems. For example, the US Geological Survey in the USA is planning a cartographic database containing all information from 55000 71/2 min. map sheets covering the entire United States (Peuquet, 1984). It is estimated that a single layer or attribute (e.g. topography or hydrology) mapped at usual cartographic precision will have a data volume of 10^{15} bits.

One of the greatest problems in geographical information processing, compared with computer-aided design or computer graphics, has always been the problem of sheer data volume generated by the surveying sciences. This is partly a result of the complexity of the earth's surface, but it is also because geographical "entities" or phenomena can rarely be so well defined or are rarely as reproducible as the components of a computer. Different scientists tend to describe the same area in different ways. Even if they stem from the same discipline, they tend to draw boundaries around geographical "objects" in different ways, and these boundaries are usually convoluted and highly irregular. Consequently, geographical phenomena, at least as described by modern earth scientists, cannot be described economically. Further problems arise because digital geographical data are likely to be imprecise, highly variable or of uncertain quality. Finally, the ways in which spatial relationships between geographical objects can be described are often highly application-specific.

The latest directions in research in geographical information processing suggest that we should look for better ways in which to describe the real situation of the world, and for new methods for dealing with the imprecision of qualitative judgments. These directions suggest that the new approaches of fractals, fuzzy logic, and methods of artificial intelligence should be seriously considered. It is clear that even with the present shortcomings of GIS technology, more and more people want to have access to geographical information systems, and they are not prepared to pay the very high prices for systems that must be currently paid. There is certainly a trend towards small, decentralized systems that can be used for specific projects, or as entry points to larger, country-wide geographical databases. But for this, there must be enough trained personnel who know what GIS is all about and how it operates (Borrough, 1990).

With its features described above, the GIS have found increasing range of applications in hydrology and water resources. Specific areas where they are used include the analyses of floods, sediment erosion, water pollution, and basin management in the broadest sense. In these applications, GIS are not used only as spatial descriptors of hydrologic parameters but also as management tools when they are integrated with hydrologic models. The following section discusses the application of the GIS in hydrology and water resources on specific examples.

III. THE USE OF GEOGRAPHIC INFORMATION SYSTEMS IN WATER RESOURCES RESEARCH

3.1. Introduction of GIS to the Analysis of Water Resources Problems

Water resources planning requires regional analyses that are based on a combination of geographic, technical and institutional factors and requirements. For a given region, this process may involve forecasting the future conditions of water quality and quantity and their geographic distribution in an area (McKinney et al., 1993). The temporal and spatial distribution of water with respect to its quality and quantity is evaluated by many specific computer-based models or some associated digital data query techniques. These models and data query algorithms use geographical data as well, since all hydrologic processes are affected geography so that these processes involve geographically distributed parameters.

The use of computers in hydrologic analysis has become so widespread that it provides the primary source of data for decision making for engineers. Since so much of hydrology is linked to processes at the earth's surface, the connection to the topography has to be supplied by a tool.

The need for a new tool that enables the researcher to evaluate geographical data has led to the use of geographic information systems (GIS) in water resources research. Within the last decade, the use of geographical information systems (GIS) for spatial hydrologic data analysis has provided many benefits for water resources research and analysis.

Geographic information systems link land cover data to topographic data and to other information concerning processes and properties related to geographic location. When applied to hydrologic systems, nontopographic information can include the description of soils, land use, ground cover, groundwater conditions, as well as man-made systems and their characteristics on or below the land surface. Description of topography is called terrain modeling, and because of the tendency of surface water to flow downhill, the hydrologic importance of terrain modeling is clear. While maps have been the most common historical forms of representing topography, the advent of digital maps in GIS provides an alternate method of storing and retrieving this information. The amount of digital data required to accurately describe the topography of even small regions make GIS a memory intensive and computationally intensive system. Even so,

there is adequate GIS software available for mainframe, mini- and microcomputers. The characteristic that differentiates a GIS from general computer mapping or drawing systems is the link to the information database (DeVantier and Feldman, 1993). Once the database is constructed, correlations between different pieces of information can be examined easily through computer generated overlay maps. For hydrologic modeling purposes, there is generally an extra step of generating hydrologic parameters that are dependent on database information. This hydrology-GIS link is a significant complicating factor, because it involves complex empirical or physics-based relations.

3.2. Characteristics of Water Resources Data

Data used in water resources management have special characteristics. Most hydrographic data represent some nominal static average depth, shore line perimeter, stream centerline, and so forth. Water bodies vary in their boundaries and properties: estuaries vary daily, rivers vary seasonally, and in response to storm events, and large lakes may vary over decades (e.g. Van lake). Temporal variability and distinct boundaries are not well handled in current GIS systems. Dynamic phenomena may be presented by taking snapshots at several time intervals and running them sequentially to create a computerized movie, which has become only recently feasible. Presently it has been suggested that fuzzy data might be presented by showing regions with intermediate values in intermediate colors; for example, if open water is shown in blue and dry land is shown in red, then wetlands might be represented in purple, with appropriate levels of color saturation and color for areas of transformation (Leipnik et al., 1993).

3.3. Raster versus Vector Considerations in GIS-Based Evaluation of Water Resources Data

Unique aspects of water and water related problems suggest a special approach for their handling in a GIS. Most GIS are either raster or vector based systems. Systems having both capabilities generally convert data from the secondary form to the prior for analysis. Often this produces a consequent loss of accuracy, precision, or both. As a rule, raster based packages are more appropriate for management, inventory, analysis, and presentation of resources that are

distributed continuously across the landscape such as forests and soils. Raster based systems are also appropriate when the primary input data come in a raster format (such as remotely sensed imagery). Vector based systems are more appropriate in applications in which the locations of the objects such as the roads, sewer, basin boundaries or political boundaries are defined precisely. Vector based systems are also appropriate when vector inputs such as CAD data or drafted engineering drawings are employed (Leipnik et al., 1993).

Data related to water resources can have high precision (e.g. sewer locations), or they can be fuzzy (e.g. wetland perimeters). Even object such as rivers that are precisely represented on maps are often highly variable in reality. This suggests that the high precision provided by vector based GIS may be inappropriate. Conversely, raster representation can give objects a blocky appearance unsuitable for identification of many features, particularly linear ones (Leipnik et al., 1993).

In any water resources project, all of the foregoing considerations may apply. For example, an aqueduct or pipeline project might best use a vector based GIS for the hydraulic engineering and pipeline corridor construction phase, and raster based GIS for the environmental impact assessment study of the right of way area. Which type of package is the most appropriate would depend on the specific application. Perhaps more than one GIS program would be optimal, although that implies learning more commands and/or additional acquisition costs and overcoming data conversion and transfer problems.

3.4. Spatial Analysis Functions of GIS in Water Resources Research

Both raster and vector based GIS software have many spatial analysis capabilities. Those most likely to be of interest to water resource managers include area, length, and perimeter calculations; overlay of thematic layers; and buffer-zone generation. Buffer zone generation is particularly suited to risk and/or impact assessment for objects or facilities with known locations. Several investigators have used a GIS to construct buffers around the locations of wellheads and the locations of known or potential contamination sites to facilitate risk assessment for wellhead protection purposes (Leipnik et al., 1993). Overlay of thematic layers is useful for impact assessment or general site selection using spatial intersection of several different environmental

themes (e.g. proximity to sensitive riparian habitat, slope, vegetation, soil type). Data layers maintained in the GIS, containing information on such regional aquifer parameters (parameters such as depth to ground water, net recharge, aquifer characteristics, soil characteristics, topography, impact of the vadose zone, and hydraulic conductivity) are used for aquifer-vulnerability. Overlay of these layers coupled to buffer zone generation around point sources of pollution is ideally suited to facilitating such aquifer-vulnerability assessments (Leipnik, et al., 1993).

3.5. Applications of GIS in Water Resources Research and Management

Hydrologic applications of GIS's have ranged from synthesis and characterization of hydrologic trends to prediction of responses to hydrologic events. While the underlying assumption of any GIS application is that the database information is available, the acquisition and compilation of the required information is often difficult. Often, appropriate data is only available in map form, so that even with modern digitizing hardware and software process is labor intensive (De Vantier and Feldman, 1993).

Many of the limitations of present GIS capabilities are more related to limitations of data collection and reduction and current hardware capabilities, than to the software architecture used for GIS data handling. Based on current progress in these areas, the optimism of those involved in development of hydrologic applications of GIS appears justified (De Vantier and Feldman, 1992).

The widely used GIS applications in different field of water resources research based on the topics mentioned in section 3.2 and section 3.3 can be listed as follows:

- (a) flood analysis (Warwick and Hanes, 1993)
- (b) erosion and erosion-based pollution prediction (Tim et al., 1992)
- (c) ground water quality and monitoring (Baker et al., 1993)
- (d) wetland analysis (Leipnik et al., 1993)
- (e) monitoring applications (remote sensing) (Schultz, 1993)
- (f) basin morphology (Warwick and Hanes, 1993)

- (g) geographic and nongeographic data queries (Heidke and Auer, 1993))
- (h) water quality and quantity model-GIS integrations (Engel et al., 1993)
- (e) expert systems and decision making (Mc Kinney et al., 1993)

It is observed from the above examples that GIS has already found versatile areas of application in water resource engineering.



IV. APPLICATION OF GIS TO ANALYSIS OF EROSION-BASED NONPOINT SOURCE POLLUTION

4.1. Nonpoint Source (NPS) Pollution and GIS

The magnitude of nonpoint source (NPS) pollution across the world is very high. It is so complex, so hard to characterize, so interconnected with poverty and human behavior patterns that it is very difficult to be properly assessed. Because of NPS pollution, though, hundreds of millions of people suffer from disease, substantial amounts of economic development investments are lost, and significant environmental remediation needs are being accumulated for future generations to address. The significance of this damage is only now being fully recognized (Duda, 1993). The major difficulty associated with NPS is that it is diffused through a land area so that it can only be described by its spatial distribution. This is in contrast to point pollution which is a point or local event and thus can be rather easily identified.

Environmental assessment of activities that cause point source discharge has now become a routine procedure for the review of environmental policy. Determining the degree of compliance with pollution controls is a fundamental prerequisite to the assessment of the adequacy of these controls. Similarly, the degree of compliance with existing land use controls needs to be established before an evaluation of controls on nonpoint source (NPS) pollution can be carried out. The auditing procedure also assists in identifying obstacles to the practical implementation of NPS pollution control strategies as well as providing indicators of the performance of land managers and administrators (Turner and Ruffio, 1993).

In order to monitor and report on NPS pollution and its relationship with land use activities, a substantial environmental database and a diverse analytical capability to evaluate that information has to be established. There is a universal need to integrate catchment-based environmental and land use information with stream ecosystem information over both space and time in order to define these relationships.

Geographic information systems are useful tools to assist with this task. GIS provide a generic knowledge-based management tool for the analysis and interpretation of primary data being

collected on land use activities and water quality. Moore (1990) has reviewed the functional advantages of using GIS for identifying and targeting areas susceptible to NPS pollution. The ability to develop knowledge-based watershed models of pollutant transport, using the analytical sub-systems of GIS, is seen as particularly useful in evaluating the performance of environmental protection strategies (Moore, 1990). It is possible with GIS to develop various scenarios of environmental management decisions and to evaluate their consequences.

4.2. Available Studies on GIS-Based Analysis of NPS

In water resources research, there are several nonpoint source pollution modeling approaches. Some of these models are developed by using several complex physical and chemical functions. Thus, these models require a lot of parameters. Such requirements hinder the applicability of these models.

The GIS-based modeling approaches commonly use geographic attributes of the watershed that affect NPS pollution. The basic procedure in NPS pollution modeling is to estimate soil erosion and pollution transported by eroded soil. In order to obtain a quick and effective solution for determining NPS pollution carried by eroded soil, a GIS-Universal Soil Loss Equation (USLE) integration is preferred by the scientists. NPS identification by USLE is based on a number of spatially distributed parameters which can be effectively described and evaluated by GIS.

Tim et al. (1992) proposed an integrated approach coupling water quality computer simulation modeling with a geographic information system. The approach identifies the critical areas of nonpoint (NPS) pollution at watershed level. Two simplified pollutant export models were integrated with the Virginia Geographic Information System (VirGIS) to estimate soil erosion and erosion based phosphorus (P) loading from the Nomini Creek watershed located in Westmoreland County, Virginia. In this study, the soil loss model (SLOSS), which estimates soil erosion and fluvial sediment yield from disturbed watershed areas was based on a modified USLE with a delivery ratio to determine sediment yield. The P loading rates from the watershed were estimated by a simplified phosphorus yield model, PHOSPH (Figure 4.1). Both models are integrated with VirGIS to facilitate database and model application and to provide an efficient and cost-effective means of identifying watershed areas having critical soil erosion and water

quality problems. It was found that 52 percent of the watershed area had critical soil erosion, sediment, and phosphorus pollution problems. In general, the study carried out by Tim et al. (1992) demonstrated the usefulness of integrating GIS with simulation modeling for nonpoint source pollution control and planning.

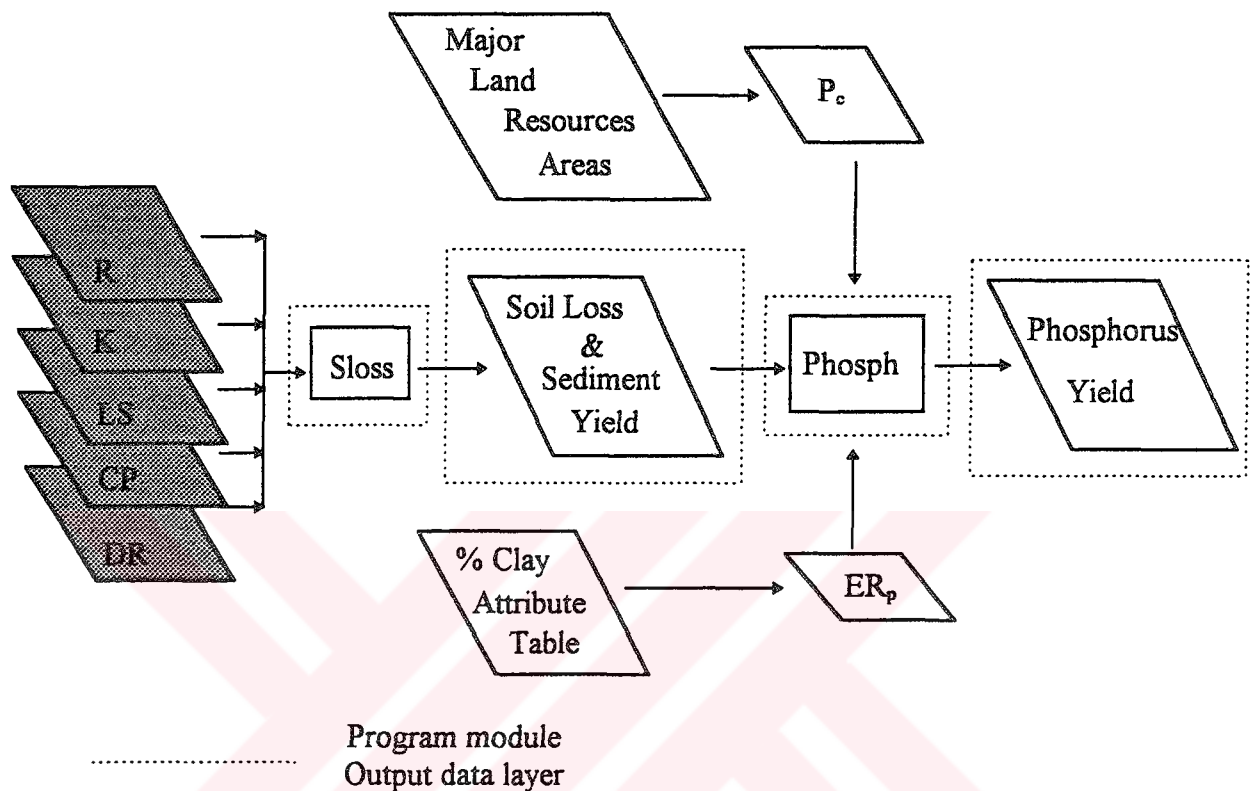


Figure 4.1. Schematic Diagram of Input Data Layers for SLOSS and PHOSPH Models (Tim et al., 1992)

Heidke and Auer (1993) evaluated some land development scenarios and water quality in Owasko Lake, New York, by applying a GIS-based nonpoint source nutrient loading model. Their approach utilizes the Universal Soil Loss Equation together with empirical loading functions to derive representative phosphorus export coefficients for the local drainage system. The methodology facilitates easy and rapid assessment of general watershed management and development scenarios of interest (Figure 4.2). A unique aspect of the approach is its dependence upon descriptive data supplied by a Geographic Information System (GIS) to establish the coincidence of specific land use, soil texture and surface slope attributes within each

of the hydrologic sub-basins comprising the overall watershed. The GIS-generated attribute matrices provide a much more accurate depiction of critical geographic characteristics known to impact nonpoint source runoff loading, thereby improving the reliability of current and projected phosphorus load to Owasko Lake.

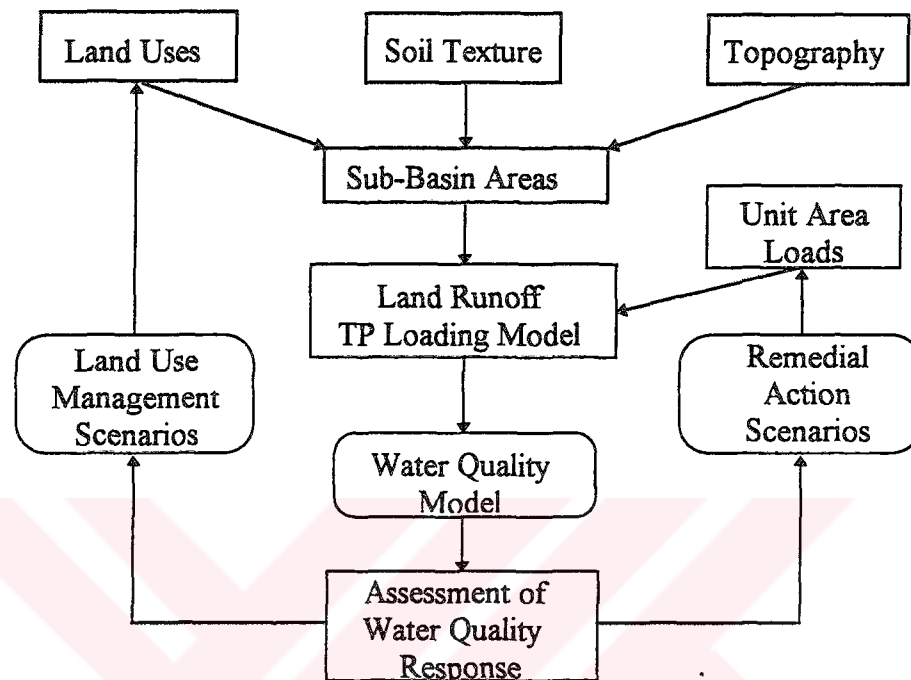


Figure 4.2. Owasko Lake Management Model (Heidke and Auer, 1993).

4.3. Methodology Applied

4.3.1. The Soil Loss Estimation by USLE

The universal soil loss equation is the most widely used erosion equation. The equation and its development utilized more than 40 years of experimental field observations gathered by the Agricultural Research Service of the USDA (Novotny and Olem, 1994). USLE developed by Wischmeier and Smith (1965), estimates rainstorm based sheet and rill erosion which occur in small watersheds. The USLE equation is described as;

$$A = (R) (K) (LS) (C) (P) \quad (4.1)$$

where;

A : calculated soil loss in ton/ha/year

R : rainfall runoff factor

K : soil erodibility factor

LS : topographic factor

C : cover and management factor

P : support practice factor

With appropriate selection of its factor values, the equation computes the average soil loss for a multicrop system, for a particular crop year in a rotation, or for a particular cropstage period within a crop year. It computes the soil loss for a given site as the product of six major factors whose most likely values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but effects of the random fluctuations tend to average out over extended periods. Because of the unpredictable short-time fluctuations in the levels of influential variables, however, present soil loss equations are highly less accurate for prediction of specific events than for prediction of long time averages (Wischmeier and Smith, 1978).

The equation basically expresses soil loss per unit area due to rain. It does not include wind erosion and it does not give direct sediment yield estimates (Novotny and Olem, 1994).

Since all factors in the USLE equation have a spatial distribution in a watershed, a GIS based evaluation of the equation gives more accurate results. In the GIS assisted approach, each factor of the equation is described in the form of digital maps, and six digital layers of the equation are overlaid in order to obtain spatially distributed soil loss in a watershed.

4.3.2. Rainfall runoff factor (R)

4.3.2.1. Definition of R

Rills and sediment deposits observed after an unusually intense storm have sometimes led to the conclusion that the significant erosion is associated with only a few storms, or that it is solely a

4.3.2.2. Rainfall Erosion Index

When factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to a rainstorm parameter identified as the rainfall erosion index (EI or R) (defined below). The relation of soil loss to this parameter is linear, and its individual storm values are directly additive. The sum of the storm EI values for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular area is the rainfall erosion index for that area.

