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APPLICATION OF GIS FOR THE ASSESSMENT OF SOIL EROSION USING UNIVERSAL SOIL LOSS EQUATION

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PREFACE

Soil erosion is one of the most serious environmental threats to the mankind over various parts of the world. The impact of various man's activities cause soil erosion problems. Therefore, it is necessary to understand the hydrological processes, which are responsible for soil erosion and sediment yield.

The erosion rate for a given site results from a combination of physical and management variables occur at that site. Actual measurements of soil loss under field conditions would not be feasible for each level of these factors. Soil loss equations were developed to enable conservation planners, environmental scientists and others concerned with soil erosion to extrapolate limited erosion data to the many localities and conditions that have not been directly represented in the research.

The Universal Soil Loss Equation (USLE) is an empirical procedure developed by Wischmeier and Smith in 1965 from statistical analysis of erosion data from a large number of plot studies under different conditions. It was developed to provide a means of estimating longtime average soil losses in runoff from specified field areas under specified cropping and management practices.

In order to automize the estimation of USLE parameters, a geographical information system, which can store and manipulate different types of data can be employed. In the present study, a GIS, Integrated Land and Water Information System (ILWIS), was used to estimate the parameters of USLE. This methodology was applied to a small catchment of Hire Nadi (76.3 sq. km.) near Yelberga in Koppal District of Karnataka. This study has been conducted by, Sh. Chandramohan T., Scientist C and Sh. Dilip G. Durbude, Scientist B, of Regional Centre, Belgaum.

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ABSTRACT

Soil erosion from a catchment is the result of complex processes, which is controlled by various climatic, topographic, geologic, geomorphic, and land use characteristics. Scientific planning for soil conservation and water management requires knowledge of the relations among those factors that cause loss of soil and water and those that help to reduce such losses. Controlled studies on field plots and small watersheds have supplied much valuable information regarding these complex factor and their interrelations.

Information on sediment yield from a catchment can be modeled using lumped and distributed models. However, for field applications, a reliable and simple method is required. The Universal Soil Loss Equation (USLE) is highly useful tool for predicting sheet and rill erosion under various conditions of land use and management. In the present study, USLE has been used to estimate the average soil loss from Hire Nadi catchment, in Yelberga taluk, Koppal District of Karnataka, under different conditions.

Due to its data handling and analysing capabilities, GIS is becoming important in natural resources management. It has proven its applicability for the analyses of various components of hydrologic cycle. In the present study Integrated Land and Water Information System (ILWIS) has been used for the estimation of USLE parameters. Average soil loss from the study area is calculated as 25.98 tons/ha/year. Various maps have been prepared showing land use types in the study area, and regions of potential soil loss, actual annual and seasonal soil loss.

1.0 INTRODUCTION

Soil erosion is the removal of surface material by wind or water. It involves detachment, transport, and subsequent deposition. Soil particles are detached both by raindrop impact and the shearing force of flowing water. Rate of detachment is non-uniform in time and space owing to variation in rainfall, runoff, soil, slope, and cover conditions. While detachment by raindrops occurs over a broad area, detachment by flow is often concentrated in small definable channels (rills). The detached soil particles are then carried further, either by runoff or wind. This whole process is known as erosion. Detachment and transport are basic processes occurring on source areas, while transport and deposition are basic processes occurring in sink areas. The soil erosion affects the infiltration rate, crop production, water holding capacity, removal of organic matter, and plant nutrients. Further, transported sediment lead to decrease in water quality, increasing eutrophication, and reduce the life of reservoirs.

The process of sediment yield occurs whenever the flow of sediment carrying river is impounded by any kind of obstacle. The deposition of eroded sediments takes place at the base of concave slopes, strips of vegetation, flood plains and reservoirs. This results in reduction of storage capacity, water supply capability, power generation, discharge control, etc. of reservoirs, rivers, or catchments. The erosion in catchment changes groundwater regime and results in lowering of water table at some places and rise at the other with the formation of arid zones and marshes respectively. The fertility of soil and its chemical composition will also be changed due to erosion.

Runoff transports particles as bed load and suspended load depending on flow hydraulics and sediment characteristics. Raindrop impact significantly increases the transport capacity of shallow sheet flow. Thin overland flow can transport only very small particles, whereas raindrop impact lifts large particles into the flow so that flow can move them short distances down slope before they settle back to the surface of the soil. These transported sediments are deposited when the sediment load exceeds the flow's total transport capacity or flow loses capacity to transport coarser sized particles present in the sediment load. Bed load material deposits immediately when transport capacity decreases below the sediment load, whereas suspended load responds more slowly to a reduced transport capacity.

Erosion may be classified as;

Sheet Erosion: It is the uniform removal of a thin relatively uniform layer of soil particles from sloping surface of soil between rills. Although important, sheet erosion is often unnoticed because it occurs gradually.

Rill Erosion: When water takes the path of least resistance to flow over soil surface, it forms minute channels called rills. Detachability and transportability are both greater in rill erosion than sheet erosion because of higher velocity. Rill erosion is of most serious, when storm are of high intensity and top soils are loose and shallow.

Gully Erosion: If the channel formed in the land are deepened and widened by erosion that their size is greater than those of common rills, the land is no longer readily usable, and the effect is then termed as gully erosion. These channels carry water and sediments during and immediately after rains. Gullies are also called ravines.

Stream Channel Erosion: It is a soil removal from stream banks or soil movements in the channel. Stream banks erode either by runoff flowing over the stream bank or by scouring and undercutting below the water surface. It is often increased by the removal of vegetation, overgrazing, tilling too near the banks, or straightening of the channel. Poor alignment and the presence of obstructions such as sandbars, increase meandering and are the major causes of erosion along the bank.