Rainfall erosion index (EI or R) is a unique parameter that has a unit while the others (K, LS, C, P,) do not. Rainfall erosion index is an indicator to calculate soil losses from continuously followed land. This factor can be calculated by a method that predicts erosion potential of a rainfall. Researchers have found out that there is a relation between soil loss and two properties of rainfall when the other factors (K, LS, C, P) that effect erosion are constant (Doğan, Güçer 1976). These two properties are;

- energy of the rainfall,
- the maximum 30 minute intensity of the rainfall

4.3.2.3. Calculation of the kinetic energy of rainfall

In order to obtain the total energy of a rainfall storm, the unit energy of that rainfall must be calculated. Therefore, the intensity of the rainfall should be found out via rain records by considering individual storms and the total rainfall depth.

Three criteria are followed to determine individual storms to be used for obtaining the R factor;

- a) two storms with 6 hours of difference between their rain periods or the storms which are less than 1.27 mm in that period are considered as individual storms;
- b) all storms with depths of more than 5 mm are evaluated; if the intensity of the storm is less than 0.8 mm/hour, that storm is not considered;

c) the storm with a depth of less than 5 mm, but with an intensity more than 10 mm/hour is considered.

First, the individual storms are determined by applying the procedure in (a), and then the storms that suit (b) and (c).

Wischmeier and Smith (1978) have calculated the unit kinetic energy of a rainfall by:

$$E_u = 210.3 + 89 \log_{10} I \quad (4.2)$$

where; E_u : unit kinetic energy (ton.m/ha/cm)
 I : intensity of the rainfall (cm/hour)

In the above, E_u represents the energy which passes from one-cm-depth of rainfall to one-ha-area.

The total kinetic energy of a rainfall is calculated by multiplying the unit kinetic energies by the individual rainfall depths (cm):

$$E = E_u \times h \quad (4.3)$$

where; E : total kinetic energy (ton-m/ha)
 E_u : unit kinetic energy (ton-m/ha/cm)
 h : depth of the rainfall (cm)

For a particular rainfall event, the intensity normally changes throughout the rainfall duration. Accordingly, the storm that has the same intensity during the rainy period is called a uniform-intensity-rain; otherwise, it is named as heterogeneous-intensity-rain.

4.3.2.4. Kinetic energy in uniform rainfall.

Uniform rainfall has a total rain curve where the gradients do not change during the rainy period. In this case, the intensity of the rainfall is calculated as follows;

$$I = (h \times 60) / t \quad (4.4)$$

where; I: rainfall intensity (cm/hour)

h: rainfall depth (cm)

t: rainfall duration (minute)

For example, the kinetic energy of a uniform rainfall which has a depth of 30 mm and a duration of 80 minutes is:

$$I = 3.0 \times 60 / 80 = 2.25 \text{ cm/hr}$$

$$E_u = 210.3 + 89 \log (2.25) = 241.64 \text{ ton-m/ha/cm}$$

Unit kinetic energy is the energy value per each cm of precipitation. Since the given precipitation amount is 3.0 cm here, the total kinetic energy is calculated by using Eq.(4.3)

$$E = 241.64 \times 3.0 = 724.92 \text{ ton-m/ha}$$

That means this particular storm has a kinetic energy capable of lifting 724.92 tons of soil to a height of 1 meter from 1 hectare of area.

4.3.2.5. Kinetic energy of heterogeneous rainfall

Normally, rainstorms have heterogeneous characteristics, and occur at various intensities during the rainfall duration. Thus they reflect different levels of kinetic energy throughout the rainfall duration. This is why heterogeneous rain curves should be divided into uniform parts. Then the total kinetic energy of the rainfall is calculated by summing the kinetic energy of each uniform part, using Eq. (4.2), Eq. (4.3), and Eq. (4.4).

$$E = \sum_{i=1}^n E_i \quad (4.5)$$

where; i: the number of uniform parts in the rain curve

4.3.2.6. Estimation of the maximum 30 minute intensity of rainstorms

Results of investigations indicated that there is a significant relationship between the soil losses of a followed field and the product of the total kinetic energy of a rainfall and the maximum 30 minute-intensity (Wischmeier and Smith, 1978). Maximum 30 minute-intensity of a rainfall is defined as the amount of rain which falls in 30 minutes of rainfall duration (cm/hr) where the peak of the curve is the highest on the diagram.

In order to evaluate the maximum intensity of a rainfall which lasts over 30 minutes, the beginning and the end points of 30 minute are marked on the pluviographical diagram where the peak of the curve is in the highest point. Then the maximum 30 minute-intensity is calculated by multiplying the length (cm) obtained from the curve by 2. For example, if 5.3 cm rain were recorded in a storm duration of 85 minutes and if the marked point for the 30 minute-period on the diagram indicates 3.2 cm of rain, then the maximum 30 minute-intensity would be :

$$I_{30} = 3.2 \times 60 / 30 = 6.4 \text{ cm/hr}$$

For a rainfall duration of less than 30 minutes, the maximum 30 minute-intensities are evaluated by multiplying the amount of rain (cm) by 2. For example if the amount of rain is 2.1 cm for 20 minutes of rainfall duration, the maximum intensity would be:

$$I_{30} = 2.1 \times 2 = 4.2 \text{ cm/hr}$$

4.3.2.7. Evaluation of the erosion index of rainfall

Erosive potential of a rainstorm is obtained by dividing the product of total kinetic energy with maximum 30 minutes-intensity by 100:

$$R = EI = \text{Total Kinetic Energy (E)} \times \text{Maximum 30 Minute-Intensity (I}_{30}) / 100$$

$$R = EI = E \times I_{30} / 100 \quad (4.6)$$

4.3.3. Soil erodibility factor (K)

4.3.3.1. Soil erodibility

The meaning of the term "soil erodibility" is different from that of the term "soil erosion". The rate of soil erosion, A , in the soil loss equation, may be influenced more by land slope, rainstorm characteristics, cover, and management than by inherent properties of the soil. However, some soils erode more readily than others even when all other factors are the same. This difference, caused by properties of the soil itself, is referred to as the soil erodibility. Several early attempts were made to determine criteria for scientific classifications of soils according to erodibility but classifications used for erosion prediction were only relative rankings (Wischmeier and Smith, 1978).

Differences in the natural susceptibilities of soils to erosion are difficult to quantify from field observations. Even a soil with a relatively low erodibility factor may show signs of serious erosion when it occurs on long or steep slopes or in areas with numerous high-intensity rainstorms. A soil with a high natural erodibility factor, on the other hand, may show little evidence of actual erosion under gentle rainfall when it occurs on short and gentle slopes, or when the best possible management is practiced. The effects of rainfall differences, slope, cover, and management are accounted for in the prediction equation by the symbols R , L , S , C , and P . Therefore, the soil erodibility factor, K , must be evaluated independently of the effects of the other factors (Wischmeier and Smith, 1978).

4.3.3.2. Definition of K factor

The soil erodibility factor, K , in the USLE is a quantitative value experimentally determined. For a particular soil, it is the rate of soil loss per erosion index unit as measured on a "unit" plot, which has been arbitrarily defined as follows (Wischmeier and Smith, 1978):

A unit plot is 22.1 m long, with a uniform length-wise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, for this purpose, is land that has been tilled and kept free of vegetation for more than 2 years. During the period of soil loss measurements, the plot is plowed and placed in conventional corn seedbed condition each spring and is tilled as

needed to prevent vegetative growth and severe surface crusting. When all of these conditions are met, LS, C, and P each equal 1.0, and K equals;

$$K = A / EI \quad \text{or} \quad K = A / R \quad (4.7)$$

The 22.1 m length and 9 percent steepness are selected as base values for LS and K because they are the predominant slope length and about the average gradient on which past erosion measurements in the United States had been made. The designated management provides a condition that nearly eliminates effects of cover, management, and land use residual and that can be duplicated on any cropland.

Direct measurements of K on well-replicated, unit plots as described reflect the combined effects of all the soil properties that significantly influence the ease with which a particular soil is eroded by rainfall and runoff if not protected. However, K is an average value for a given soil, and a direct measurement of the factor requires soil loss measurements for a representative range of storm sizes and antecedent soil conditions. To evaluate K for soils that do not usually occur on a 9 percent slope, soil loss data from plots that meet all other specified conditions are adjusted to this base by the S factor (Wischmeier and Smith, 1978).

4.3.3.3. Values of K for Specific Soils

Representative values of K for most of the soil types and texture classes can be obtained from tables prepared by soil scientists using the latest available research information. These tables are available in developed countries like USA and those in Europe. Values for the exact soil conditions at a specific site can be computed by the use of the soil erodibility nomograph presented in the next subsection.

Usually a soil type becomes less erodible with a decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction. In general, the organic matter content ranks next to particle-size distribution as indicator of erodibility. However, a soil's erodibility is a function of the complex interactions of a substantial number of its physical and chemical properties and often varies within a standard texture class.

Values of K determined for several soil types on which erosion plot studies under natural rain were conducted are listed in Table 4.1 (Novotny and Olem, 1994). These values are not exact and valid numbers for every investigation area, but they give an idea about their range with respect to soil types.

Table 4.1. Estimated soil erodibility factor, K, for technical soil classes (Novotny and Olem, 1994).

TECHNICAL CLASS	K FOR ORGANIC MATTER CONTENT (%)		
	0.5	2	4
Sand	0.05	0.03	0.02
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.16
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.35
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silt clay	0.25	0.23	0.19
Clay	0.13-0.20		

K factors can also be classified with respect to soil erodibility (Table 4.2) (Doğan ve Güçer, 1976).

Table 4.2. K factors with respect to soil erodibility (Doğan and Güçer, 1976).

$0.00 < K \leq 0.05$	Very low erodibility
$0.05 < K \leq 0.10$	Low erodibility
$0.10 < K \leq 0.20$	Medium erodibility
$0.20 < K \leq 0.40$	High erodibility
$0.40 < K \leq 0.60$	Very high erodibility

A direct measurement of the erodibility factor is both costly and time consuming and has been feasible only for a few major soil types. To achieve a better understanding of how and to what extent each of various properties of a soil affects its erodibility, an interregional study was initiated in 1961 in USA. The study included the use of field-plot rainfall simulators in at least a dozen States to obtain comparative data on numerous soils, laboratory determinations of physical and chemical properties, and operation of additional fallow plots under natural rain. Several empirical erodibility equations were reported. A soil erodibility nomograph (Figure 4.4.) for farmland and construction sites provided a more generally applicable working tool (Wischmeier and Smith, 1978).

4.3.3.4. Nomograph Solution

To solve the values of K on a nomograph, one has to use appropriate data to enter the scale at the left and then proceed to points representing the soil's percent sand (0.10-2.0 mm), percent organic matter, structure code, and permeability class as illustrated by the dotted line on the nomograph. The horizontal and vertical moves must be made in the listed sequence. Linear interpolations between plotted lines may be used. The structure code and the permeability classes are defined on the nomograph for reference.

Many agricultural soils have both fine granular topsoil and moderate permeability. For these soils, K may be read from the scale labeled "first approximation of K", and the second block of the graph is not needed. For all the other soils, however, the procedure must be completed to the soil erodibility scale in the second half of the graph. Since the soil erodibility nomograph was developed in U.S.A, K values in the nomograph must be converted in metric system by multiplying a conversion coefficient of 1.292.

The mechanical analysis, organic matter, and structure data are those for the topsoil. The permeability class is the profile permeability. Coarse fragments are excluded when determining percentages of sand, silt and clay.

Note: K value read from the nomograph is multiplied by a conversion factor of 1.292 to convert to the metric system.

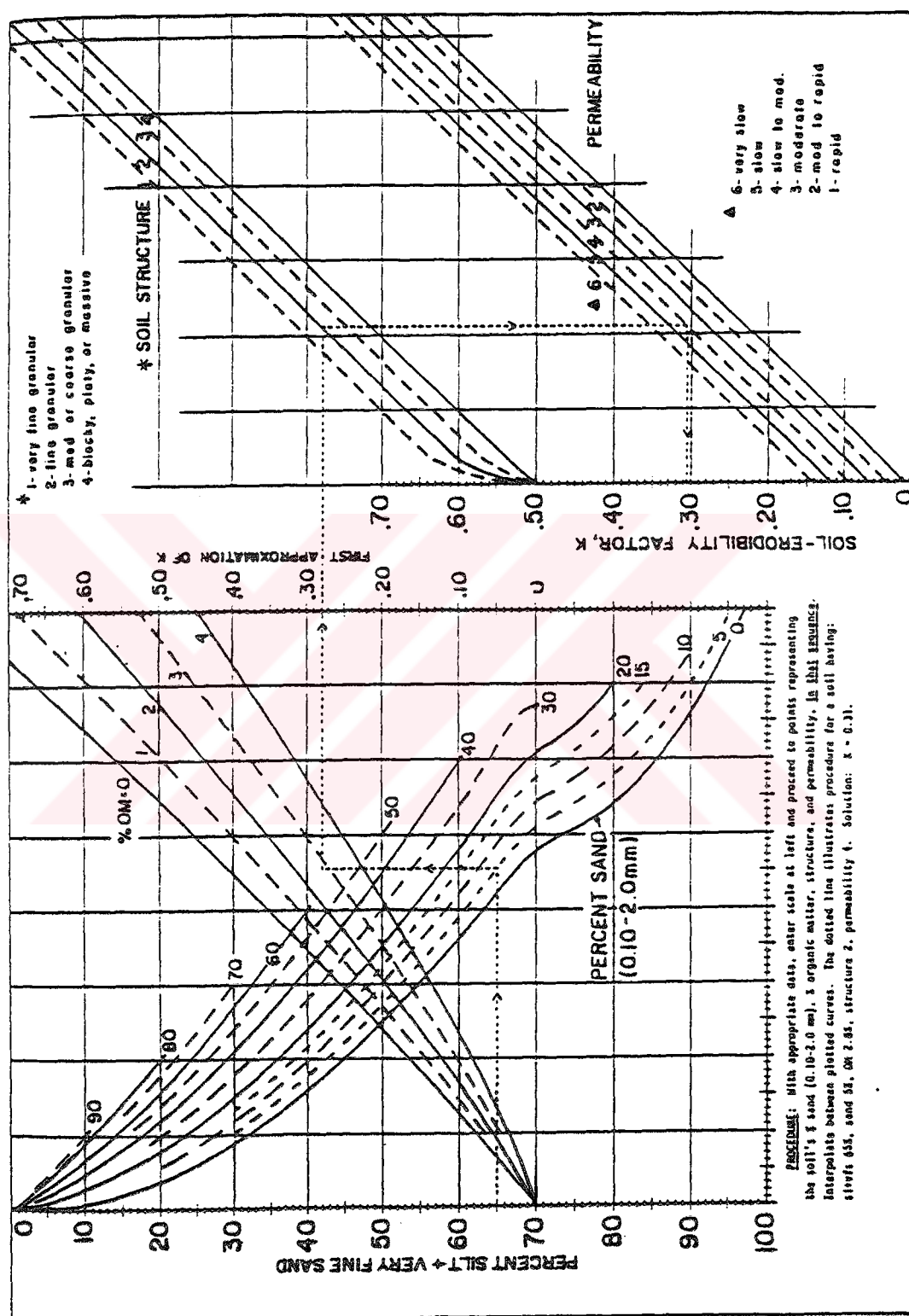


Figure 4.4. The soil erodibility nomograph (Wishmeier and Smith, 1978)

4.3.3.5. Confidence Limits of the nomograph

In tests against measured K values ranging from 0.03 to 0.69, 65 percent of the nomograph solutions differed from the measured K values by less than 0.02, and 95 percent of them by less than 0.04. Limited data available in 1971, in USA for mechanically exposed B and C subsoil horizons indicated about comparable accuracy for these conditions. However, more recent data taken on desurfaced high clay subsoil's showed the nomograph solution to lack the desired sensitivity to differences in erodibilities of these soils horizons. For such soils the content of free iron and aluminum oxides ranks next to particle-size distribution as an indicator of erodibility. Some high-clay soils form what has been called irreversible aggregates on the surface when tilled. These behave like larger primary particles (Wishmeier and Smith, 1978).

4.3.4. Topographic factor (LS)

Both the length and the steepness of the land slope significantly affect the rate of soil erosion by water. The two effects have been evaluated separately in research and are represented in the soil loss equation by L and S, respectively. In field applications, however, considering the two as a single topographic factor, LS, is more convenient (Wischmeier and Smith, 1978).

4.3.4.1. Slope Effect Chart

LS is the expected ratio of soil loss per unit area from a field slope to that from a 22.1 m length of uniform 9-percent slope under identical conditions. This ratio for specified combinations of field slope length and uniform gradient may be obtained directly from the slope-effect chart (Figure 4.5.) (Wischmeier and Smith, 1978).

The slope effect chart in Fig. 4.5 can be formulated as:

$$LS = \sqrt{L} * (0.0138 + 0.00974 S + 0.00138 S^2) \quad (4.8)$$

where; L is the slope length in meters, and S percent slope

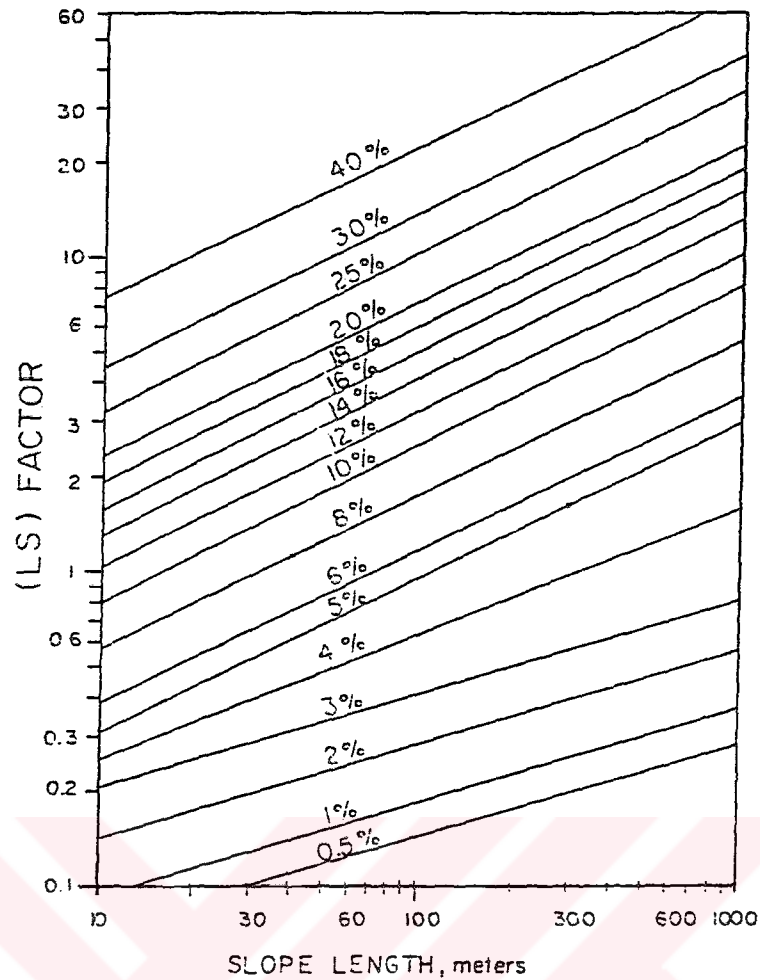


Figure 4.5. Slope-Effect Chart (Novotny and Olem, 1994)

On this chart, one enters on the horizontal axis with the field slope length, moves vertically to the appropriate percent-slope curve, and reads LS on the scale at the left. For example, the LS factor for a 100 m length of 8 percent slope is 1.8.

The LS factor is also derived by the equation (Williams et al., 1985):

$$LS = (L / 22.1)^m \cdot (65.41 S^2 + 4.565 S + 0.065) \quad (4.9)$$

where L is the slope length in meters, S percent slope, and m to be computed as follows:

$$m = 0.6 (1 - \exp(-35.835 S)) \quad (4.10)$$

However, the Eq. (4.9) gives relatively high values of LS for slope-lengths longer than 100 m, in contrast to the LS derived from Fig. 4.5.

4.3.4. 2. Slope Length Effect

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff water enters a well defined channel that may be part of a drainage network or a constructed channel. A change in land cover or a significant change in gradient along a slope does indicate the start of a new slope length for purposes of soil loss estimation (Wischmeier and Smith, 1978).

Soil loss per unit area generally increases substantially as slope length increases. The greater accumulation of runoff on the longer slopes increases its detachment and transport capabilities.

Equation (4.8) can be divided into two parts. The first part comprises the length effect in the form of:

$$L = \sqrt{L} \quad (4.11)$$

Second is the slope effect with:

$$S = (0.0138 + 0.00974 S + 0.00138 S^2) \quad (4.12)$$

These two parts have been obtained from several plot studies in USA by Wischmeier (Wischmeier and Smith, 1978).

4.3.5. Cover and management factor (C)

4.3.5.1. Cover and management effects

Cover and management effects cannot be independently evaluated because their combined effect is influenced by many significant interrelations. Almost any crop can be grown continuously, or it can be grown in rotations. Crop sequence influences the length of time between successive crop

canopies, and it also influences the benefits obtained from residual effects of crop and management (Wischmeier and Smith, 1978).

The erosion control effectiveness of meadow sod turned under before a row crop depends on the type and quality of the meadow and on the length of time elapsed since the sod was turned under. Seedbeds can be clean tilled or they can be protected by prior crop residues. They can be left rough, with mulch available capacity for surface storage and reduction of runoff velocity or they can be smoothed by secondary tillage.

Crop residues can be removed, left on the surface, incorporated near the surface, or plowed under. When left on the surface they can be chopped or dragged down, or they can be allowed to remain as left by the harvesting operation. The effectiveness of crop residue management will depend on the amount of residue available. This, in turn, depends on the amount and distribution of rainfall, on the fertility level, and on the management decisions made by the farmer.

The canopy protection of crops not only depends on the type of vegetation, the stand and the quality of growth, but it also varies greatly in different months or seasons. Therefore, the overall erosion reducing effectiveness of a crop depends largely on how much of the erosive rain occurs during those periods when the crop and management practices provide the least protection.

4.3.5.2. Definition of factor C

Factor C in the soil loss equation is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow. This factor measures the combined effect of all the interrelated cover and management variables.

The loss that would occur on a particular field, if it were continuously in fallow condition, is computed by the product of $R.K.LS$ in the soil loss equation. Actual loss from the cropped field is usually much less than this amount. Just how much less depends on the particular combination of cover, crop sequence, and management practices. It also depends on the particular stage of growth and development of the vegetal cover at the time of the rain. C adjusts the soil loss estimate to suit these conditions.

The correspondence of periods of expected highly erosive rainfall with periods of poor or good plant cover differs between regions or locations. Therefore, the value of C for a particular cropping system will not be the same in all parts of a country. Deriving appropriate C values for a given area requires knowledge of how the erosive rainfall in that area is likely to be distributed through the 12 months of the year and how much erosion control protection the growing plants, crop residues, and selected management practices will provide at the time when erosive rains are most likely to occur (Wishmeier and Smith, 1978).

4.3.5.3. Crop stage period

The change in effectiveness of plant cover within the crop year is gradual. For practical purposes, the year is divided into a series of cropstage periods defined so that cover and management effects may be considered approximately uniform within each period.

C factor is evaluated for six cropstage periods defined as follows:

- Period F** : rough fallow; inversion plowing to secondary tillage;
- Period SB** : seedbed; secondary tillage for seedbed preparation until the crop has developed 10 percent canopy cover;
- Period 1** : establishment; end of SB until crop has developed a 50 percent canopy cover (Exception: period 1 for cotton ends at 35 percent canopy cover);
- Period 2** : development; end of period 1 until canopy cover reaches 75 percent (60 percent for cotton);
- Period 3** : maturing crop; end of period 2 until crop harvest; this period was evaluated for three levels of final crop canopy.
- Period 4** : residue or stubble; harvest to plowing or new seeding.

The value of C on a particular field is determined by many variables, one of which is weather. Major variables that can be influenced by management decisions include crop canopy, residue mulch, incorporated residues, tillage, and their interactions. Each of these effects may be treated as a subfactor whose numerical value is the ratio of soil loss with the effect to corresponding loss without it. C is the product of all the pertinent subfactors. The prepared tables that give a mean value of the C consider these subfactors.

4.3.5.4. Crop canopy

Leaves and branches that do not directly contact the soil have little effect on the amount and velocity of runoff from prolonged rains, but they reduce the effective rainfall energy by intercepting falling raindrops. Water drops falling from the canopy may regain appreciable velocity but usually less than the terminal velocities of free-falling raindrops. The amount by which energy expended at the soil surface is reduced depends on the height and density of the canopy (Figure 4.6).

4.3.5.5. Residue mulch

Residue mulches and stems from close-growing vegetation are more effective than equivalent percentages of canopy cover. Mulches intercept falling raindrops so near the surface that the drops regain no fall velocity, and they also obstruct runoff flow and thereby reduce its velocity and transport capacity. Figure 4.6 shows the both canopy and mulch effect when average fall distance of drops from canopy to the ground is about 1 m.

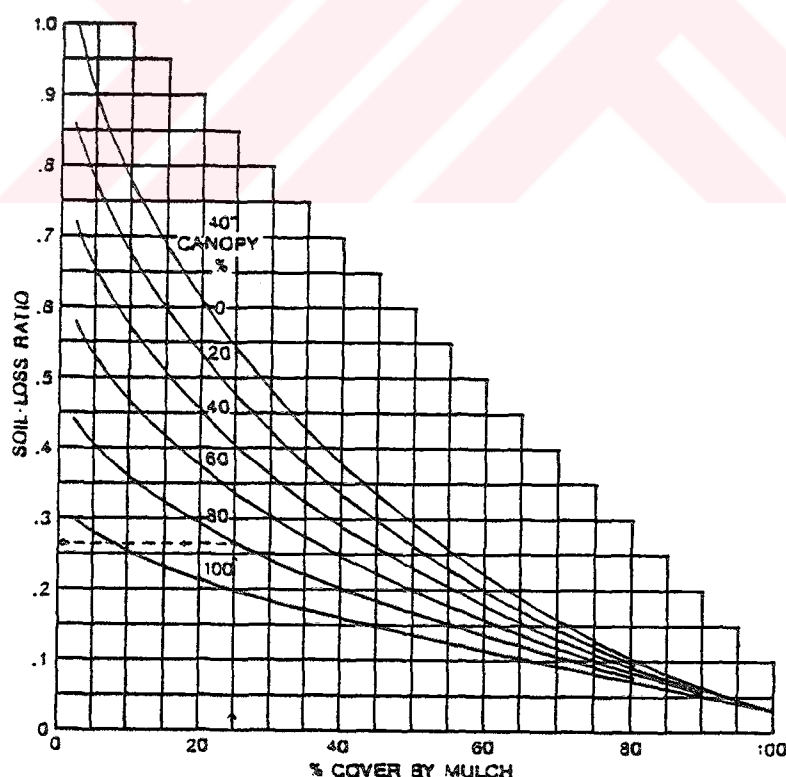


Figure 4.6. Combined mulch and canopy effects when average fall distance of drops from canopy to the ground is about 1.0 meter.

4.3.5.6. Incorporated residues

Especially, during the seedbed and establishment periods, the erosion reducing effectiveness of residues mixed into the upper few centimeters of soil by shallow tillage is appreciably greater than the residual effect of long-term annual incorporation with moldboard plow. However, the incorporated residues are less effective than if left on the surface.

4.3.5.7. Tillage

The type, frequency and timing of tillage operations influence porosity, roughness, compaction and microtopography. These, in turn, affect water intake, surface storage, runoff velocity, and soil detachability, all of which are factors in potential erosion. These effect are highly correlated with cropland residual effect.

4.3.5.8. Soil loss ratios for cropland

C factor is usually given in terms of its average annual value for a particular combination of crop system, management, and rainfall pattern. To derive site values of C, soil loss ratios for the individual cropstage periods must be combined with erosion-index distribution data.

To compute C values for several management practices, each management practice in different cropstage periods should be observed and soil losses should be recorded. An appropriate value of the C parameter for a specific area should be determined by long-term local experiments. In developed countries that have constructed their periodic data capture programs about environmental data, there are tables for C factors for each cropstage and practice management. For example, Table 4.3 gives the average soil loss ratios (C factors) for several crops for each cropstage and several crop management systems in United States. These values were derived from 250 000 plot studies and are enough to the true average values to provide highly valuable planning and monitoring guidelines (Wischmeier and Smith, 1978). Table 4.3 gives a part of the C values for several crop and management practices prepared by Wishmeier. Table 4.4 is used when the stalks are chopped and distributed without soil tillage in the 4th cropstage period.

Table 4.3. Values of C for cropland (Wischmeier and Smith, 1978)

Line No	Cover, crop sequence and management	Spring Residue	Soil loss ratio for cropstage period and canopy cover							
Corn after C, GS or COT in Meadowless systems			F	SB	1	2	3:80	90	96	4L
1	RdL, sprg TP	4.500	31	55	48	38	-	-	20	23
2		3.400	36	60	52	41	-	24	20	30
3		2.600	43	64	56	43	32	25	21	37
4		2.000	51	68	60	45	33	26	22	47
5	RdL, fall TP	HP	44	65	53	38	-	-	20	-
6		GP	49	70	57	41	-	24	20	-
7		FP	57	74	61	43	32	25	21	-
:	:	:	:	:	:	:	:	:	:	:
Grain after C, G, GS, COT										
129	In disced residues	4.500	70	-	12	12	11	7	4	2
130		3.400	60	-	16	14	12	7	4	2
131			50	-	22	18	14	8	5	3
132			40	-	27	21	16	9	5	3
133			30	-	32	25	18	9	6	3
134			20	-	38	30	21	10	6	3

Note: Details of Table 4.3 is given in APPENDIX A.

Table 4.4. Soil loss ratios (percent) for cropstage 4 when stalks are chopped and distributed without soil tillage (Wischmeier and Smith, 1978)

Mulch cover ¹	Corn or Sorghum		Soybeans		Grain stubble ⁴
	Tilled seedbed ²	No-till	Tilled seedbed ²	No-till in corn rd ³	
20	48	34	60	42	48
30	37	26	46	32	37
40	30	21	38	26	30
50	22	15	28	19	22
60	17	12	21	16	17
70	12	8	15	10	12
80	7	5	9	6	7
90	4	3	-	-	4
95	3	2	-	-	3

¹ Part of a field of surface directly covered by pieces of residue mulch.

² This column applies for all systems other than no-till.

³ Cover after bean harvest may include an appreciable number of stalks carried over from the prior corn crop.

⁴ For grain with meadow seeding, include meadow growth in percent cover and limit grain period 4 to 2 mo. Thereafter, classify as established meadow.

To obtain the annual C value, the soil loss ratios selected with respect to appropriate management practices are multiplied by percentage of erosion index (EI) value in its cropstage period and then summed for each cropstage period.

4.3.5.9. C values for pasture, range, and idle land

Factor C for a specific combination of cover conditions on these types of land may be obtained from Table 4.5. This table is also developed in the USA. The values in the table include the subfactors and are not effected cropstage periods since these lands are assumed to continuously have the same land cover.

Table 4.5. Factor C for permanent pasture, range, and idle land¹ (Wischmeier and Smith, 1978)

Type and height ²	Percent cover ³	Cover that contacts the soil surface						
		Type ⁴	Percent ground cover					
			0	20	40	60	80	95
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall weeds or short brush with average drop fall height of 20 in.	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6 1/2 ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush.	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
Average drop fall height	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

¹ The listed C values assume that the vegetation and mulch are randomly distributed over the entire area.

² Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.

³ Portion of total-area surface that would be hidden from view by canopy in a vertical projection.

⁴ G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in deep.
W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

4.3.5.10. C values for undisturbed forest land

In undisturbed forests, infiltration rates and organic matter content of the soil are high, and much or all of the surface is usually covered by a layer of compacted decaying forest duff or litter several centimeters thick. Factor C for undisturbed forest land may be obtained from Table 4.6.

Table 4.6. Factor C for undisturbed forest land.

Percent of area covered by canopy of trees and underground	Percent of area covered by duff at least 2 in deep	Factor C ¹
100-75	100-90	.0001-.001
70-45	85-75	.002-.004
40-20	70-40	.003-.009

¹ The ranges in listed C values are caused by the ranges in the specified forest litter and canopy covers and by variations in effective canopy heights.

For general magnitudes of factor C for agricultural land, permanent pasture and idle rural land, Table 4.7 is also used. The values in Table 4.7 indicate the range of factor C for different land cover and land use.

Table 4.7. Values of C for Cropland, Pasture, and Woodland (Novotny and Olem, 1994)

Land Cover	Land Use, C	Land Cover	Land Use, C
Continuous fallow tilled up and down slope	1.0	For permanent pasture idle land undamaged woodland	
Shortly after seeding prior to harvest	0.3-0.8	Ground cover 85%-100%	
For crops during main part of growing season		As grass	0.003
Wheat	0.05-0.15	As weeds	0.01
Corn	0.1-0.3	Ground cover 80%	
Cotton	0.4	As grass	0.01
Soybean	0.2-0.3	As weeds	0.04
Meadow	0.01-0.02	Ground cover 60%	
		As grass	0.04
For managed woodland		As weeds	0.09
Tree canopy of 75%-100%	0.001		
40%-75%	0.002-0.004		
20%-40%	0.003-0.01		

4.3.6. Support practice factor (P)

4.3.6.1. Definition of P factor

By definition, factor P in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture. Improved tillage practices, sod-based rotations, fertility treatments and greater quantities of crop residues left on the field contribute materially to erosion control and frequently provide the major control in a cropland. However, these are considered conservation cropping and management practices and the benefits derived from them are included in C.

The most important supporting cropland practices are contour tillage, stripcropping on the contour and terrace systems. Stabilized waterways for disposal of excess rainfall are a necessary part of each of these practices.

4.3.6.2. Contouring

In general the practice of tillage and planting on the contour has been effective in reducing erosion. Contouring appears to be the most effective on slopes in the 3 to 8 percent range. As land slope decreases, it approaches equality with contour row slope, and soil loss ratio approaches 1. As slope increases, contour row capacity decreases and the soil loss ratio again approaches 1. Effectiveness of contouring is also influenced by the slope length. When rainfall exceeds infiltration and surface detention in large storms, breakovers of contour rows often result in concentrations of runoff that tend to become progressively greater with increases in slope length. Therefore, on slopes exceeding some critical length the amount of soil moved from a contoured field may approach or exceed that from a field on which each row carries its own runoff water down slope (Wischmeier and Smith, 1978).

4.3.6.3. Contour stripcropping

Stripcropping, a practice in which contoured strips of sod are alternated with equal width strips of row crops or small grain, is more effective than contouring alone.

Observations from stripcropping studies showed that much of the soil eroded from a cultivated strip was filtered out the runoff as it was slowed and spread within the first several centimeters of the adjacent sod strip (Wischmeier and Smith, 1978). Thus, the stripcrop factor derived from soil loss measurements at the end of the slope accounts for off-the-field soil movement but not for all movements within the field.

4.3.6.4. Terracing

The most common type of terrace on highly sloping land is the broadbase, with the channel and ridge cropped the same as the interterrace area. The steep backslope terrace is the most common on steeper land. Another type of terrace, using a level and broad channel with either open or closed ends, was developed to conserve moisture in dryland farming (Wischmeier and Smith, 1978).

Terracing combined with contour farming and another conservation practices is more effective than those practices without the terraces because it positively divides the slope into segments equal to the horizontal terrace interval.

4.3.6.5. P values

The value of the P factor for contoured, stripcropped and terraced fields with different slopes, are given in Table 4.8.

Table 4.8. P factor for three types of supporting practice (Doğan and Güçer, 1976).

SLOPE	CONTOURING	STRIPCROPPING	TERRACING
1.1-2.0	0.60	0.30	0.30
2.1-7.0	0.50	0.25	0.25
7.1-12.0	0.60	0.30	0.30
12.1-18.0	0.80	0.40	0.40
18.1-24.0	0.90	0.45	0.45

4.3.7. Sediment yield and sediment delivery ratio

Sediment yield refers to the amount of sediment measured at a watershed outlet or a point on the waterway. Sediment yield is not equal to the upland erosion. Eroded soil materials often move only short distances before a decrease in runoff velocity causes their deposition. They may remain in the fields where they originated or may be deposited on more level slopes that are away from the stream system (Novotny and Olem, 1994).

The ratio of sediment delivered at a given area in the stream system to the gross erosion is the sediment delivery ratio for that drainage area. Thus, the annual sediment yield of a watershed is defined as follows:

$$SY = (A) (DR) \quad (4.13)$$

where; A: total gross erosion computed from USLE (Eq. 4.1)

DR : sediment delivery ratio

A general equation for computing watershed delivery ratios is not yet available since they depend on several properties of the watershed like infiltration, roughness, vegetation cover, hydrograph or runoff drainage, etc. But the ratios for some specific drainage areas have been computed directly from local data obtained from sediment gauging stations. As a rough approach Roehl (1992) established a relationship between the delivery ratio and watershed size (Novotny and Olem, 1994). Figure 4.7 shows delivery ratios of a watershed associated with its size.

Tim et al. (1992) have proposed an equation for deriving sediment delivery ratio of a specified area in a watershed. The point value of delivery ratios can be calculated from topography (relief and slope) of watershed, water body, and land use data maps according to the expression;

$$DR_i = \exp (-k S_{fi} L_{fi}) \quad (4.14)$$

where; k: coefficient that varies with land cover;

S_{fi} : slope function;

L_{fi} : length of the flow path between the point i and channel outlet.

By simplification, DR_i can be assumed as;

$$DR_i = 10 (R / L) \quad (4.15)$$

where; R is the relief which is the difference in elevation between a land point and the point which surface flow reaches to stream channel (Hession and Schanholtz, 1988)

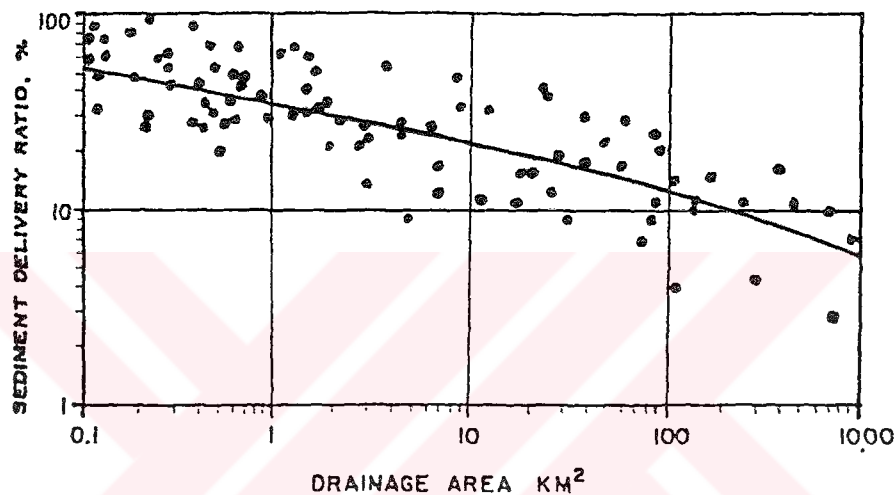


Figure 4.7. Relation of sediment delivery ratio to the watershed area (Novotny and Olem, 1994).

4.3.8. Enrichment ratio and organic N transport by sediment

Enrichment ratio is the concentration of contaminant in the sediment divided by that of the soil. Most soil contaminants are adsorbed by clay and organic matter because of their high surface area, leading to strong adsorption bonds. When rainwater reaches the surface horizon of the soil, some contaminants are desorbed and go into solution; others remain adsorbed and move with soil particles. The contaminant content of runoff sediment is then higher than that in the parent soil. The difference is called enrichment ratio and defined as follows:

$$ER = C_r / C_s \quad (4.16)$$

where; C_r : contaminant concentration of the runoff per gram sediment;

C_s : contaminant content of the parent soil per gram;

The enrichment concept can be applied to clay, organic matter, and all contaminants adsorbed by soil particles, which include phosphates, ammonium, metals, and pesticides. It is not appropriate to apply the enrichment ratio to contaminants that are mobile in soils, such as nitrates or soluble pesticides (Novotny and Olem, 1994).

The enrichment ratio refers to the difference in particle size distribution and associated or adsorbed contaminant content of washload particles and soils from which the sediment originates. Enrichment of sediments by clay is a two-step process: enrichment during particle pick up and enrichment during redeposition of the coarser particles during delivery in overland and channel flows. Thus, as the delivery ratio decreases with the increasing watershed area or time of overland flow, the enrichment ratio of the washload increases as shown in Figure 4.8.

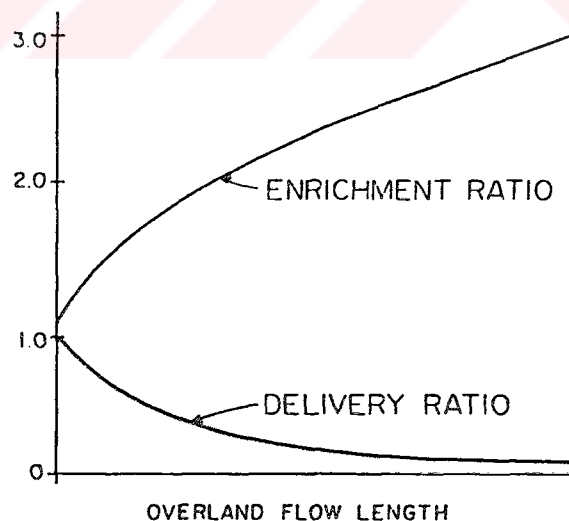


Figure 4.8. Relation of the sediment delivery to enrichment of sediment by clays (Novotny and Olem, 1994).

The lower limit of enrichment ratio is 1.0 if the sediment size distribution is the same as that of the soil. Thus, $1 \leq ER \leq 1 / DR$. The logarithmic equation estimating enrichment ratio is given as (Williams et al., 1985):

$$ER = X_1 C_s^{X_2} \quad (4.17)$$

where C_s is the sediment concentration in g/m^3 and X_1 and X_2 are parameters set by the upper and lower limits of the sediment concentration. To approach an enrichment ratio of 1.0, the sediment concentration would be extremely high. Conversely, a very low sediment concentration would cause the enrichment ratio to approach $1/DR$.