Mass Erosion: Mass erosion is the mass movement of soil as in landslides, landslips, soil creep and mudflows. It occurs in small number every wet season and in large number about once in ten years. The quantity of sediment moved from the hill slopes into rivers by mass movement is far in excess of that contributed from gullies, rills and overland flow.

Tunnel Erosion: Tunnel erosion occurs where there is intense penetration of the ground water. This is an underground disintegration of soils, which occurs practically in any thick layer of finely grained soils, and it sometimes referred as a special form of gully erosion. It frequently occurs in forested land causing both soil loss and water loss.

Rainfall and runoff provide the basic energy input to drive the erosion process. Steepness of slope plays an important role in the process of erosion. Soil properties such as soil texture, structure, and the land cover also have a major role in erosion process. The effects of land use on sediment yield are closely linked to those of climate and physiography, since the latter may exert a major control on land use practices. Where it's effect can be isolated, it is clear that the major contrasts in sediment yield may be attributed to the influence of land use. The precise sequence and timing of land use change within a basin will exert a strong control on the resultant pattern of sediment yield.

The soil loss and sediment yield problems are important in India, because of varying topographical and geological conditions, pressure of human and animal population on the land resources, and small land holdings. This is further aggravated by improper land use and faulty land management practices being adopted in the upland watersheds. It is estimated that at present 150 million ha. (about 45 % of total area of the country) of land under agriculture, forests, grass lands, and other land uses, is in need of soil conservation.

Scientific study of soil erosion has a long history in the geographic and geomorphic sciences, where much of the emphasis is on erosion as one of the natural landscape forming processes. Early agriculturally focused research on soil erosion depends on successful agronomic research methodologies, which consisted of planned experimentation followed by quantitative (often statistically guided) analysis of the results obtained.

Later on, alternative methodologies were tried, where more emphasis was given on physical processes involved. Parameters are used, which were to be experimentally determined and were more closely related to the processes involved in erosion and deposition. This new approach to soil erosion and deposition proved useful at the scale of runoff plots and small agricultural plots and efforts are being made at a rapid pace to utilise this approach to interpret erosion and deposition processes on larger scales.

There is growing recognition of interacting erosion experimentation with the development of models of the processes involved. Experimentation is essential to provide the database which models must be able to comprehend. Several soil erosion prediction models have been developed during the past 40 years. The Universal Soil Loss Equation (USLE) is the most widely used model. This model was designed to predict average annual sheet and rill erosion from cropland east of Rocky Mountains (Wischmeier and Smith, 1965), and does not account for soil deposition or gully, stream bank, and streambed erosion. The USLE as now used has been studied and refined and is generally considered the state-of-the-art erosion model (Blackburn, 1980).

2.0 REVIEW OF LITERATURE

A number of studies have been carried out to investigate the erosion rate and the governing physical factors. Several models are available for predicting individual storm sediment yield from agricultural watersheds. Most of these models vary in complexity and are designed for use on small watersheds. Complex two-dimensional models have been developed for predicting individual storm sediment yield and determining the location and amount of deposition on small watersheds. These models would be quite useful for detailed studies. However, most conservation planning for erosion control uses empirical model to estimate average annual soil loss.

Models available in the literature for sediment yield estimation can be grouped into two categories; physically based models and lumped models. Generally in physically based models, the ground surface is separated into interrill and rill erosion areas. Detachment over interrill areas is mainly caused by the impact of raindrop, while runoff is considered to be the dominant factor in rill detachment and sediment transport. The physically based models are expected to provide reliable estimates for the sediment yield. However, these models require the use of various model components related to meteorology, hydrology, hydraulics and soil. As a result, the number of input parameters required for these models will be more, and hence practical application of such models are limited.

Observations, measurements, and research obviously are the forerunners of mathematical modeling. The US Soil Erosion Service and Soil Conservation Service were concerned with conservation of agricultural lands. Erosion experimental stations were established in the 1930's with the responsibility of measuring rainfall, runoff, and soil erosion from small plots. As a result of the erosion plot research, the first erosion models (equations) were developed. Ellison (1945) showed the effect of rainfall energy in sheet erosion by the equation,

$$E = KV^{4.33}d^{1.07}I^{0.65}$$

where, E is the grams of soil intercepted in splash samplers during a 30 min period, V is the velocity of drops in feet per second, d is the diameter of the drops in millimeters, I is the intensity of rainfall in inches per hour, and K is a constant.

Musgrave (1947) analysed 40,000 plot-years of data to develop his relationship to incorporate land characteristics as,

$$E = IRS^{1.35}L^{0.35}P_{30}^{1.75}$$

where, E is the soil loss in acre-inches, I is the inherent erodibility of the soil in inches, R is a cover factor, S is degree of slope in percent, L is the lengths of slope in feet, and P_{30} is the 2-yr. 30 min. rainfall amount in inches. Graphs to solve the Musgrave equation were prepared by Lloyd and Eley (1952). Van Doren and Bartelli (1956) proposed an erosion equation for different soils and cropping conditions that estimated annual soil loss as a function of nine factors.

Wischmeier and Smith (1958) re-examined the erosion plot data used by Musgrave and US Weather Bureau rainfall data and in 1958 published their first results toward development of a soil loss equation. The Universal Soil Loss Equation (USLE) put forward by Wischmeier and Smith (1965) was based on over 10,000 plot years of natural and simulated runoff data. The average annual soil loss in tons/acre A is calculated as,

$$A = RKLSCP$$

where, A is the average annual soil loss in tons/acre, R is a rainfall factor, K is a soil-erodibility factor, LS is a slope length and steepness factor, C is a cropping factor, and P is a conservation practice factor.

Efforts to mathematically predict soil erosion by water started only about half centuary ago. The development of erosion prediction technology began with analyses such as those by Cook (1936) to identify the major variables that affect soil erosion by water. Cook listed three factors; the susceptibility of soil to erosion, the potential erosivity of rainfall and runoff, and the soil protection afforded by plant cover. Later, Zingg (1940) published the first equation for calculating field soil loss. It described mathematically the effects of slope steepness and slope length on erosion. The following year, Smith (1941) added factors for cropping system and supporting practices to the equation. He also added the concept of a specific annual soil loss limit, and used the resulting equation to develop a graphic method for selecting conservation practices for certain soil conditions.

Browning and associates (1947) added soil erodibility and management factor to the Smith equation and prepared more extensive tables of relative factor values for different soils, rotations, and slope lengths. This approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepnesses, with and without contouring, terracing, or strip-cropping. Smith and Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. Soil loss ratios at different slopes were given for contour farming, strip-cropping, and terracing. Relative erosion rates for a wide range of crop rotations were also given. The following year, Smith and Whitt (1948) presented a rational erosion estimating equation, A = CSLKP. The C factor was the average annual soil loss from claypan soils for a specific rotation, slope length, slope steepness, and row direction. The other factors for slope (S), length (L), soil group (K), and supporting practice (P) were dimensionless multipliers to adjust the value of C to other conditions.

Since 1965, efforts have gone into improvement of the USLE and it has been expanded for additional types of land use, climatic conditions and management practices (Blackburn, 1980).

Renard et al. (1974) modified the USLE to more clearly approximate soil loss from rangeland watersheds. They included an additional term to the USLE to accommodate channel erosion. The modified equation is,

$$A = (RKLSCP)\,E_C$$

where, the new term E_C reflects channel erosion. They state that this term is analogous in many respects to the sediment delivery ratio.

Williams (1975) modified USLE to MUSLE for predicting individual storm sediment yield from cropland watersheds. A sediment routing technique was developed to route sediment yield from small watersheds through streams and valleys to the outlets of large watersheds. MUSLE estimates sediment delivered to the stream by using a runoff factor instead of the rainfall energy factor. This modification enabled prediction of sediment yield resulting from individual storms. Onstard and Foster (1975) modified the USLE to include both rainfall and runoff energy terms to include both rainfall and runoff energy.

Renard et al. (1991) revised the USLE to RUSLE by retaining the six factors to calculate annual soil loss from a hillslope. The technology for evaluating these factor values has been altered and new data added. The technology has been computerised to assist with the calculation. Major changes were made for each of the factors; the R factor and K factor is changed to reflect variability within the year, the L factor and S factor are changed to reflect the ratio of interrill to rill erosion, and the C factor is calculated as the product of terms reflecting prior land use, surface cover, crop canopy, and surface roughens.

The lumped models such as USLE, MUSLE, or RUSLE, combine the erosion from all processes over a catchment/plot into one equation. Rainfall characteristics, soil properties, and ground surface conditions are represented by empirical constants and such models are frequently in use. To represent spatial heterogeneity within a catchment, it can be divided into small areas and calculations can be made for each of these sub-areas.

Complex 2-dimensional models have been developed for predicting individual storm sediment yield and determining the location and amount of deposition on small watersheds. Williams (1977) states that these models should be quite useful for detailed studies. However, input requirements are considerably greater than for the USLE. Because they lack channel routing component, these models are not applicable to large watersheds.

The USDA Forest service, under an interagency agreement with USEPA compiled a set of watershed analyses and prediction procedures (Snyder, 1980). These state-of-the-art techniques are collectively referred to as WRENSS (Water Resources Evaluation of Nonpoint Sources-Silvicultural). The objective of the soil erosion component in WRENSS is to estimate the quantity of accelerated soil loss under given silvicultural activity conditions. An empirical procedure was chosen for estimating soil loss using the USLE, modified for use in forest environments. The cropping management factor and the erosion control practice factor have been replaced by a vegetation management factor to form the MSLE. In recent years, number of studies have been conducted using WEPP model (USDA, 1995), a process oriented model, which predicts hydrologic and erosion processes. It simulates rainfall, infiltration, water balance, runoff, plant growth, and erosion impacts in order to predict effects of management on erosion. Other physically based models include AGNPS (Young et al., 1987), ANSWERS (Beasley et al., 1980), WEPP (Nearing et al., 1989), and SHETRANS (Wicks and Bathrust, 1996).

3.0 UNIVERSAL SOIL LOSS EQUATION (USLE)

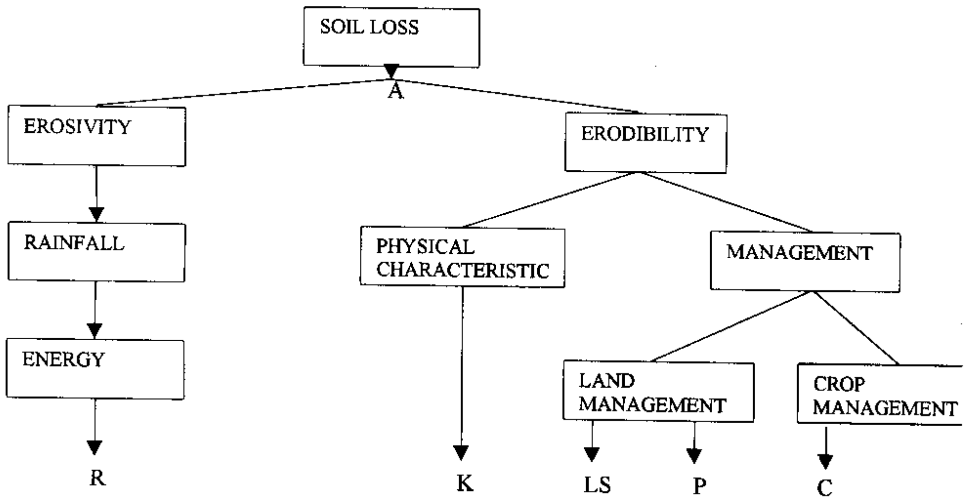
The USLE erosion model is designed to predict the long-term average field soil losses under specified conditions. This model enables the planners to estimate the average rate of soil erosion for each feasible alternative combinations of crop system and management practices in association with a specified soil type, rainfall pattern, and topography. When these predicted losses are compared with given soil loss tolerances, they provide specific guidelines for effecting erosion control within specified limits.