The simultaneous solution of Eq. (4.17) at the boundaries assuming sediment concentrations range to from 500 to $250,000 g/m^3$ gives (Williams et al., 1985):

$$X_2 = \log (1 / DR) / 2.699 \quad (4.18)$$

$$X_1 = 1 / (0.25)^{X_2} \quad (4.19)$$

Organic N transport by sediment can be calculated by using sediment yield and enrichment ratio of each subbasin. A loading function developed by McElroy et al.(1976) is used to estimate organic N loss for each subbasin. The loading function is;

$$ONY = 0.001 (SY) (CON) (ER) \quad (4.20)$$

where; ONY : the organic N runoff loss at the subbasin outlet in kg/ha,

SY : sediment yield in ton/ha from Eq.(4.13)

CON : concentration of organic N in the top soil layer in g/ton

4.4. Data Needs for USLE Applications

As described above, Universal Soil Loss Equation (USLE) is commonly used for identifying the erosion-based pollution. An effective application of USLE for a small watershed requires several types of information about the study area. In order to get accurate results, the data that USLE

needs should be obtained precisely from the watershed or databases must be constructed like those in the developed countries.

The data needs of the for an effective USLE application can be defined as:

1. rainfall records;
2. soil types and their properties;
3. land use and management practices;
4. topographic information;
5. water quality observations;

4.5. Integration of USLE with GIS

The USLE-GIS integration is established by converting all parameters of USLE into raster-based format and by evaluating these digital parameter layers as described subsection 4.3.

Each parameter (R, K, C, P) and topography are digitized from the associated paper map. LS factor of the watershed is derived from digital elevation model obtained from topography. Then the digital maps in vector format are converted into raster format in which each parameter of a specific cell is known (Figure 4.9). The USLE equation (Eq. 4.1) is applied to five digital parameter-layers by overlaying them. These operations are performed on a study area and the results are described in Section V.

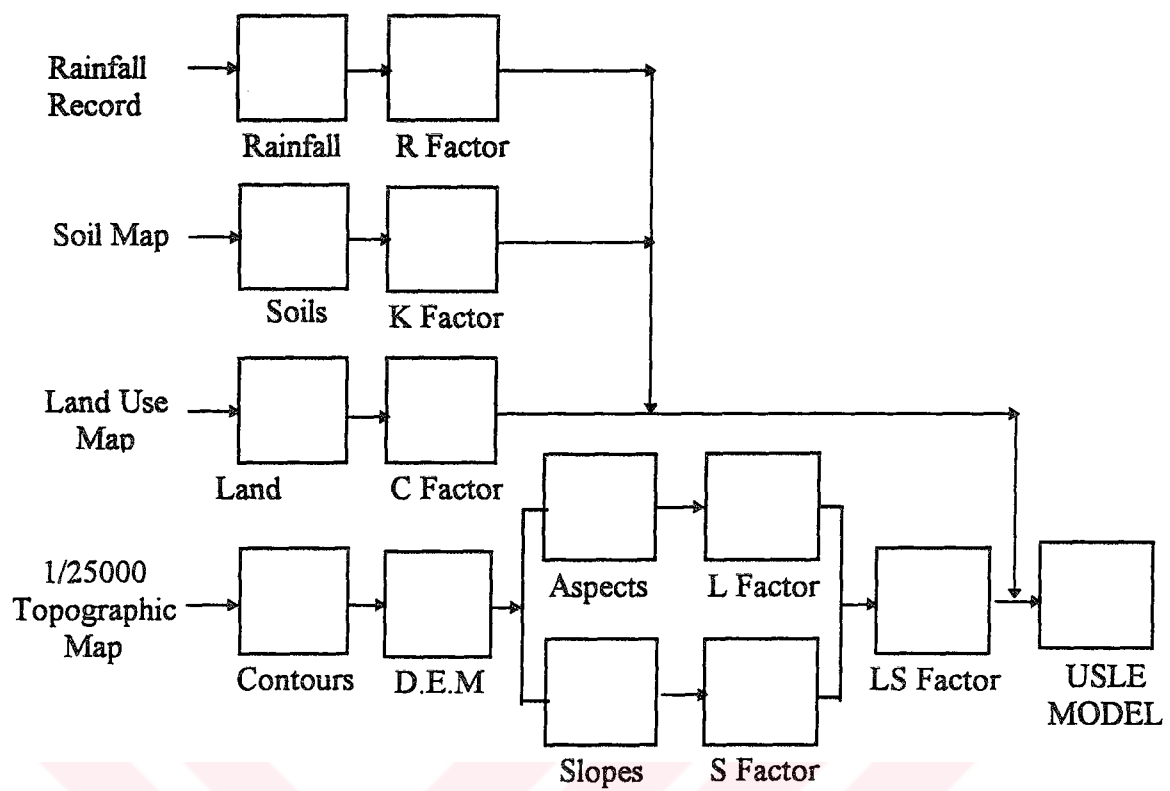


Figure 4.9. Integration of USLE with GIS

V. APPLICATION

5.1 General

The Universal Soil Loss Equation (USLE) applications are being widely used in developed countries to estimate soil loss and NPS associated with soil erosion. In Turkey, within the last 20 years, there also have been some studies to determine the local values of USLE parameters. However, these studies have remained on a local basis and the evaluated parameters have yet not been established in widely usable formats (e.g. maps, tables). The studies in Turkey are carried out by the Ministry of Agriculture (Tarım ve Köyişleri Bakanlığı, Köy Hizmetleri Genel Müdürlüğü, Topraksu Araştırma Enstitüleri). Due to the lack of information about the spatially distributed values of the USLE parameters in Turkey, the presented work is carried out on a demonstrative case where most of the USLE parameters are taken as assumed values.

As a demonstrative basin, a small region in the Gediz river basin around the city of Uşak is selected. The topography of this area is known via available maps. The other required data (soil types, land use and management, sediment observations, etc.) are not available in organized and spatially distributed formats. Therefore, these characteristics are assumed in as much a realistic manner as possible. In essence, the purpose of the presented study is to demonstrate the integration of USLE with GIS. Once this integration is realized satisfactorily, the approach can be used for a real case as information about USLE parameters become available. It must also be noted that the approach is developed for a small watershed as it is considered that the spatial distribution of USLE parameters and underlying mechanisms of soil loss can be best evaluated in small basin.

The study is carried out by the specific GIS software called IDRISI, produced by Clark University in the USA. IDRISI is an educational version of a raster based geographic information system. Thus, some applications that need vector formats are not applied in the study. However, IDRISI can generally be used in water resources research by considering basic raster procedures such as producing digital elevation models (DEM), basin boundaries determination, slopes determination, image overlaying, etc.

In this study, first, the vector identification of the topographic map is obtained by digitizing a 1:25000 contour map. The digitized contour map is then converted into raster format, and it is used to obtain the digital elevation model by operating INTERCON module in IDRISI. WATERSHED and ASPECT modules in IDRISI are operated to generate basin boundaries and river network of the watershed.

The generated images of the elevation model for the basin have considerable accurate results in comparison with the real case. Figs. 5.1 through 5.3 show the digital elevation model with river network, subbasins, and 3-D topography of the demonstration basin, respectively. In Figure 5.1, the elevation increases from light-gray-zones to the black-zones. The demonstration watershed consists of 15 subbasins. Figure 5.2 shows 15 subbasins of the watershed with respect to their basin number indicated with the gray scale. The lightest gray scale refers to subbasin 1 and the darkest gray scale refers to subbasin 15, respectively.

The raster images generated by IDRISI have 45000 (225x200) pixels, each one being a square with 30x30 m dimensions.

The USLE parameters are obtained by digitizing associated maps or spatial distribution information described below. USLE calculations that are a multiplication of 5 parameters (R, K, LS, C, P) are derived by overlaying each five digital-parameter-layer in raster format.

The calculations are applied to each subbasin as follows:

$$\text{Gross Erosion (Eq. 4.1); } A_i = (R_i) (K_i) (L_i) (C_i) (P_i)$$

$$\text{Sediment Yield (Eq. 4.13); } SY_i = (A_i) (DR_i)$$

$$\text{Organic N Yield (Eq. 4.20); } ONY_i = 0.001 (SY_i) (CON_i) (ER_i)$$

where i represents the number of subbasin.

The following sections describe the investigation of each USLE parameter for the demonstration basin.

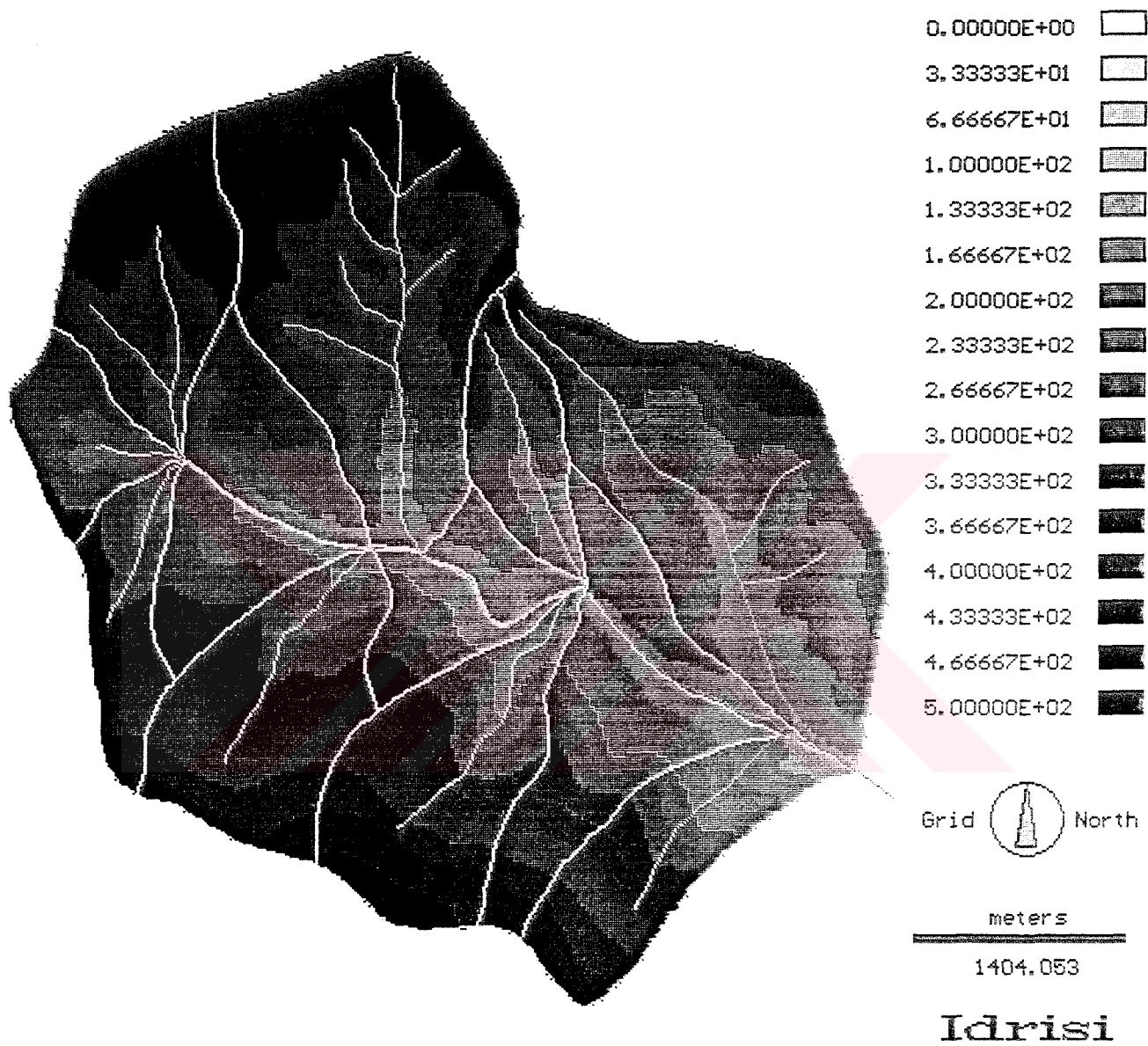


Figure 5.1. Digital Elevation Model and River Network of the Demonstration Basin.

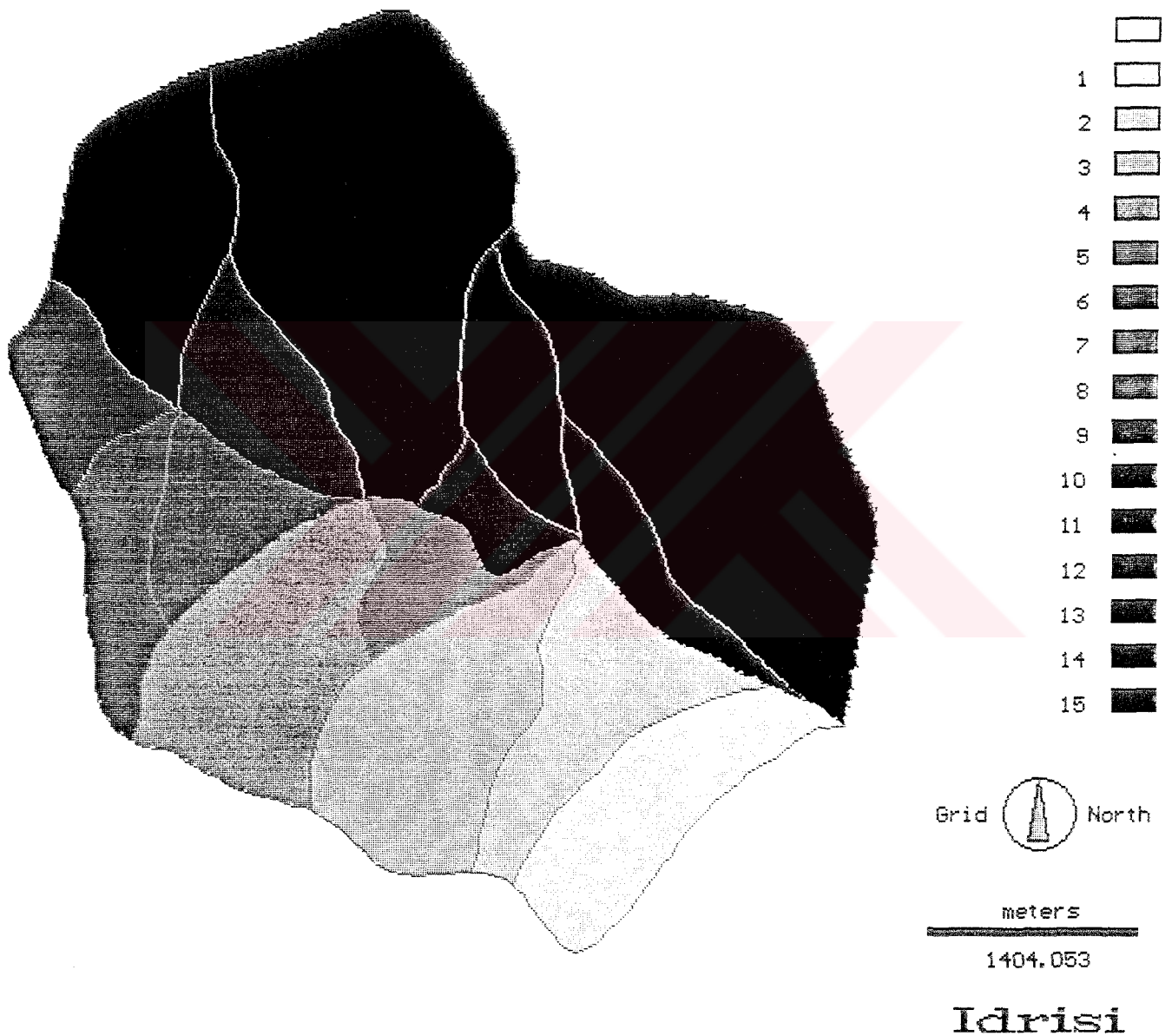


Figure 5.2. Subbasins of the Demonstration Basin.

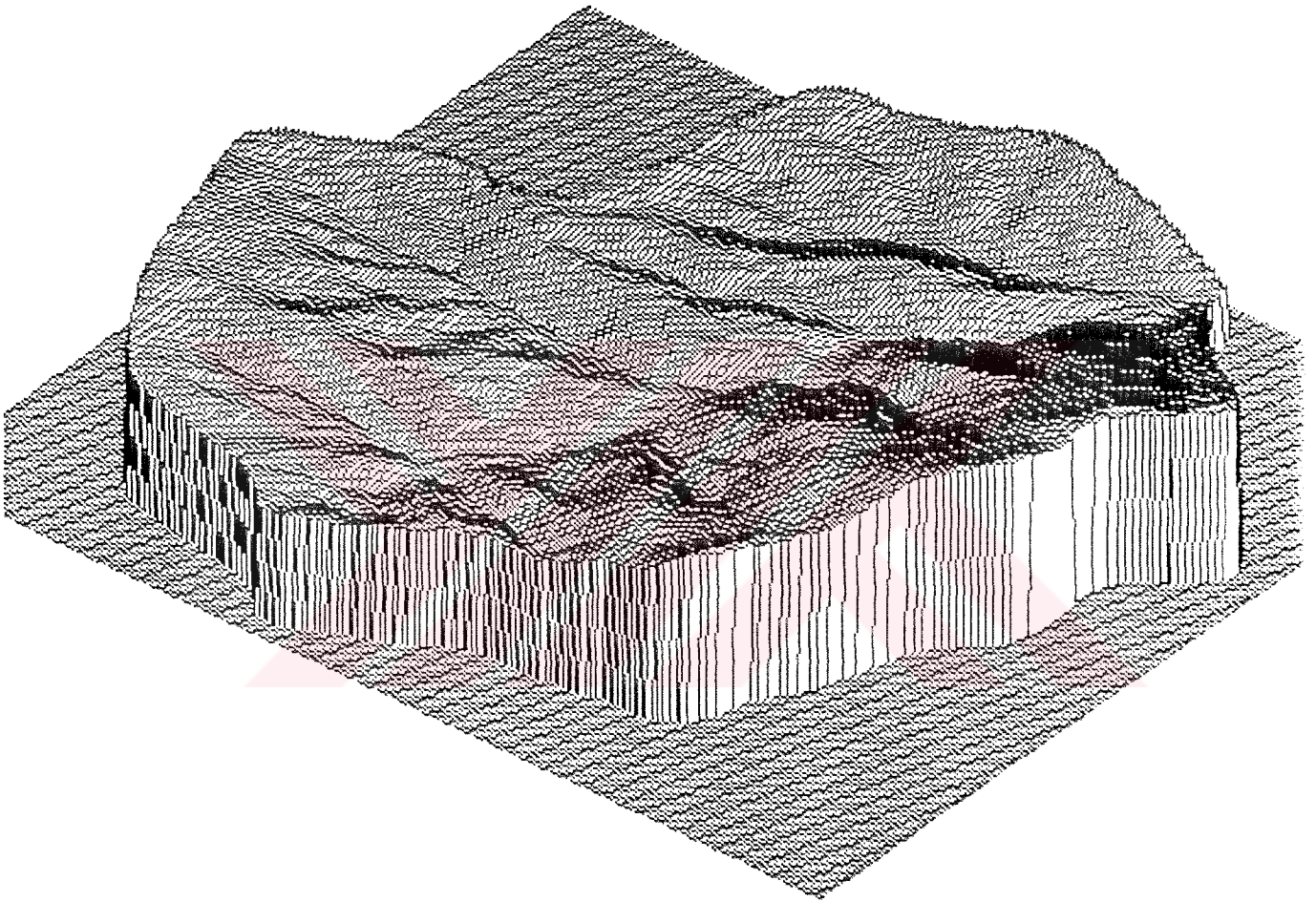


Figure 5.3. 3-D Topography of the Demonstration Basin.

5.2. Determination of the USLE parameters

5.2.1. Rainfall runoff factor (R)

The rainfall and runoff factor which is derived from the kinetic energy of the storm and its maximum 30 minute-intensity is obtained using Fig. 4.3 for Uşak. Table 5.1 presents rainfall runoff factor (R) for Uşak as given by Doğan (1987). This table is prepared by evaluating the rainfall records between 1957 and 1981 as described section 4.3.2.

Table 5.1 Time Distribution of the R Factor in the Demonstration Basin (Doğan, 1987).

M O N T H S												Total
1	2	3	4	5	6	7	8	9	10	11	12	
E I												
1.653	1.286	1.104	1.047	8.982	9.125	3.822	3.717	3.677	2.933	3.044	2.564	43.044

Since the study is carried out to determine the annual soil loss erosion, the total value of R in a year (43.044 ton.m/ha) is used for the demonstration basin. As the selected watershed is small (about 23 km²) the spatial distribution of the R factor in the basin can be assumed to be uniform. Figure 5.4 gives the spatial distribution of the R factor in the demonstration basin.

In Figure 5.4, R factor of the which is in the order of 43.044 tonm/ha is colored by the 15th gray scale. The other numbers in the legend are generated by IDRISI using linear interpolation with 15 equal intervals. However, these numbers are not included in the image since a uniform distribution is foreseen for R.

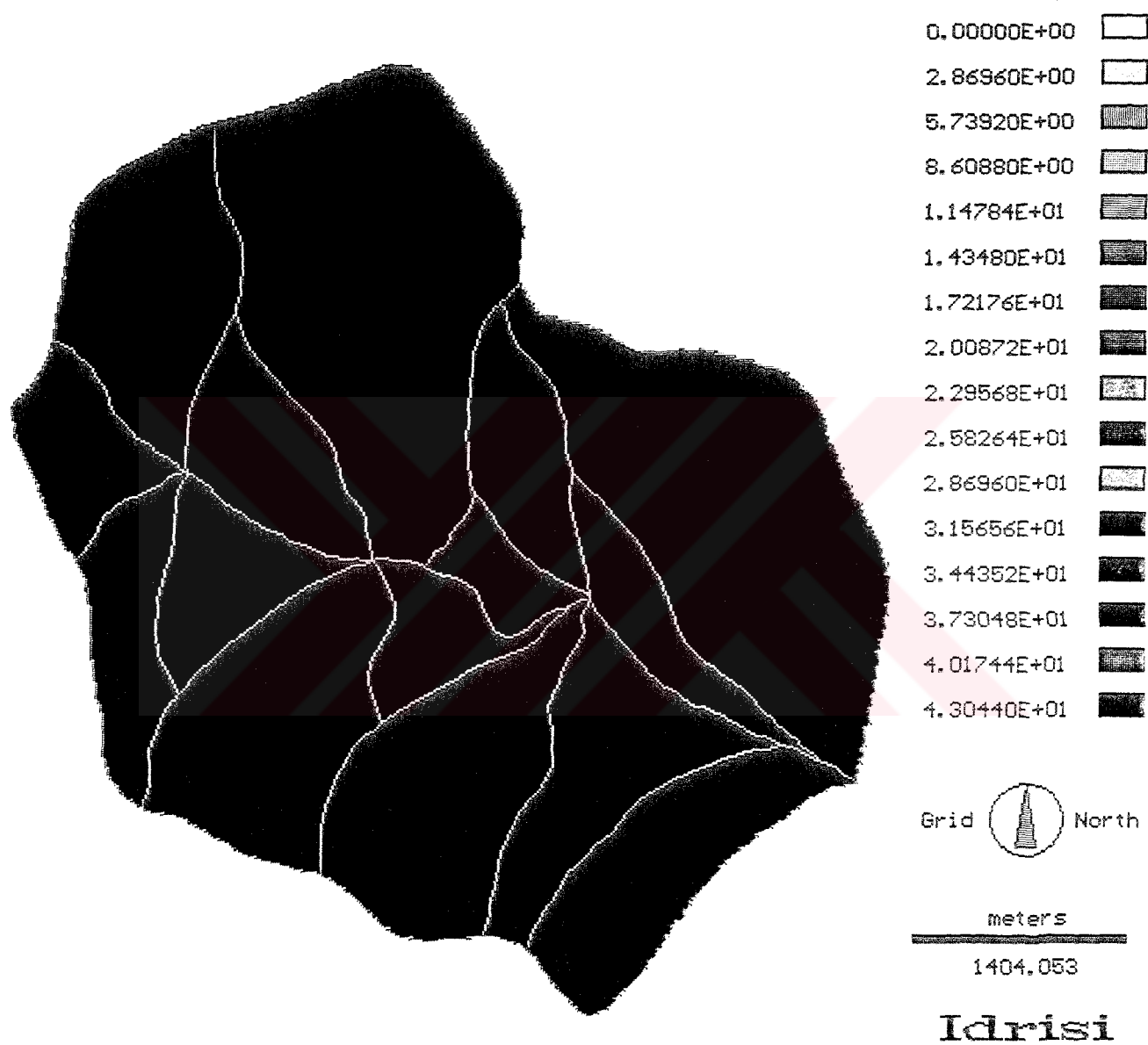


Figure 5.4. Spatial Distribution of the R Factor in the Demonstration Basin.

5.2.2. Soil erodibility factor (K)

In order to get an accurate result, K factor has to be determined experimentally by field measurements. In addition if the mechanical analysis of the soil types in the study area were available K factor can be determined from the nomograph in Fig. 4.4. In this study, K values are selected from Table 4.1 randomly within the range of 0.1 to 0.36. In the demonstration basin, the spatial distribution of the soil types and their erodibility factor are assumed as in Fig. 5.5.

In Figure 5.5 the lightest parts of the image indicate the lowest erodibility factor, and the darkest parts indicate the highest erodibility, respectively. The overall image of the K factors in the basin shows that most of the subbasins have high erodibility in contrast to the southern part where K is low.

From Fig. 5.5, the average soil erodibility factor (K) is determined as 0.28 which indicates roughly that the average soil type in the demonstrated basin is sandy loam.

5.2.3. Topographic factor (LS)

The topographic factor (LS) which depends on the mean slope and the slope-length of the subbasins is derived from the values obtained from images of both the mean slope and the slope-length of the demonstrated basin. Figs. 5.6 and 5.7 show the mean slopes and slope-lengths of the subbasins.

The mean slope image of the demonstrated basin is obtained by averaging the cell slopes associated with each subbasin. Fig. 5.8 indicates the cell slope distributions for the demonstrated basin. In Figure 5.8, the bright zones show low slopes and dark zones show the highest slopes. As can be seen from the Figure 5.6, the south part of the image (1st, 2nd, 3rd, 4th, 5th subbasins) and 15th subbasin have high slopes in contrast to other basins.

The mean slope-length of a subbasin is derived by the module DISTANCE in IDRISI which calculates distances from each cell to the stream. In Fig. 5.7 the slope length of subbasin 2 is the longest and it is indicated with a dark gray scale.

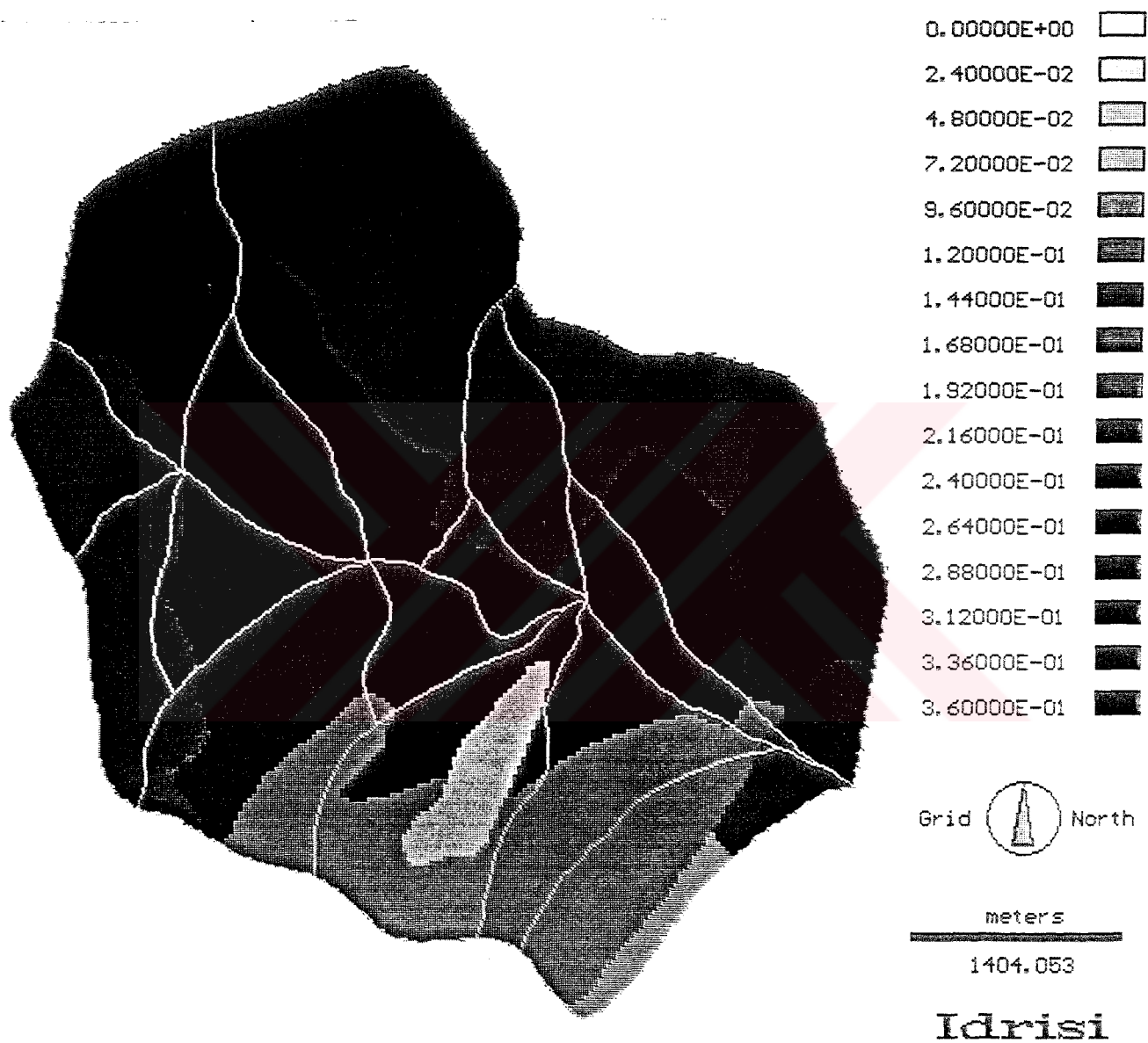


Figure 5.5. Spatial Distribution of the K Factor in the Demonstration Basin.

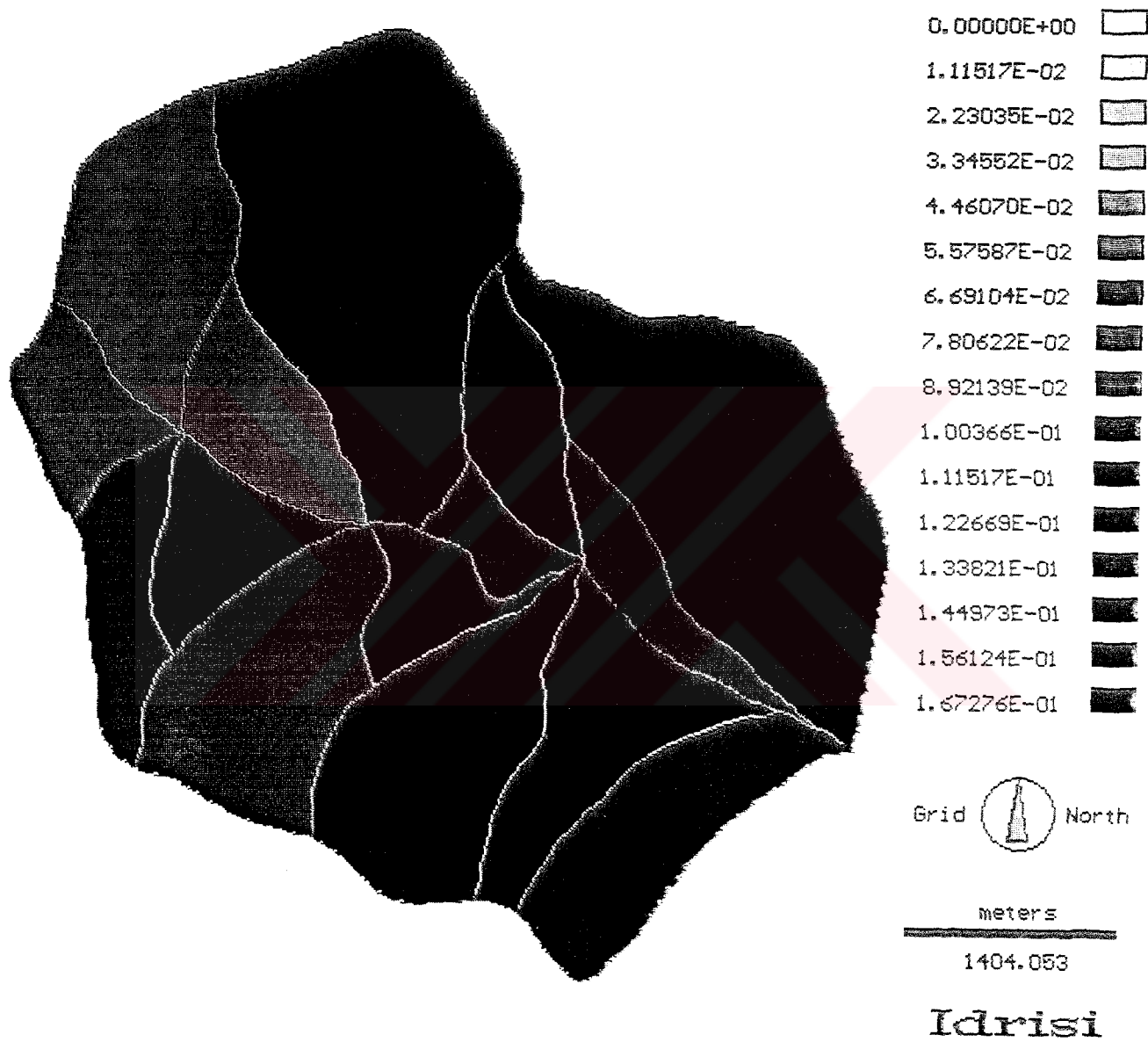


Figure 5.6. Mean Slopes of the Subbasins.

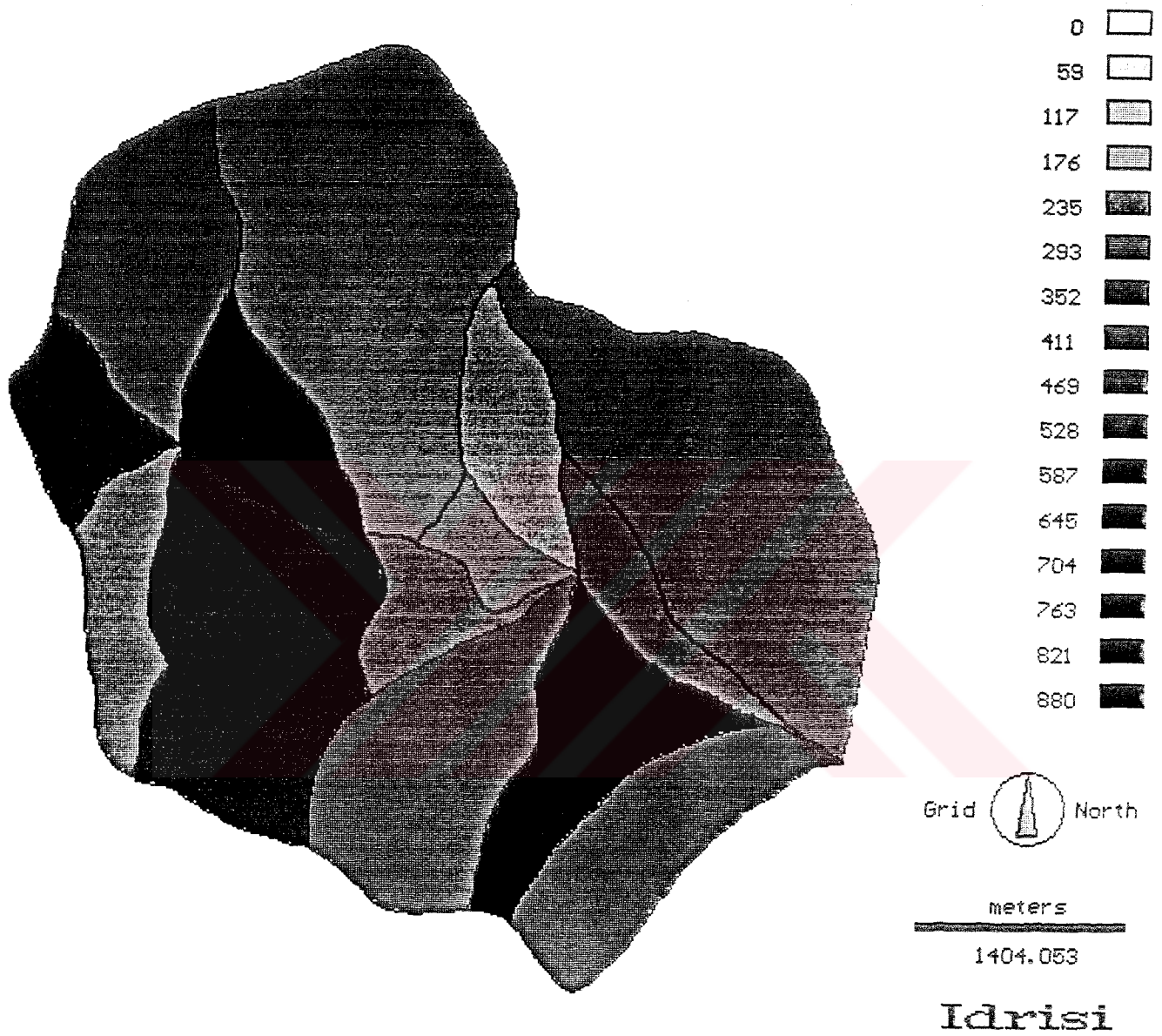


Figure 5.7. Mean Slope-Lengths of the Subbasins.

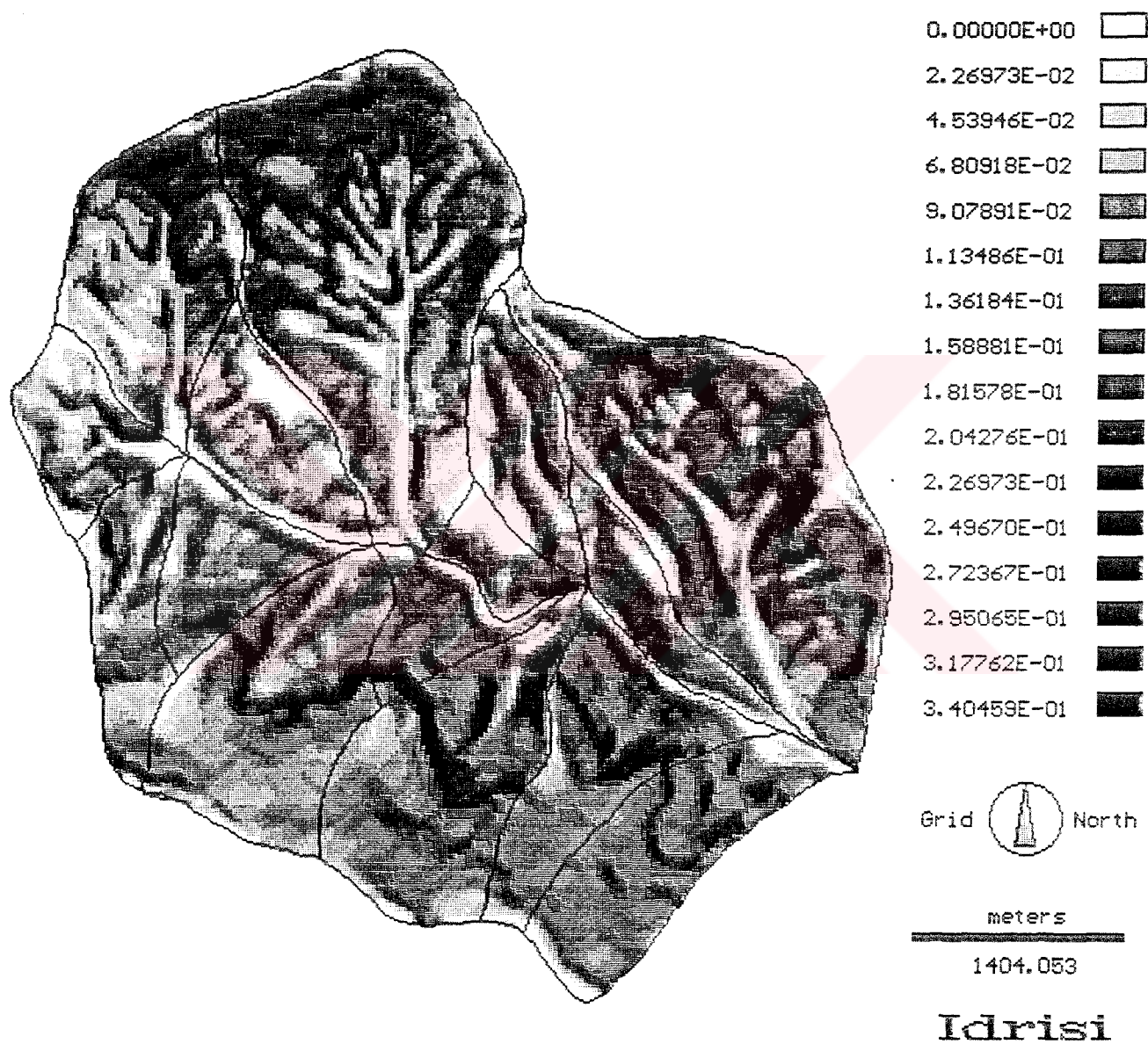


Figure 5.8. Cell-based slopes in the Demonstrated Basin.

In order to calculate the topographic factor (LS) of a subbasin, mean slope and slope-length of that subbasin are entered on the slope-length chart in Fig. 4.5. Fig. 5.9 shows the topographic factors obtained from slope-length chart in Fig. 4.5.

Eq. (4.8) represents the formulation of the slope-length chart and it gives relatively close results for LS as compared to the slope-length chart. Thus, the LS factors are also calculated by Eq.(4.8). This equation is applied to the two images of mean slope (Fig. 5.6) and slope-length (Fig. 5.7) by OVERLAY procedures in IDRISI. The resulting image is given in Fig. 5.10. As can be seen from Fig. 5.10, the result is close to the image obtained from slope-length chart in Fig. 5.9.

Eq. (4.9) is another equation proposed by Williams et al. (1985) to calculate the LS factor. However, this equation gives very high LS values if the slope-length is longer than 100 meters and the slope is greater than 12%. Therefore, the Eq. (4.9) is not considered in the computation of the LS factor.