Research that eventually led to development of the USLE started in 1940 in the corn belt (Zingg, 1940). Research by Smith (1941), Smith and Whitt (1947) and Browning et al. (1947) provided the impetus for the erosion modeling concept that resulted in the Musgrave equation (Musgrave 1947). The USLE was developed at the National Runoff and Soil Loss Data Centre, in 1965 by Wischmeir and Smith. The procedure was later refined (Wischmeier and Smith, 1978), by incorporating more data from runoff plots, rainfall simulators, and from field experience. Since 1965, research has expanded the use of the USLE by improving estimation techniques of its factors to account for additional kinds of land uses, climatic conditions, and management practices. The USLE has overcome many drawbacks of its predecessors and its major features include;

- more complete separation of factor effects so that results of a change in the level of one or several factors could be more accurately predicted
- an erosion index that provided a more accurate, localised estimate of erosive potential of rainfall and associated runoff
- a quantitative soil erodibility factor that was evaluated directly from research data without reference to any common benchmark
- an equation and nomograph capable of computing the erodibility factor for numerous soils from soil survey data
- a method of including effects of interactions between cropping and management parameters

- a method of incorporating the effects of local rainfall patterns through the year and specific cropping conditions in the cover and management factor

The USLE model groups the numerous physical and management parameters that influence erosion under six factors, which can be expressed numerically. Interrelation between the variables involved in water erosion processes are represented in the following flowchart.



The USLE is given by,

Soil Loss = F (rainfall erosivity, soil susceptibility, topography, management)

$$A = RKLSCP$$

where,

A = the computed soil loss per unit area, usually in tons per acre per year

R = the rainfall and runoff factor, the number of rainfall erosion index (EI) units, plus a factor for runoff from snowmelt or applied water, where such runoff is significant

K = the soil erodibility factor, the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6 ft length of uniform 9% slope in continuously clean-tilled fallow

L = the slope length factor, the ratio of soil loss from the field slope length to that from a 72.6 ft length under identical conditions

S = the slope steepness factor, the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions

C = the cover and management factor, the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow

P = the support practice factor, the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight row farming up and down the

Rainfall Erosivity factor, R --- The R factor is determined by both rainfall and the energy imparted to the land surface by the rain drop impact. Rainfall erosion index implies a numerical evaluation of a rainstorm or of a rainfall pattern, which describes its capacity to erode soil from an unprotected field. It is a function of intensity and duration of rainfall and mass, diameter, and velocity of the rain drop. Erosivity is expressed as the long term mean annual rainfall erosion index based on the kinetic energy of the rain. Keeping the soil and slope parameters constant, studies indicated that the most valuable combination of indicators of erosion loss from fallow soil is the rainfall energy. It is a product term, which measures the interaction effect of storm energy and maximum prolonged intensity, antecedent moisture index, and total antecedent rainfall energy since the last tillage operation.

In India, using 45 stations, distributed in different rainfall zones, simple linear relationship between erosivity index and annual or seasonal rainfall has been developed (Singh et al, 1981).

Annual R-factor, $Ra = 79 + 0.363 * P$

Seasonal R-factor, $Rs = 50 + 0.389 * P$, where P is the rainfall in mms.

Soil erodibility factor, K --- The soil erodibility factor relates the rate at which different soils erode. K is expressed as soil loss per unit of area per unit of R for a unit plot (a plot of 22.3 m long with a uniform slope of 9 % under continuous fallow and tilled parallel to the slope). Under the conditions of equal slope, rainfall, vegetative cover, and soil management practices, some soils will erode more easily than others due to inherent soil characteristics. Erodibility varies with soil texture, organic matter content, aggregate stability, shear strength, infiltration capacity, and organic matter content.

Direct measurement of soil erodibility factor is both costly and time consuming and has been feasible only for a few major soil types. A soil erodibility nomograph for crop land and construction sites has been developed from field plot studies from different parts of USA. This provides a more generally applicable tool.

This factor was originally determined quantitatively from the runoff plots. The direct measurement of K on unit runoff plots reflect the combined effects of all variables that significantly influence the ease with which a soil is eroded or the particular slope other than 9% slope. The soil loss is adjusted through slope factor S.