Consequently, LS factor is considered as the value of LS obtained from the graphical solution in Fig. 5.9. As can be seen from Fig.(5.9) LS factor of the 2nd subbasin is the highest value in the demonstration basin since its mean slope and slope length are the highest. The other subbasins which have high slopes show moderate magnitudes of LS relatively as their slope lengths are shorter than that of subbasin 2.

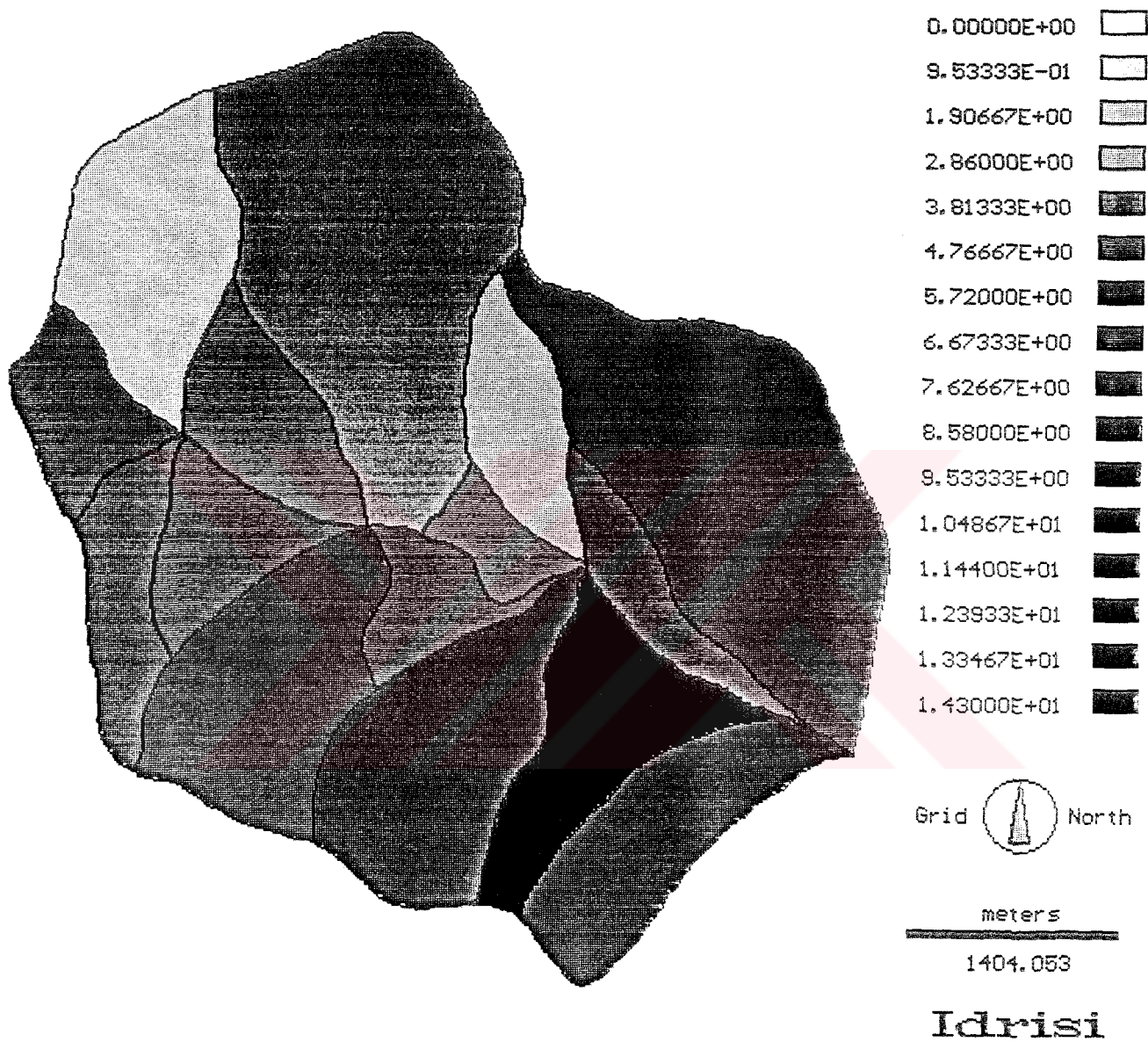


Figure 5.9. Topographic Factor obtained from Slope-Length Chart of the Demonstrated Basin.

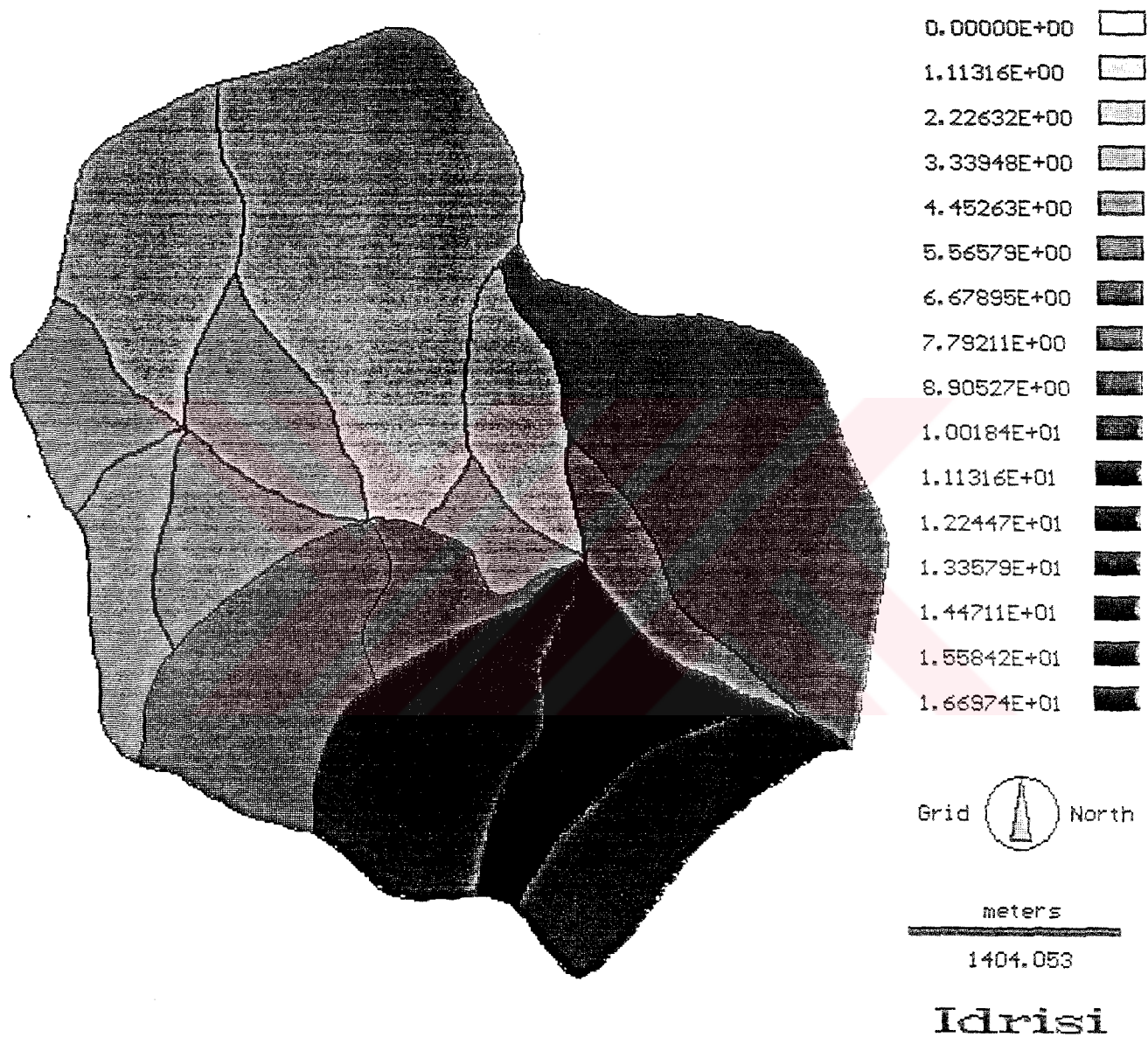


Figure 5.10. Topographic Factor obtained from Eq. (4.8) of the Demonstrated Basin.

5.2.4. Cover and management factor (C)

In the demonstration basin, in order to calculate the cover and management factor (C), land use and management practices are assumed as follows:

In croplands there are two kind of crops:

(a) **Wheat:** Wheat is seeded on October 15 in a 40 percent cover of disked wheat residue. The wheat would normally develop a 10 percent cover by November 1, 50 percent by December 1, 75 percent by April 15, and 100 percent in the maturing stage. It is harvested in June 15, leaving an 80 percent surface cover of straw, and small grass and stalks are chopped and distributed without soil tillage.

(b) **Corn:** Corn is seeded on May 10. Corn would normally develop a 10 percent cover by June 1, 50 percent by June 20, 75 percent by July 10, and 100 percent in the maturing stage. Its final canopy is 96 percent. It is harvested on November 15, with residues left on the surface.

In pasture:

In the permanent pasture, vegetative canopy of 25% of total area is short brush with an average height of 50 cm. The surface is covered by grass with 20%.

In the forest:

Percentage of area covered by canopy of trees and undergrowth is 30% and percentage of area covered by litter is 50%.

Computation of factor C for cropland is described in Table 5.3 where the soil loss ratios are obtained from Table 4.3 and Table 4.4. Table 5.2 is used to calculate the portion of the C factor in the specified cropstage.

Table 5.2.: Cumulative Percentages of R Factor in a Year.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
%EI	3.8	6.8	9.4	11.8	32.7	53.9	62.8	71.4	80.0	86.8	93.8	100

Table 5.3. Computation of the C Factor for Cropland.

1	2	3	4	5	6	7
Pl W	15/10	83.40	SB	0.034	0.270	0.010
10pct	1/11	86.80	1	0.070	0.210	0.015
50pct	1/12	93.80	2	0.168	0.160	0.027
75pct	15/04	10.60	3	0.327	0.050	0.016
Hv W	15/06	43.30	4	0.401	0.070	0.028
Annual C for Wheat ≈ 0.100						
Pl C	10/05	18.80	SB	0.139	0.600	0.083
10pct	1/06	32.70	1	0.141	0.520	0.073
50pct	20/06	46.80	2	0.101	0.410	0.041
75pct	10/07	56.90	3	0.265	0.200	0.053
Hv C	15/10	83.40	4	0.354	0.300	0.106
Annual C for Corn ≈ 0.350						

Pl: Plant
Hv: Harvest
C : Corn
W : Wheat

In the above table, the columns stand for the following:

- Column 1: List in chronological sequence all the land cover changes that begin new cropstage periods,
- Column 2: List the date on which each cropstage period begins,
- Column 3: Cumulative percentage of EI for each date in column 2, (Table 5.2.),
- Column 4: Identify the cropstage periods,
- Column 5: Differences between a number and the next number in column 2,
- Column 6: The soil loss ratios obtained Table 4.3 with respect to crop, crop sequence, management, and cropstage period,
- Column 7: Product of values in column 5 and 6,

Column 7 describes the C factors in each cropstage period, and the sum of that column defines the annual value of the C factor.

As can be seen from Table 5.3, C factor is the highest in the cropstage period SB. Through the crop growth, C factor decreases and in 4th (Harvest) period it increases again.

Factor C for permanent pasture and undisturbed forest land is derived from Tables 4.5 and 4.6 with respect to their canopy properties.

Finally, Table 5.4 shows the C factor for each land use

Table 5.4. C Factor for Each Land Use and Management Practices in the Demonstration Basin.

Land Use	Factor C
Cropland	
Wheat	0.10
Corn	0.35
Pasture	0.17
Forest	0.005

Figure 5.11 shows the distribution of C factors of the demonstration basin. In this figure the brightest zones indicate forest, the darkest zones indicate corn farms, light gray zones wheat farms, and gray zones indicate pastures, respectively.

5.2.5. Support practice factor (P)

It is assumed that only 1 farm with corn crops, has erosion protection practice that is contouring. The mean slope of that farm is calculated from Fig. 5.8 by the module named MEAN in IDRISI. The average slope of that farm is 12 percent and its P factor is derived from Table 4.8 as 0.80. The remaining areas have the value of 1.0 for the P factor since there are no erosion protection practices available. Figure 5.12 shows the spatial distribution of the P factor in the demonstration basin. The darkest areas have a P value of 1 and the dark gray areas in which there is erosion protection of contouring has a P value of 0.80.

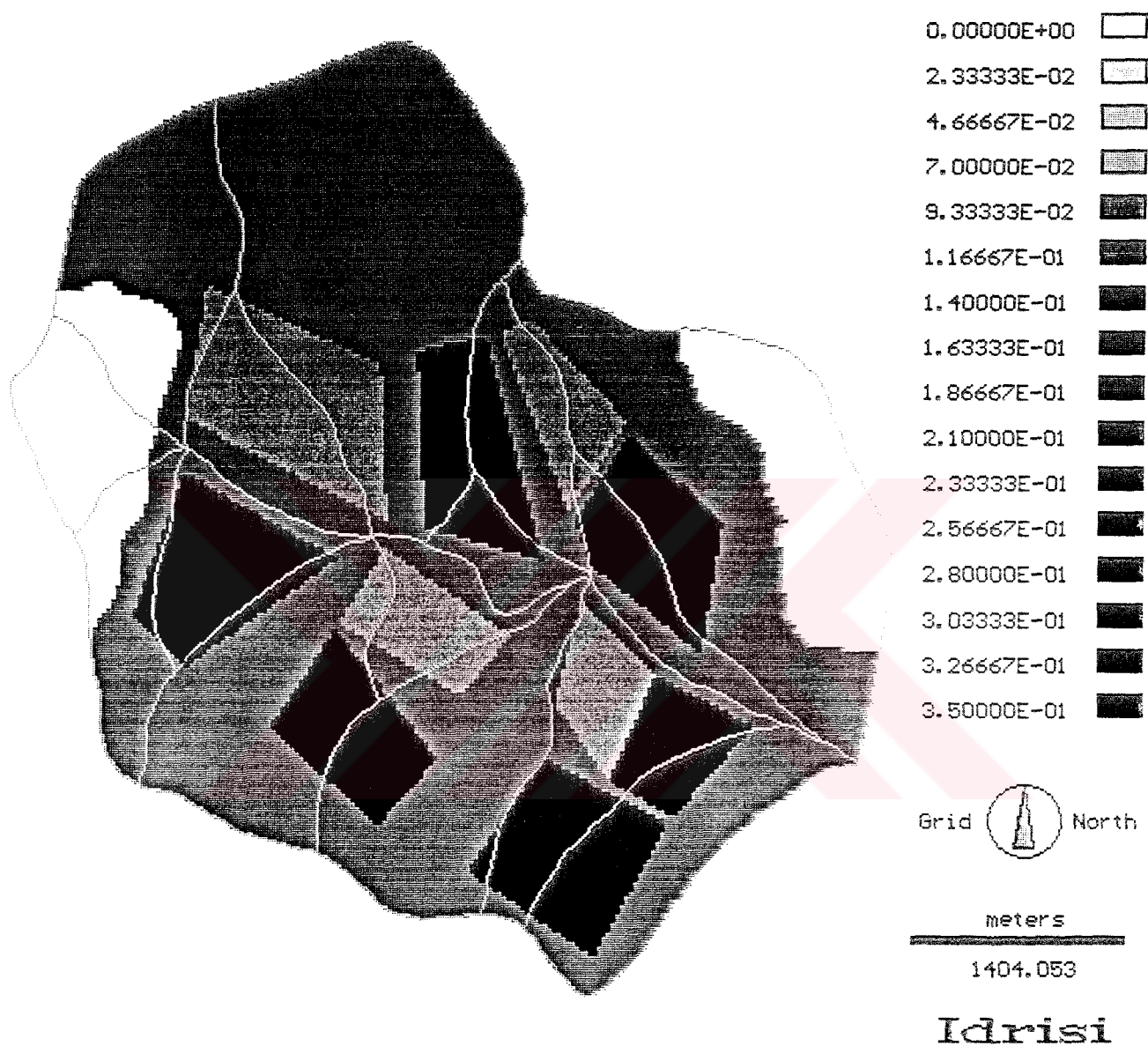


Figure 5.11. Spatial Distribution of C Factors of the Demonstration Basin.

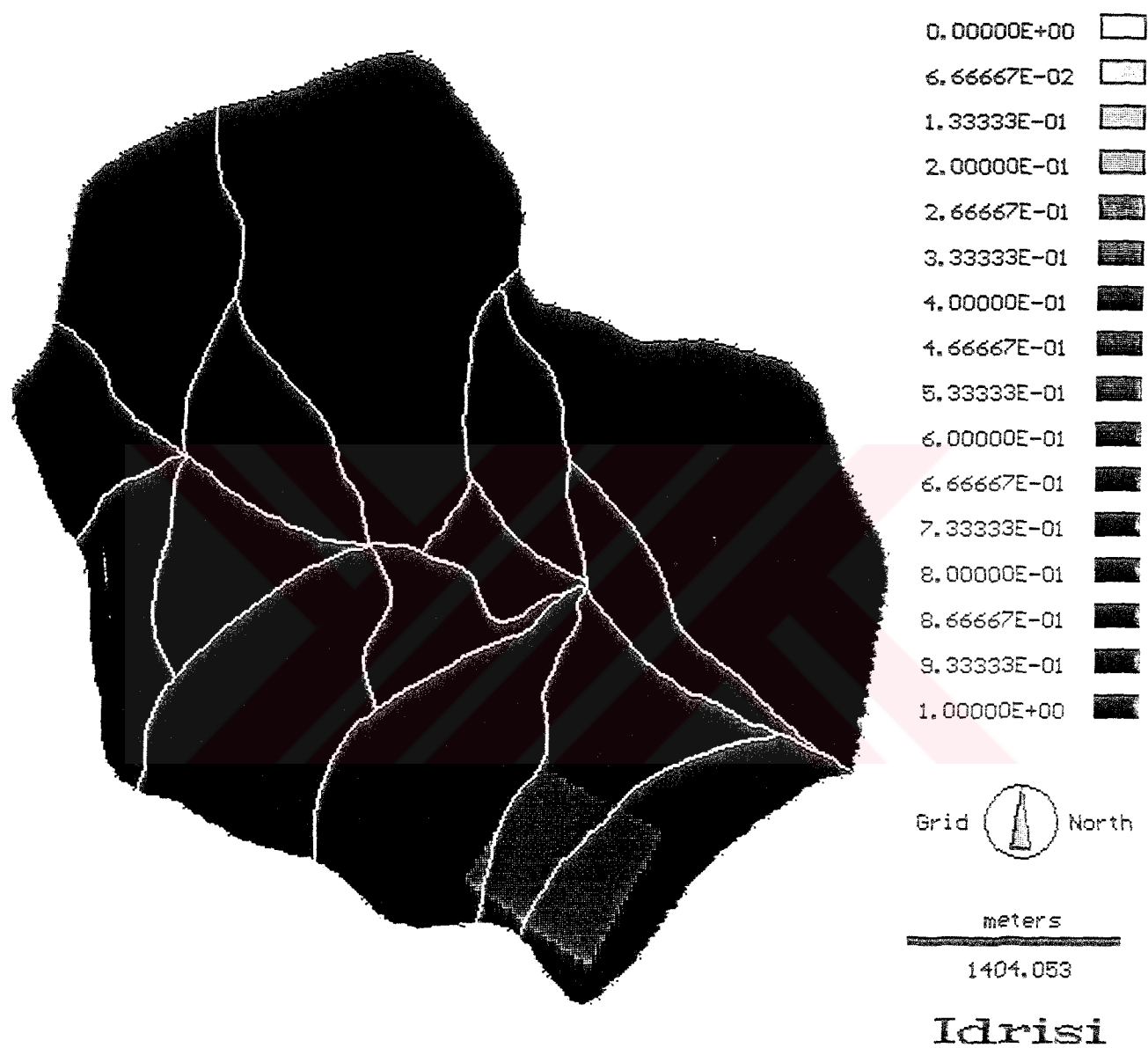


Figure 5.12. Spatial Distribution of P Factor in the Demonstration Basin.

5.2.6. Sediment delivery ratio (DR)

Determination of the sediment delivery ratios (DR) of a specific basin requires sediment observations of that basin. Since sediment delivery ratio depends on several properties of the watershed, it has to be determined by considering properties such as runoff characteristics. In the demonstrated basin, sediment delivery ratios of subbasins are derived from Fig. 4.7 which is established by evaluating sediment observations of several basins in the USA with respect to their basin size. The relation between sediment delivery ratios and basin size is developed on a statistical basis, but it can be used in the case of initial approximations. Fig. 4.7 can be employed to get a rough estimation of DR. Table 5.5 shows the demonstrative subbasins, their size and their sediment delivery ratios associated with their areas, respectively.

Table 5.5. Sediment Delivery Ratios of the Subbasins.

No. Sub.B.	Area(km ²)	DR
1	1.54	0.32
2	1.48	0.33
3	2.08	0.30
4	1.98	0.31
5	0.61	0.39
6	0.84	0.37
7	0.88	0.36
8	0.76	0.38
9	1.00	0.35
10	1.73	0.32
11	4.31	0.24
12	0.40	0.40
13	0.89	0.36
14	0.68	0.38
15	3.96	0.26

5.2.7. Enrichment ratio (ER)

Enrichment ratio depends on sediment concentration and its particle size distribution. An increase in the sediment delivery ratio causes the sediment concentration to increase, that means that the percentage of coarser particles (sand and silt) increases more than the percentage of clay particles. However, when the delivery ratio decreases, the sediment concentration also decreases and the percentage of clay in the sediment increases. This means that the enrichment ratio of clay also increases.