USDA (1978) suggested a nomograph, as shown in figure 1, and an equation for determining soil erodibility of soils, using particle size, organic matter, and permeability class. The values of erodibility factor for different land use as reported by Ashokan (1981) are as below;

Forest and Wood land	0.59
Grass and Waste land	0.43
River bed and paths	0.56
Crop land	0.58

Slope length and steepness factor, LS --- Slope length is important mainly with respect to the increase in the flow of water on slopes. The slope length factor is the ratio of soil loss from the field slope length to that from 22.13 meter length plots under identical

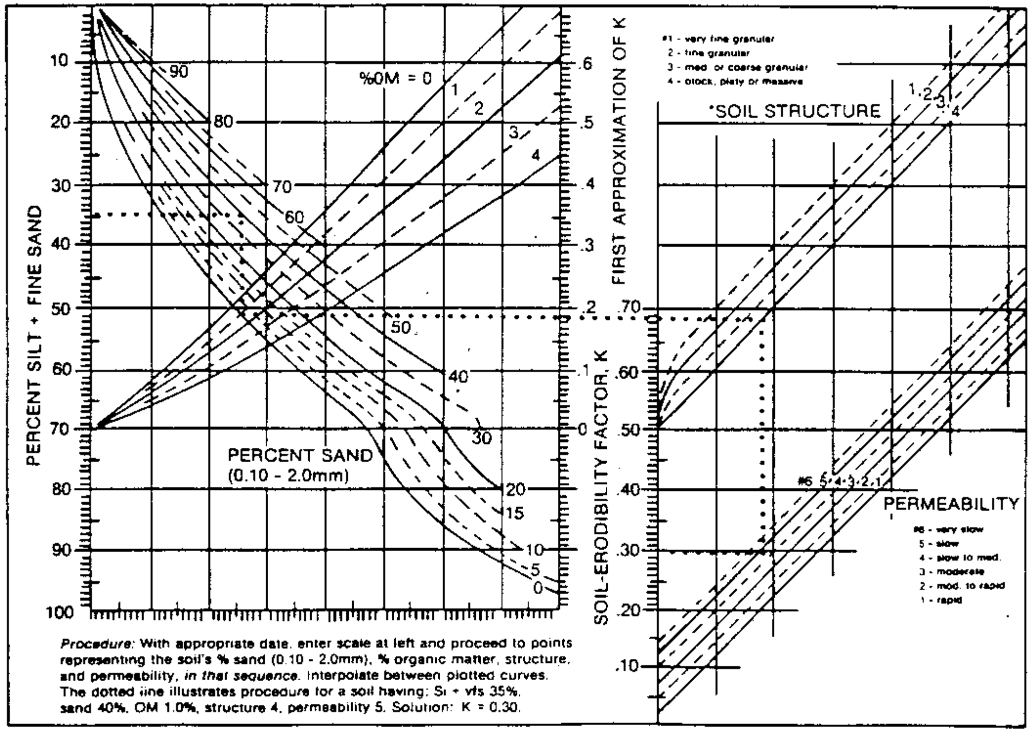


Figure 1. Nomograph for determining the Soil Erodibility Factor (USDA, 1978)

conditions. Slope length is defined as the distance from the point of origin of overland flow to the point where either slope gradient decreases enough that soil deposition begins, or the runoff waters enters a well defined channel.

The slope steepness factor is the ratio of soil loss from the field slope gradient to that from 9 % slope under otherwise identical conditions. The land factor S of this equation was derived from data obtained on cropland, under natural rainfall, on slopes ranging from 3 to 18 % and less than 125 meter in length. Potential extrapolation of the data with accuracy beyond this range has not been determined by direct soil loss measurements.

It is more convenient to consider length and slope as a single topographic factor when applied to field situations. The LS values have recently been expanded to compute soil loss from slopes that are appreciably convex, concave, or complex. This is accomplished by dividing irregular slopes into small number of equal length segments, which can be considered uniform. The LS value for the irregular slope is the sum of the values of the individual segments.

The procedure for irregular slopes can include evaluation of changes in soil type within slope length. The LS values for small segments are multiplied by the respective values of K before summing. Within limits, the procedure can be extended to account for changes in cover along the slope length by adding a column of segment C values. This practice is not applicable for situations where a cover change along the slope causes deposition.

Cover and management factor, C --- The main role of vegetation cover in the interception of the rain drops is that their kinetic energy is dissipated by them. The crop management factor is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean, tilled fallow or identical soil and slope and under the same rainfall. A large amount of research and development energy has gone into the many existing C factors cropland. Factor C has been extended to include pasture, range, and idle land.

However, available soil loss data from undisturbed lands were not sufficient to derive C values by direct comparison of measured soil loss rates, as was done for the development of C values for cropland.

Jaiswal (1982) proposed the following values for C factor from his studies on Gagas watershed of Upper Ramganga catcment;

Crop land	0.32
Hay land and grazing land	0.21
Forest and wood land	0.02
Barren land	1.00

Support practice factor, P --- Conservation practice conditions consist mainly in the methods of land use and land tillage, and the agrotechnology. The P factor in USLE is expressed as a ratio, which compares the soil loss from the investigated plot cultivated up and down the slope gradient. The amount of soil loss from a given land is influenced by the land management practice adopted. The value of P ranges from 1.0 for up and down cultivation to 0.25 for contour strip cropping of gentle slope. The P factor as used for soil conservation planning on cropland would rarely apply to range land, and P will usually equal 1.0.

4.0 INTEGRATED LAND AND WATER INFORMATION SYSTEM (ILWIS)

A geographic information system (GIS) is a computer based system for collecting, storing, retrieving, analysing, and displaying of spatial data. The increasing volume of available environmental information with all its complexity and subsequent demands for its storage, analysis and display, have led to the rapid development in the application of computers to environmental and natural resources data handling and the creation of subsequent information system. Effective utilisation of large volumes of spatial data depends on the existence of efficient data handling and processing system such as GIS, which is capable of transforming these data into usable information.