The delivery ratio and sediment concentration are related to each other and they have to be determined by field observations. Thus, a selection of unsuitable values of DR and C_a affect Eq. (4.17). Although Eq. (4.17) is constructed by the assumption that sediment concentration stays between 500 to 250000 gr/m^3 , the sediment concentration in that range causes the enrichment ratios to stay within the $1 \leq \text{ER} \leq 1/\text{DR}$ range for different delivery ratios. In the Eq. (4.17) the average sediment concentration of the demonstration basin is selected as 100 gr/m^3 to verify the Eq. (4.17).

Table 5.6 represents the delivery ratios and enrichment ratios calculated with respect to the delivery ratios of the subbasins. The sediment concentration is assumed as $C_a=100 \text{ gr/m}^3$ in these computations. The enrichment ratios verify the condition $1 \leq \text{ER} \leq 1/\text{DR}$.

Table 5.6. Sediment Delivery Ratios and Enrichment Ratios of the Subbasin.

No. Sub.B.	Area(km^2)	DR	ER
1	1.54	0.32	3.0
2	1.48	0.33	2.9
3	2.08	0.30	3.2
4	1.98	0.31	3.1
5	0.61	0.39	2.5
6	0.84	0.37	2.6
7	0.88	0.36	2.7
8	0.76	0.38	2.5
9	1.00	0.35	2.8
10	1.73	0.32	3.0
11	4.31	0.24	4.0
12	0.40	0.40	2.4
13	0.89	0.36	2.7
14	0.68	0.38	2.5
15	3.96	0.26	3.7

After USLE parameters are determined for the demonstrative basin, the results are merged as described in section 5.1 to arrive at gross erosion, sediment yield and organic N yield. The results are presented in the following sections.

5.3. Spatial Distribution of Critical Cell-Based USLE Parameters.

To determine the critical soil loss regions in the basin, the spatial distribution of cell-based USLE parameters is obtained by multiplying the 5 USLE parameters in the specified 30x30m cells.

Each cell is assumed as a closed plot where surface flow cannot enter a cell from another cell. The LS factor is computed by using the cell-length (30m) and the slope of each cell. The USLE equation (Eq. 4.1) is applied to each 5 digital-parameter-layers (Fig. 5.4, Fig. 5.5, Fig. 5.11 and Fig. 5.12) by OVERLAY module in IDRISI, and the resulting image is given in Fig. 5.13. Fig. 5.13 does not indicate soil loss of each cell but gives an information about cell sensitivity with respect to parameters that affect erosion.

Since IDRISI is not capable of vector format applications Eq.(4.14) and Eq.(4.15) can not be applied. If the point value of the delivery ratio were derived from Eq.(4.15), the potential erosion distribution of the basin could be obtained by multiplying Fig. 5.13 by the delivery ratio of each cell.

However, Fig. 5.13 does give roughly some information about the critical zones of soil loss. In this figure light zones adsorbs the rainfall energy more than dark zones do, so the south part of the demonstration basin and also most part of the subbasins 14 which has great slopes, are more sensitive to erosion.

5.4. Gross Erosion

Gross erosion of the demonstrated basin is computed by Eq.(4.1).

Eq. 4.1 is applied to each subbasin by overlaying the 5 parameters of USLE. The resulting multiplication image is in Fig. 5.14 where all parameter patterns can be seen easily.

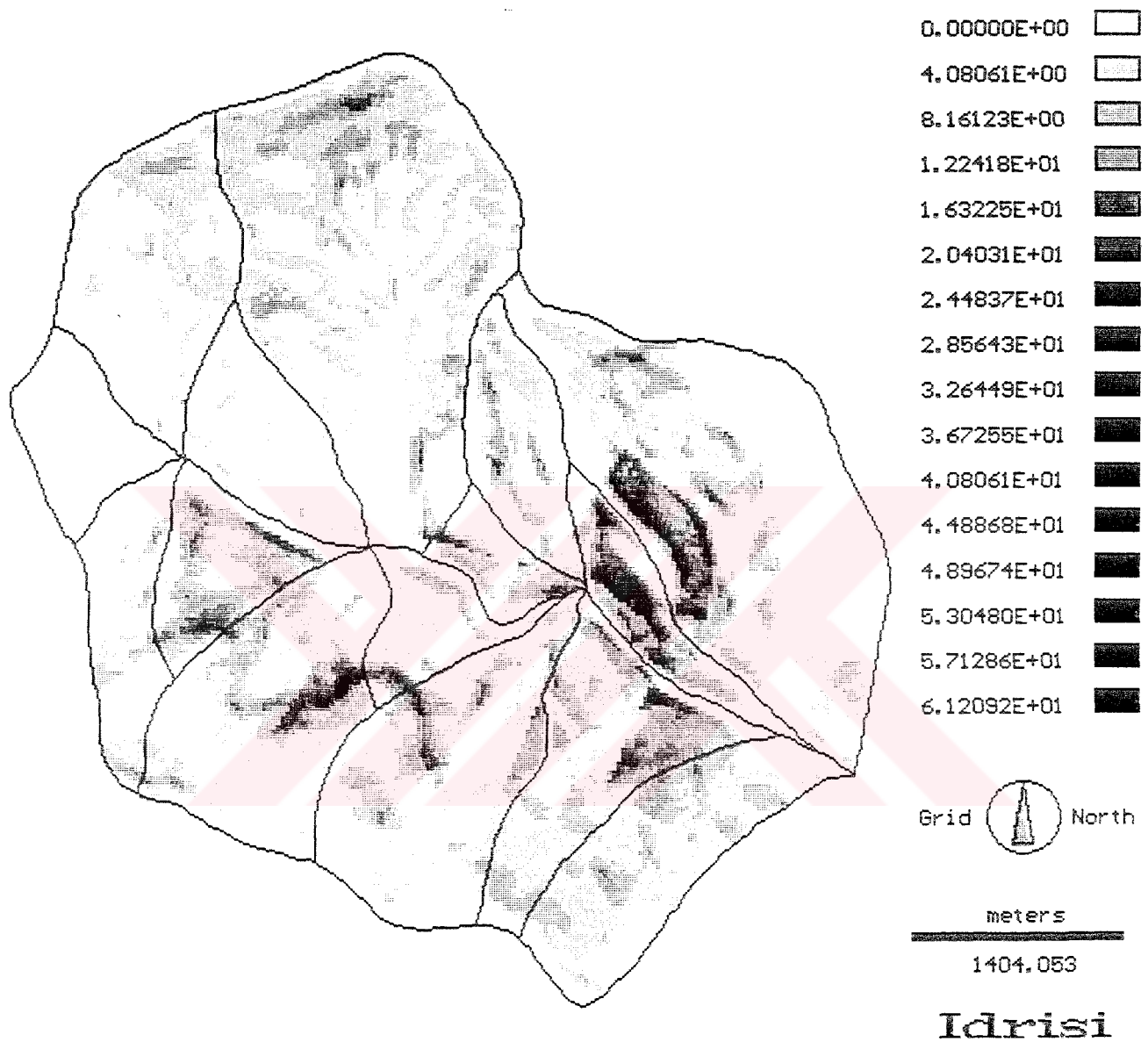


Fig. 5.13. Cell-Based Description of Basin Sensitivity to Erosion in terms of USLE Parameters.

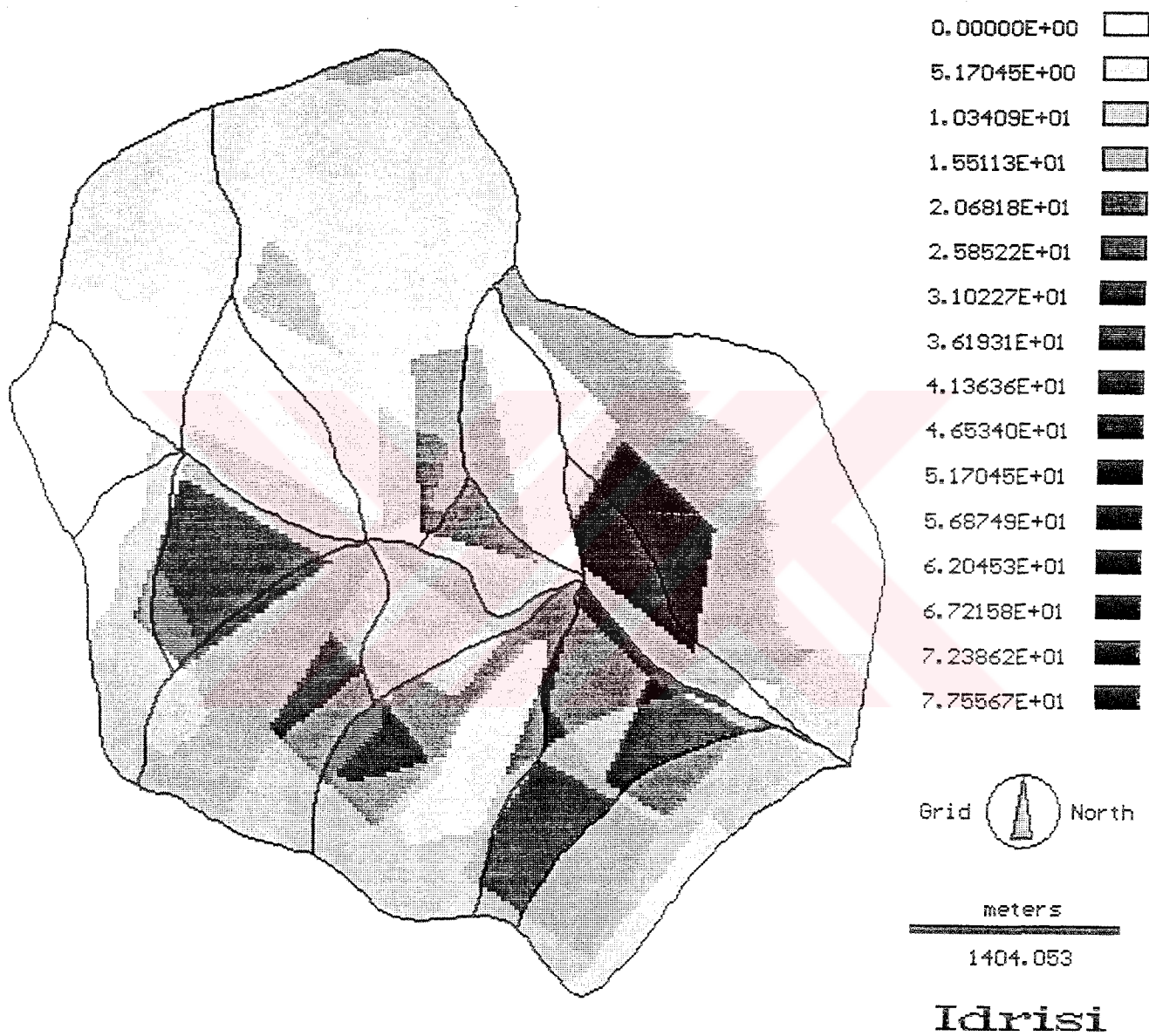


Figure 5.14. Patterns of the USLE parameters.

The mean gross erosion of the subbasins, is computed by MEAN module for each subbasin, and their spatial distribution is given in Fig. 5.15. As can be seen in Fig. 5.15 the southern part of the demonstration basin has more erosion productivity than the other parts. Subbasin 8 has the lowest gross erosion since most of its area is under forest zone. Subbasin 2 has the highest gross erosion value since its topographic factor (LS) and cover & management factor (C) are high. Subbasin 6 has high gross erosion value for the same reasons. Table 5.7 gives the gross erosion in ton/ha for each subbasin.

Table 5.7. Gross Erosion of the Subbasins.

No. Sub.B.	Area(km ²)	DR	ER	A(ton/ha)
1	1.54	0.32	3.0	14.20
2	1.48	0.33	2.9	29.46
3	2.08	0.30	3.2	15.03
4	1.98	0.31	3.1	18.19
5	0.61	0.39	2.5	12.72
6	0.84	0.37	2.6	28.76
7	0.88	0.36	2.7	8.07
8	0.76	0.38	2.5	0.77
9	1.00	0.35	2.8	8.62
10	1.73	0.32	3.0	4.10
11	4.31	0.24	4.0	9.40
12	0.40	0.40	2.4	15.96
13	0.89	0.36	2.7	9.00
14	0.68	0.38	2.5	22.76
15	3.96	0.26	3.7	12.64

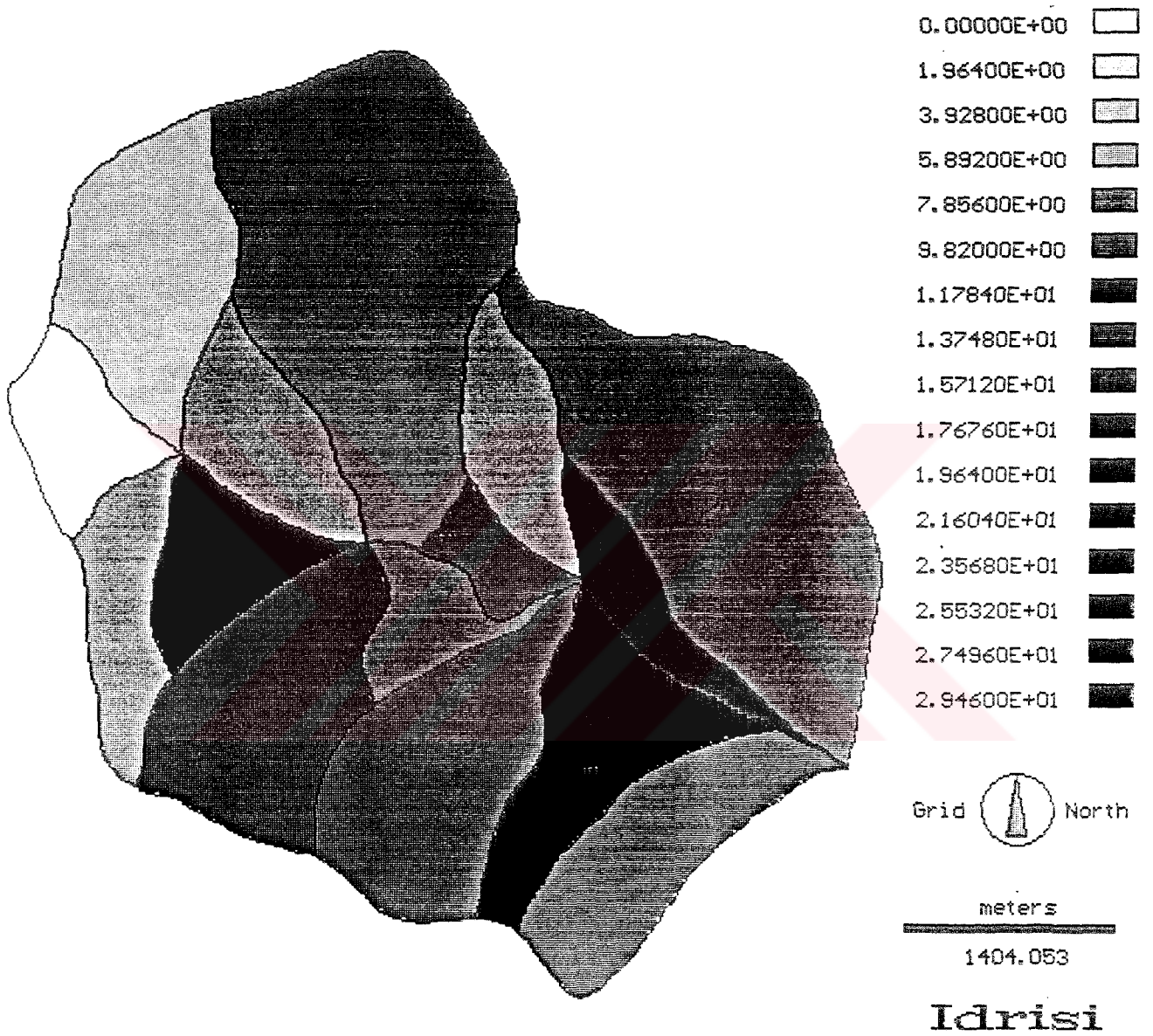


Figure 5.15. Spatial Distribution of Gross Erosion in the Demonstrated Basin.

5.5. Sediment Yield

The sediment yield of the demonstrative basin is computed Eq.(4.13). Each gross erosion value of the subbasin is multiplied by its sediment delivery ratio given in Table 5.5. Table 5.8 gives the sediment yield (SY ton/ha) of each subbasin.

Table 5.8. Sediment Yield of Each Subbasin.

No. Sub. B.	Area(km ²)	DR	ER	A(ton/ha)	SY(ton/ha)
1	1.54	0.32	3.0	14.20	4.54
2	1.48	0.33	2.9	29.46	9.72
3	2.08	0.30	3.2	15.03	4.59
4	1.98	0.31	3.1	18.19	5.64
5	0.61	0.39	2.5	12.72	4.96
6	0.84	0.37	2.6	28.76	10.64
7	0.88	0.36	2.7	8.07	2.91
8	0.76	0.38	2.5	0.77	0.29
9	1.00	0.35	2.8	8.62	3.02
10	1.73	0.32	3.0	4.10	1.31
11	4.31	0.24	4.0	9.40	2.26
12	0.40	0.40	2.4	15.96	6.38
13	0.89	0.36	2.7	9.00	3.24
14	0.68	0.38	2.5	22.76	8.65
15	3.96	0.26	3.7	12.64	3.29

5.6. Organic N Yield

Organic N yield due to soil erosion is computed by Eq.(4.20). In Eq.(4.20) the organic N concentration of the soil is assumed to have average value of 1250 gr/ton which covers all subbasins. Table 5.9 indicates the sediment yield of each subbasin (SY ton/ha) and their organic N yield (ONY kg/ha) transported by sediment.

Table 5.9. Organic N Yields of Each Subbasin.

No. Sub. B.	Area(km ²)	DR	ER	A(ton/ha)	SY(ton/ha)	ONY(kg/ha)
1	1.54	0.32	3.0	14.20	4.54	17.04
2	1.48	0.33	2.9	29.46	9.72	35.24
3	2.08	0.30	3.2	15.03	4.51	18.04
4	1.98	0.31	3.1	18.19	5.64	21.85
5	0.61	0.39	2.5	12.72	4.96	15.50
6	0.84	0.37	2.6	28.76	10.64	34.58
7	0.88	0.36	2.7	8.07	2.91	9.81
8	0.76	0.38	2.5	0.77	0.29	0.91
9	1.00	0.35	2.8	8.62	3.02	10.56
10	1.73	0.32	3.0	4.10	1.31	4.92
11	4.31	0.24	4.0	9.40	2.26	11.28
12	0.40	0.40	2.4	15.96	6.38	19.15
13	0.89	0.36	2.7	9.00	3.24	10.94
14	0.68	0.38	2.5	22.76	8.65	27.03
15	3.96	0.26	3.7	12.64	3.29	15.20

5.7. Evaluation

As described in the previous sections, the presented study intends to investigate rainfall-based erosion and the resulting nonpoint source pollution by integration of the USLE approach with GIS. Data availability has hindered the application of the methodology to an actual basin so that the results of the study have remained on an experimental basis. Nevertheless, the basic purpose of the work is accomplished; namely that, a GIS-based approach is developed to identify soil loss and erosion-based nonpoint source pollution. Steps to be taken in such an approach are identified experimentally so that the method can be directly applied to a real case when the required input data become available.

The GIS applications are carried out by the software IDRISI, which is basically developed and used for educational purposes. IDRISI is a raster-based GIS that cannot be operated in vector format. It has certain operational limitations such that the manipulation of data requiring high memory storage is difficult. Consequently, not only vector format operations but also some raster operations cannot be performed by IDRISI. For example, point values of the delivery ratio, as described by Eqs. (4.13) and (4.14), could not be identified due to software limitations.

Nevertheless, IDRISI can still perform numerous geographical analyses and is fairly easy to use. The other widely used GIS softwares like ARC/INFO and ILWIS can manipulate vectoral data and can provide a higher memory storage as compared to IDRISI. Thus, the use of such advanced (and expensive) softwares in the analysis of erosion and erosion-based NPS can produce more effective results.

Topography is an important feature of the presented approach. Accordingly, IDRISI is used to identify the topography of the demonstrative basin, watershed boundaries and the river network. The digital elevation model of the basin is developed by digitizing the basin map of scale 1:25000. IDRISI has proved to be efficient in these applications.

In integrating USLE with GIS, parameters of the model have been described as digital layers by digitizing the available maps. Next, the spatial distribution of each parameter layer has been overlayed by functions of IDRISI. This process has resulted in the distribution of gross erosion among subbasins. Gross erosion is evaluated here as erosion values per unit hectare of land to omit the effects of basin areas. Otherwise, a subbasin with a significant erosion potential may reflect insignificant amounts of total erosion due to its small area; whereas it is quite possible that the some subbasin may be a critical region with respect to erosion.

Figure 5.14 shows the effects of USLE parameters upon each subbasin. Subbasins 2, 6, 12, and 14 reflect high values for these parameters. For instance, the 2nd and the 6th subbasins have intensive agricultural practices; the 2nd basin also shows high values of the topographic factor. Therefore, these subbasins can be considered as critical regions in terms of gross erosion. Such regions can also be observed clearly in Fig. 5.15.

The distribution of the total sediment load in the basin is also considered as sediment load per unit area, which shows high values in subbasin 2, 6, and 14 as summarized in Table 5.8.

On the other hand, organic N loads which are transported in an adsorbed form by particulate clay, are determined by evaluating the N content of soil and enrichment ratios. The result of these analyses are given in Table 5.9. Subbasins 2 and 6 again reflect high values of organic N as they have significant sediment loads.

As it may be followed from the application, the most significant factors that affect erosion are land use and vegetation for regions with homogenous soil structure. Thus, it is imperative to identify such critical erosion regions and to assess basin management plans within this respect.

In identifying basin erosion, the integration of USLE with GIS has improved the assessment of critical regions and the spatial distribution of effective parameters. If USLE is applied by itself without GIS, the computations are based on the average value of each USLE parameter and the direct measurements taken from paper maps. However, these manual applications are time consuming and staff intense. In the manual approach, the spatial distribution of each parameter can not be evaluated accurately. Furthermore, any measurement taken from the paper map does not cover the entire distribution of a particular parameter; it is taken only from specific locations.

In the GIS assisted approach, all USLE parameters are transformed into digital forms by digitizing the relevant maps. If the maps are already available in the form of database, the digitizing procedure is not necessary and all the required information can be imported into the system.

GIS enables to produce several parameters in digital forms in the determination of USLE parameters. For example, subbasin boundaries are generated by one command on the digital elevation model; or the slope of each cell is computed automatically, and the average slope of the subbasin is then calculated by averaging the associated cell slopes.

Following from the above considerations, it can be stated that GIS permits more effective and accurate applications of the USLE model provided that sufficient spatial data are available.

VI. CONCLUSION

6.1. The Use of GIS in Water Resources Research

The GIS have been used effectively in a variety of hydrologic applications in developed countries. Since a GIS application depends on spatially distributed (geographic or nongeographic) data, a significant requirement is the availability of an efficiently organized database. In essence, the effectiveness of the use of GIS relies on the available data and system (software) properties as well. Unsuitable systems for specific hydrologic applications lead to studies which are staff and time intensive, but which have low accuracy.

On the other hand, the costs of implementing a GIS can be significant, especially when the costs of data collection and manipulation are considered. Thus, it is best if the database can be shared for several related purposes.

In Turkey, there are no organized databases covering digital spatial and related data about environmental concepts. Thus, an effective application of GIS in water resources research on a basin wide basis is not possible; however, some individual and regional applications can be realized by obtaining local information.

As a result, it can be stated that the GIS would constitute powerful tools in water resources planning and management if countrywide spatial and nonspatial data capture programs can be installed and if these data could be shared by willing technical and governmental institutions.

6.2. Erosion and Erosion-Based Pollution

Through the concept of environmentally sustainable development, the international community is now preparing several management strategies to address water quality concerns. The pollution sources which have point and nonpoint characteristics are evaluated with respect to many considerations. Point sources can be identified by direct measurements and mitigated by known

protection practices; the identification of nonpoint sources of pollution is subject to uncertainties in contrast to point sources. Addressing nonpoint sources of pollution is now considered by efforts of environmental protection agencies.

In Turkey, huge amounts of water pollution comes from nonpoint sources; thus, the control of NPS must be a national priority. However, to develop a strategy for mitigation of nonpoint sources requires effective information about pollution sources so that researchers or planners can explain pollution phenomena.

In this study, a quick and effective evaluation of erosion and erosion based pollution is introduced, using a GIS assisted approach to USLE applications. GIS-USLE integration produces considerably effective results if the information required by USLE are available in databases like those of the developed countries. The presented study is prepared by using assumed data (except for topography) due to the lack of such informational databases in Turkey. GIS-USLE integration is constructed by overlaying the digital-parameter-layers of USLE model in the GIS domain. The introduced methodology can be applied to rural basins to determine both the sediment and the related pollution caused by land use, topography and soil types in that basin. The approach can also be used to determine sediment deposition in water storage systems like dams and lakes.

6.3. Future Studies

The study presented constructs a basis for identification of rainstorm erosion and erosion based pollution with GIS. As part of future studies, it is intended to build up a nonpoint source pollution simulation model-GIS integration in an interactive environment and to apply that system to an actual basin.

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APPENDIX - A

TABLE 5.—Ratio of soil loss from cropland to corresponding loss from continuous fallow

Line No.	Cover, crop sequence, and management ¹	Spring residue ²	Cover after plant ³	Soil loss ratio ⁴ for croplage period and canopy cover ⁵					Soil loss ratio ⁴ for croplage period and canopy cover ⁵							
				F	S	B	1	2	3	4	5	6	7			
CORN AFTER C. GS, G OR COY IN MEADOWLESS SYSTEMS																
Holdboard plow, conv till																
1		4,500		31	35	48	38		20	23						
2		3,400		36	60	52	41		24	20	30					
3		2,600		43	64	56	43		32	25	21	37				
4		2,000		51	68	60	45		33	26	22	47				
5	Adh, fall TP	HP ¹		44	65	53	38		20							
6		GP		49	70	57	41		24	20						
7		FP		57	74	61	43		32	25	21					
8		LP		63	78	65	45		32	26	22					
9	Adh, sprg TP	HP		66	74	65	47		32	26						
10		GP		67	75	66	47		37	23	63					
11		FP		68	76	67	48		35	27	69					
12		LP		69	77	68	49		33		74					
13	Adh, fall TP	HP		76	82	70	49		22							
14		GP		77	83	71	50		27	23						
15		FP		78	85	72	51		33	27						
16		LP		79	86	73	52		35							
17	Wheeltrack pl, Adh, TP ¹	4,500		—	31	27	23		18	23						
18		3,400		—	36	32	30		22	18	30					
19		2,600		—	43	36	32		29	23	19	37				
20		2,000		—	51	43	36		31	24	20	47				
21	Deep off-set disk or disk plow	4,500	10	—	45	38	34		—	20	23					
22		3,400	10	—	52	43	37		—	24	20	30				
23		2,600	5	—	57	48	40		32	25	21	37				
24		2,000	—	—	61	51	42		33	26	22	47				
25	No-till plant in crop residue ¹	6,000	95	—	2	2	2		—	2	14					
26		6,000	90	—	3	3	3		—	3	14					
27		4,500	80	—	5	5	5		—	5	15					
28		3,400	70	—	8	8	8		—	8	19					
29		3,400	60	—	12	12	12		12	12	9	8	23			
30		3,400	50	—	15	15	14		14	11	9	27				
31		2,600	40	—	21	20	18		17	13	11	30				
32		2,600	30	—	26	24	22		21	17	14	36				
Chisel, shallow disk, or Ad coll, as only tillage:																
33	On moderate slopes	6,000	70	—	8	8	7		7	17						
34			60	—	10	9	8		8	17						
35			50	—	13	11	10		9	18						
36			40	—	15	13	11		10	19						
37			30	—	18	15	13		12	20						
38			20	—	22	20	18		16	21						
39	Do.	4,500	70	—	9	8	7		7	18						
40			60	—	12	10	9		8	18						
41			50	—	14	13	11		9	19						
42			40	—	17	15	13		10	20						
43			30	—	21	18	15		13	21						
44			20	—	25	22	19		16	22						
CORN AFTER WC OF RYEGRASS OR WHEAT SEEDING IN C STUBBLE																
WC reaches steaming stage:																
79	No-till pl in killed WC	4,000		7	7	7			7	7		7	6 (11)			
80		3,000		11	11	11			11	11		9	7			
81		2,000		15	15	14			14	14		11	9			
82		1,500		20	19	18			18	18		14	11			
Strip till one-fourth row space Rows U/D slope																
83		4,000		13	12	11			11	11		9	(11)			
84		3,000		18	17	16			16	16		13	10			
85		2,000		23	22	20			19	15		12				
86		1,500		28	26	24			22	17		14				
Rows on contour ¹¹																
87		4,000		10	10	10			10	10		8	(11)			
88		3,000		13	13	13			13	13		9				
89		2,000		20	20	19			19	15		12				
90		1,500		25	24	23			22	17		14				
91	TP, conv seedbed	4,000		36	60	52	41		24	20			(11)			
92		3,000		43	64	56	43		31	25	21					
93		2,000		51	68	60	45		33	26	23					
94		1,500		61	73	64	47		35	27	23					
WC succulent blades only:																
95	No-till pl in killed WC	3,000		11	11	17	23		18	16			(11)			
96		2,000		15	15	20	23		20	17						
97		1,500		20	20	23	26		21	18						
98		1,000		26	26	27	27		22	19						
99	Strip till one-fourth row space	3,000		18	18	21	25		20	17			(11)			
100		2,000		23	23	25	27		21	18						
101		1,500		28	28	28	28		23	19						
102		1,000		33	33	31	29		23	20						
CORN IN SOD-BASED SYSTEMS																
No-till pl in killed sod:																
103	3 to 5 tons hay yld			1	1	1			1	1		1	1			
104	1 to 2 tons hay yld			2	2	2			2	2		2	2			
Strip till, 3.5 ton M:																
105	50 percent cover, tilled strips			2	2	2			2	2		2	4			
106	20 percent cover, tilled strips			3	3	3			3	3		3	5			
Strip till, 1.2 ton M:																
107	40 percent cover, tilled strips			4	4	4			4	4		4	6			
108	20 percent cover, tilled strips			5	5	5			5	5		5	7			
Other tillage after sod:																
				(11)	(11)	(11)			(11)	(11)		(11)	(11)			
CORN AFTER SOYBEANS																
109	Strip TP, conv till	HP		40	72	60	48		—	—		25	29			
110		GP		47	78	65	51		—	—		30	37			
111		FP		56	83	70	54		40	31	26	44				
112	Full TP, conv till	HP		47	75	60	48		—	—		25	—			
113		GP		53	81	65	51		—	—		30	23			
114		FP		62	86	70	54		40	31	26	—				

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45	Do.	3,400	60	13	11	10	10	8	20	115	Fall & sprg chisel or cul	HP	120	40	35	29	23	29
46			50	16	13	12	12	9	24	116		GP	25	45	39	33	27	33
47			40	19	17	16	14	11	25	117		GP	20	51	44	39	34	27
48			30	23	21	19	17	14	26	118		FP	15	59	51	44	36	28
49			20	29	25	23	21	16	27	119		LP	10	67	59	48	36	28
50			10	36	32	29	24	20	30	120	No-till pl in crop resid	HP	140	25	20	19	14	11
51	Do.	2,600	50	17	16	15	15	13	10	121		GP	30	33	29	25	22	18
52			40	21	20	19	19	15	12	122		FP	20	44	38	32	27	23
53			30	25	23	22	22	18	14	123	BEANS AFTER CORN	HP		33	60	52	38	20
54			20	32	29	28	27	22	17	124	Sprg TP, gdl, conv till	GP		39	64	56	41	21
55			10	41	36	34	33	25	21	125		FP		45	68	60	43	29
56	Do.	2,000	40	23	21	20	20	15	12	126		HP		45	69	57	38	20
57			30	27	25	24	23	19	13	127	Fall TP, Rdl, conv till	GP		52	73	61	41	21
58			20	35	32	30	28	22	18	128		FP		59	77	65	43	29
59			10	46	42	38	33	26	22	129			(1)	(1)	(1)	(1)	(1)	(1)
60	On slopes > 12 percent. Lines 33-59 times factor of:			1.3	1.3	1.1	1.0	1.0	1.0	1.0	Chisel or Rdl cult:		(1)	(1)	(1)	(1)	(1)	(1)
	Disk or harrow after spring chisel or Rdl cult:										BEANS AFTER BEANS		(1)	(1)	(1)	(1)	(1)	(1)
	Lines 33-59 times factor of:										GRAIN AFTER C, G, GS, CO ¹¹							
61	On moderate slopes			1.1	1.1	1.1	1.0	1.0	1.0	1.0	In disked residues:	4,500	70	12	12	11	7	4
62	On slopes > 12 percent			1.4	1.4	1.2	1.0	1.0	1.0	1.0		3,400	60	16	14	12	7	4
	Ridge plant: ¹²												50	22	18	14	8	5
63	Lines 33-59 times factor of:												40	27	21	16	9	5
64	Rows on contour ¹¹												30	32	25	18	9	6
65	Rows U/D slopes < 12 percent												20	38	30	21	10	6
66	Rows U/D slopes > 12 percent												40	29	24	19	9	6
	Till plant:												20	43	34	24	11	7
67	Lines 33-59 times factor of:												10	52	39	27	12	7
68	Rows on contour ¹¹												30	38	30	23	11	7
69	Rows U/D slopes < 7 percent												20	46	36	26	12	7
70	Strip till one-fourth of row spacing:												10	56	43	30	13	8
71	Rows on contour ¹¹																	
72	Rows U/D slopes																	
73																		
74																		
75																		
76	Rows on contour ¹¹																	
77																		
78																		
	POTATOES																	
159	Rows with slope																	
160	Contoured rows, ridged when canopy cover is about 50 percent ¹¹																	

See footnotes.

Footnotes for table 5.

- ¹ Symbols: B, soybeans; C, corn; conv till, plow, disk and harrow for seedbed; col, cotton; F, rough fallow; fld cult, field cultivator; G, small grain; GS, grain sorghum; M, grass and legume meadow, at least 1 full year; pl, plant; Rdl, crop residues left on field; Rdr, crop residues removed; SB, seedbed period; sprg, spring; TP, plowed with moldboard; WC, winter cover crop; —, insignificant or an unlikely combination of variables.
- ² Dry weight per acre after winter loss and reductions by grazing or partial removal: 4,500 lbs represents 100 to 125 bu corn; 3,400 lbs, 75 to 99 bu; 2,600 lbs, 60 to 74 bu; and 2,000 lbs, 40 to 59 bu; with normal 30-percent winter loss. For Rdr or fall-plow practices, these four productivity levels are indicated by HP, GP, FP and LP, respectively (high, good, fair, and low productivity). In lines 79 to 102, this column indicates dry weight of the winter-cover crop.
- ³ Percentage of soil surface covered by plant residue mulch after crop seeding. The difference between spring residue and that on the surface after crop seeding is reflected in the soil loss ratios as residues mixed with the topsoil.
- ⁴ The soil loss ratios, given as percentages, assume that the indicated crop sequence and practices are followed consistently. One-year deviations from normal practices do not have the effect of a permanent change. Linear interpolation between lines is recommended when justified by field conditions.
- ⁵ Cropstages periods are as defined on p. 18. The three columns for cropstage 3 are for 80, 90, and 95 to 100 percent canopy cover at maturity.
- ⁶ Column 41 is for all residues left on field. Corn stalks partially standing as left by some mechanical pickers. If stalks are shredded and spread by picker, select ratio from table 5-C. When residues are reduced by grazing, take ratio from lower spring-residue line.
- ⁷ Period 4 values in lines 9 to 12 are for corn stubble (stover removed).

- ⁸ Inversion plowed, no secondary tillage. For this practice, residues must be left and incorporated.
- ⁹ Soil surface and chopped residues of matured preceding crop undisturbed except in narrow slots in which seeds are planted.
- ¹⁰ Top of old row ridge sliced off, throwing residues and some soil into furrow areas. Reridging assumed to occur near end of cropstage 1.
- ¹¹ Where lower soil loss ratios are listed for rows on the contour, this reduction is in addition to the standard field contouring credit. The P value for contouring is used with these reduced loss ratios.
- ¹² Field-average percent cover; probably about three-fourths of percent cover on undisturbed strips.
- ¹³ If again seeded to WC crop in corn stubble, evaluate winter period as a winter grain seeding (lines 132 to 148). Otherwise, see table 5-C.
- ¹⁴ Select the appropriate line for the crop, tillage, and productivity level and multiply the listed soil loss ratios by soil residual factors from table 5-D.
- ¹⁵ Spring residue may include carryover from prior corn crop.
- ¹⁶ See table 5-C.
- ¹⁷ Use values from lines 33 to 62 with appropriate dates and lengths of cropstage periods for beans in the locality.
- ¹⁸ Values in lines 109 to 122 are best available estimates, but planting dates and lengths of cropstages may differ.
- ¹⁹ When meadow is seeded with the grain, its effect will be reflected through higher percentages of cover in cropstages 3 and 4.
- ²⁰ Ratio depends on percent cover. See table 5-C.
- ²¹ See item 12, table 5-B.

TABLE 5-B.—Soil loss ratios for conditions not evaluated in table 5

COTTON:¹

See table 5-A.

CROPSTAGE 4 FOR ROWCROPS:

Stalks broken and partially standing: Use col. 4L.

Stalks standing after hand picking: Col. 4L times 1.15.

Stalks shredded without soil tillage: See table 5-C.

Fall chisel: Select values from lines 33-62, seedbed column.

CROPSTAGE 4 FOR SMALL GRAIN:

See table 5-C.

DOUBLE CROPPING:

Derive annual C value by selecting from table 5 the soil loss percentages for the successive cropstage periods of each crop.

ESTABLISHED MEADOW, FULL-YEAR PERCENTAGES:

Grass and legume mix, 3 to 5 t hay 0.4

Do. 2 to 3 t hay .6

Do. 1 t hay 1.0

Sericea, after second year 1.0

Red clover 1.5

Alfalfa, lespedeza, and second-year sericea 2.0

Sweetclover 2.5

MEADOW SEEDING WITHOUT NURSE CROP:

Determine appropriate lengths of cropstage periods SB, 1, and 2 and apply values given for small grain seeding.

PEANUTS:

Comparison with soybeans is suggested.

PINEAPPLES:

Direct data not available. Tentative values derived analytically are available from the SCS in Hawaii or the Western Technical Service Center at Portland, Oreg. (Reference 5).

SORGHUM:

Select values given for corn, on the basis of expected crop residues and canopy cover.

SUGARBEETS:

Direct data not available. Probably most nearly comparable to potatoes, without the ridging credit.

SUGARCANE:

Tentative values available from sources given for pineapples.

SUMMER FALLOW IN LOW-RAINFALL AREAS, USE GRAIN OR ROW CROP RESIDUES:

The approximate soil loss percentage after each successive tillage operation may be obtained from the following tabulation by estimating the percent surface cover after that tillage and selecting the column for the appropriate amount of initial residue. The given values credit benefits of the residue mulch, residues mixed with soil by tillage, and the crop system residual.

Percent cover by mulch	Initial residue (lbs/A)			
	> 4,000	3,000	2,000	1,500
90	4	—	—	—
80	8	18	—	—
70	12	13	14	—
60	16	17	18	19
50	20	22	24	25
40	25	27	30	32
30	29	33	37	39
20	35	39	44	48
10	47	55	63	68

¹ For grain residue only.

WINTER COVER SEEDING IN ROW CROP STUBBLE OR RESIDUES:

Define cropstage periods based on the cover seeding date and apply values from lines 129 to 145.

TABLE 5-C.—Soil loss ratios (percent) for cropstage 4 when stalks are chopped and distributed without soil tillage

Mulch cover ¹	Corn or Sorghum		Soybeans		Grain Stubble ⁴
	Tilled seedbed ²	No-till	Tilled seedbed ²	No-till in corn rd ³	
20	48	34	60	42	48
30	37	26	46	32	37
40	30	21	38	26	30
50	22	15	28	19	22
60	17	12	21	16	17
70	12	8	15	10	12
80	7	5	9	6	7
90	4	3	—	—	4
95	3	2	—	—	3

¹ Part of a field surface directly covered by pieces of residue mulch.

² This column applies for all systems other than no-till.

³ Cover after bean harvest may include an appreciable number of stalks carried over from the prior corn crop.

⁴ For grain with meadow seeding, include meadow growth in percent cover and limit grain period 4 to 2 mo. Thereafter, classify as established meadow.

TABLE 5-D.—Factors to credit residual effects of turned sod¹

Crop	May yield	Factor for cropstage period:				
		F	SB and 1	2	3	4
Tons						
First year after mead:						
Row crop or grain ...	3-5	0.25	0.40	0.45	0.50	0.60
	2-3	.30	.45	.50	.55	.65
	1-2	.35	.50	.55	.60	.70
Second year after mead:						
Row crop	3-5	.70	.80	.85	.90	.95
	2-3	.75	.85	.90	.95	1.0
	1-2	.80	.90	.95	1.0	1.0
Spring grain	3-5	—	.75	.80	.85	.95
	2-3	—	.80	.85	.90	1.0
	1-2	—	.85	.90	.95	1.0
Winter grain	3-5	—	.60	.70	.85	.95
	2-3	—	.65	.75	.90	1.0
	1-2	—	.70	.85	.95	1.0

¹ These factors are to be multiplied by the appropriate soil loss percentages selected from table 5. They are directly applicable for sod-forming meadows of at least 1 full year duration, plowed not more than 1 month before final seedbed preparation.

When sod is fall plowed for spring planting, the listed values for all cropstage periods are increased by adding 0.02 for each additional month by which the plowing precedes spring seedbed preparation. For example, September plowing would precede May disking by 8 months and 0.02(8—1), or 0.14, would be added to each value in the table. For nonsod-forming meadows, like sweetclover or lespedeza, multiply the factors by 1.2. When the computed value is greater than 1.0, use as 1.0.