The data to be entered in a GIS are of two types; spatial and associated non-spatial attribute data. The spatial data represent the geographic location of features, which are input using points, lines, and areas. Non-spatial (attributes) data supplies respective values or descriptions associated with spatial data. Spatial data can be of vector or raster formats. In the vector representation, the objects in the real world are denoted by points and lines, whereas raster models consist of regular grid of square or rectangular cells.

Besides the other applications of GIS, it can be used in Hydrology for;

- land use planning and management
- natural resources mapping and management
- land information systems
- urban and regional planning
- management of well log data

The GIS software used in this study is ILWIS (Integrated Land and Water Information System), developed at International Institute of Aerospace Survey and Earth Sciences (ITC), Enschede, The Netherlands. ILWIS provides user with state of art of data gathering, data input, data storage, data manipulation and analysis, and data output capabilities (Valenznela, 1990).

ILWIS is a Windows based, integrated GIS and Remote Sensing application consisting of;

- display of raster and multiple vector maps in map window
- display of tables in table windows
- interactive retrieval of attribute information
- image processing facilities
- manipulation of maps in Map Calculator
- GIS analysis tools

ILWIS functionality for vectors includes: digitizing with mouse/digitizer, interpolation from isolines or points, calculation of segment or point density, pattern analysis. ILWIS functionality for raster includes: distance calcultion, creation of a Digital Elevation Model (DEM), calculation of slope/aspect, deriving attribute maps, classifying maps, manipulating maps with iff-statements, with Boolean logic, crossing maps, etc.

For satellite imagery: creation of histograms, colour composites, sampling and classification, filtering, multi-band statistics. Furthermore, it provides import and export routines, editing of point, segment, polygon, and raster maps, change of projection/coordinate systems of maps, and output possibilities with annotation.

A conversion program attains the importation of remote sensing data, tabular data, raster maps, and vector files in several other formats. Analog data can be transferred into vector format by means of digitizing program. Complex modelling of features can be executed by the map calculation. It includes an easy to use modelling language and the possibility of using mathematical functions and macros. It integrates tabular and spatial databases. Tabular and spatial databases can be used independently and on an integrated basis. Calculation, queries, and simple statistical analyses can be performed by table calculator. The process of database creation for an area in ILWIS involved collection of relevant data, including converting these data into digital format, digitization error checking and correction, polygonization of segment files and finally conversion of data acquired in vector structure to raster format.

5.0 STUDY AREA

The watershed considered for the present study is the drainage area of a small stream joining Hire Nadi at Budgumpi in Koppal district. Hire Nadi joins Tungabhadra reservoir downstream of Koppal. This covers an area of 76.35 km^2 in Yelberga taluka of Koppal district in Karnataka state. The area lies between north latitudes of 15°32' and 15°41' and east longitudes of 76°04' and 76°10'. The location of the study area with its drainage network is given in figure 2. The main stream is a 5th order stream and length of the longest stream is 18.76 kms.

The topography of the area is generally flat to gently sloping (1 tó 5 %) except at the upstream end of the watershed. The elevation ranges from 557 to 710 metre above mean sea level. Climatically the area is coming under the semi-arid zone. The mean maximum temperature for the area is 39.6°C, while the mean minimum temperature is 18° C. Humidity in this region varies between 63 to 78 %.

Four raingauge stations, Yelberga, Koppal, Bevoor, and Kushtagi, situated around the study area were taken for the analysis. Average annual rainfall for the area is about 580 mm, out of which about 80 % occur during south-west monsoon season (during June to October). The average rainfall values for these stations are given in table 1.

Major portion of the study area is covered with agriculture land and the rest consists of barren and shrubby land. Since the area lies in the low rainfall region, rabi cultivation is comparatively more than the kharif cultivation. Double crops, occupies areas irrigated by groundwater and tanks. The main soil type for the area is light red to brown coloured sandy clay loam soil and dark coloured clay loam soil. Since there was no maps or details available regarding the details of soil and land use, remote sensing satellite data along with the details obtained from field surveys were used for their delineation.

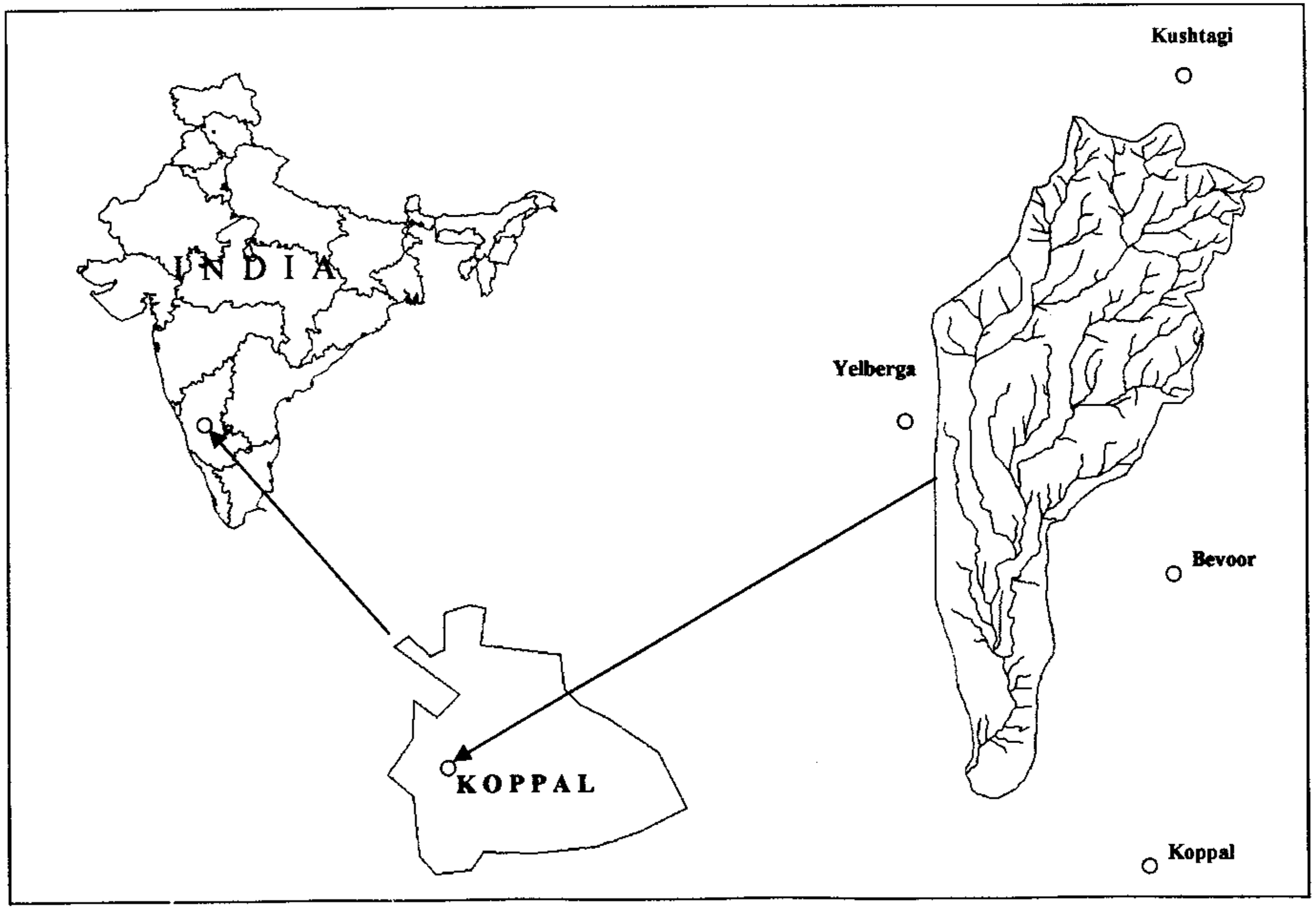


Figure 2. Location of Study Area

Table 1. Monthly Mean Rainfall (in mms.) for the Stations Considered for the Study

Station → **Data Length →**	**Yelburga** **(1957-99)**	**Koppal** **(1967-99)**	**Bevoor** **(1977-99)**	**Kushtagi** **(1957-99)**
January	0.93	0.81	0.46	1.03
February	0.59	0.14	0.00	1.75
March	2.33	1.93	0.00	2.80
April	24.25	17.22	15.72	20.52
May	49.02	48.86	38.94	44.11
June	75.83	77.58	100.23	87.88
July	70.20	70.52	78.33	64.29
August	88.87	88.16	83.89	75.74
September	142.70	167.26	111.37	147.07
October	102.26	118.22	65.22	104.27
November	18.80	32.4	46.03	24.05
December	8.23	8.13	7.37	9.44
Ave. Annual	584.10 mm	631.23 mm	547.55 mm	582.95 mm
Ave.Monsoon	479.94 mm	521.75 mm	439.03 mm	479.25 mm
Ave N.Monsoon	104.17 mm	109.48 mm	108.52 mm	103.70 mm

6.0 ANALYSIS AND RESULTS

For the present study, IRS-1 C LISS III data (Row 62 and Path 98) was used along with the scanned SOI toposheet no. 57 A/2 (1:50,000) as the base map. Monthly rainfall data for four rain gauge stations around the watershed, namely Yelburga, Kushtagi, Bevoor, and Koppal were collected from the Karnataka State Irrigation Department and average annual and seasonal, monsoon (July to October) and non-monsoon rainfall values were estimated. Field survey was conducted to collect soil samples from various locations throughout the entire study area. These samples have been tested for its texture and moisture characteristics to delineate different soil characteristics. About 78 % of the study area is covered by dark grey coloured black soil followed by red soil, which is distributed over 16 % of the total area and the rest is covered with brown coloured soil. Details regarding cropping pattern and management practices were collected during the field visits.

The digital data (29^{th} November, 1998) procured from NRSA, Hyderabad was used for land use classification in the study area. The GIS software namely, Integrated Land and Water Information System (ILWIS) was used for data processing and analysis. Coordinate system for the study area was created with Universal Traverse Mercator (UTM) projection for zone 43 in which the study area lies, using Everest (India, 1956) Ellipsoid and Everest (Indian, Nepal) datum. The toposheet was geo-referenced with respect to the above said coordinate system. The watershed boundary, contours, drainage, etc. were generated. The digital satellite data was geo-referenced and rectified with the base map. The boundary of the watershed is delineated from the base map using the contour and drainage pattern of the base map.

All the data has been transferred to GIS database and base maps were prepared. These maps were used to generate USLE parameters, which were stored in ILWIS under various conditions. These parameters were then combined to assess the seasonal soil erosion and the potential soil erosion for the study area.

From the digital remote sensing data, the False Colour Composite (FCC) was prepared using band1, band 2 and band 3 combinations. The image features on the FCC were interpreted for the preparation of land use map using appropriate interpretation keys. The sample set was selected for the training of pixels after the ground truth verification. These training pixels of the sample set were further used for land use classification. The supervised classification with the maximum likelihood classifier was used. Also, the spatial distribution of the soil characteristics was done through the ILWIS software by using the results of the laboratory analysis of soil samples and further ground truth verification. Thus the mapping of land use and soil characteristics has been done. Figure 3 shows the soil and land use types for the study area. The spatial distribution of the land use in the study area is shown in table 2.

Table 2. Major Land Use Classes for the Study Area

LandUse Type	Agriculture (Crop) Land			Shruby Land	Barren Land	Stony Waste land	Water Body
	Kharif	Rabi	Double crop				
Area in Sq. Km.	6.13	34.22	11.72	17.94	5.9	0.16	0.29
Area in (%)	8.03	44.82	15.34	23.49	7.73	0.21	0.38

Different thematic maps, such as drainage map, land use map, soil map, etc. were prepared using the base map, remote sensing data, and ground truth verification. The digitized contour and spot height information were used to obtain the DEM (digital Elevation Model) with the help of various interpolation routines available in ILWIS. This DEM was used for the creation of slope map. The slope classification was done as per the Integrated Mission for Sustainable Development (NRSA, 1995) guidelines. Figure 4 shows the DEM and classified slope map for the watershed.

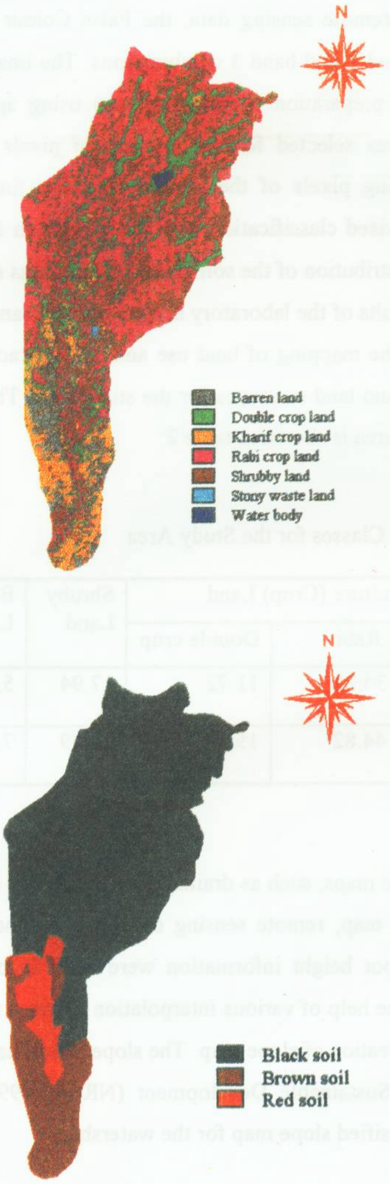


Figure 3. Land Use and Soil Types of the Study Area

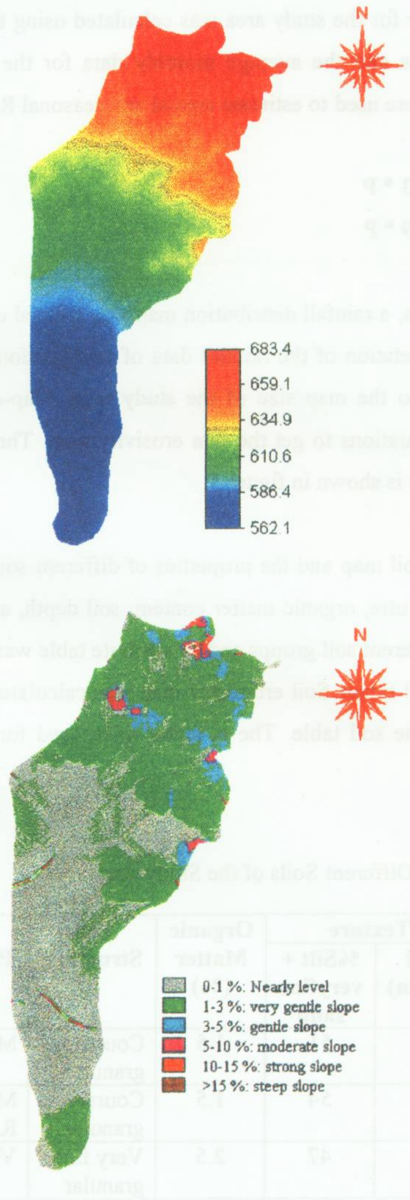


Figure 4. DEM and Classified Slope Map for the Study Area

R-Factor: The R-factor for the study area was calculated using the point data map of the four raingauge stations and the average monthly data for the raingauge stations. The following equations were used to estimate annual and seasonal R-factor.

$$Ra = 79 + 0.363 * P$$

$$Rs = 50 + 0.389 * P$$

In ILWIS terms, a rainfall distribution map was created using the moving average method for the interpretation of the rainfall data of each stations. This rainfall map was filtered and reduced to the map size of the study area. Map-calculation was done by applying the above equations to get the rain erosivity map. The annual and seasonal R-factor map for the area is shown in figure 5.

K-Factor: Using the soil map and the properties of different soil types such as sand-silt-clay contents, soil textutre, organic matter content, soil depth, and permeability, k-factor was calculated for different soil groups and an attribute table was prepared which gives k-factor for different soil types. Soil erodibilty map was calculated using the soil map and attribute k-factor in the soil table. The K-factor table used for the calculation is given table 3.

Table 3. K-Factor for Different Soils of the Study Area

Soil Type	**Soil Texture**		**Organic Matter (%)**	**Soil Structure**	**Rate of Permeability**	**K factor**
	% Sand (0.1to2mm)	**%Silt + veryfine sand**				
Brown Soil	27	51	1.5	Course granular	Moderate	0.32
Red Soil (Lateritic)	35	54	1.5	Course granular	Moderate to Rapid	0.45
Black soil	15	47	2.5	Very fine granular	Very slow	0.26

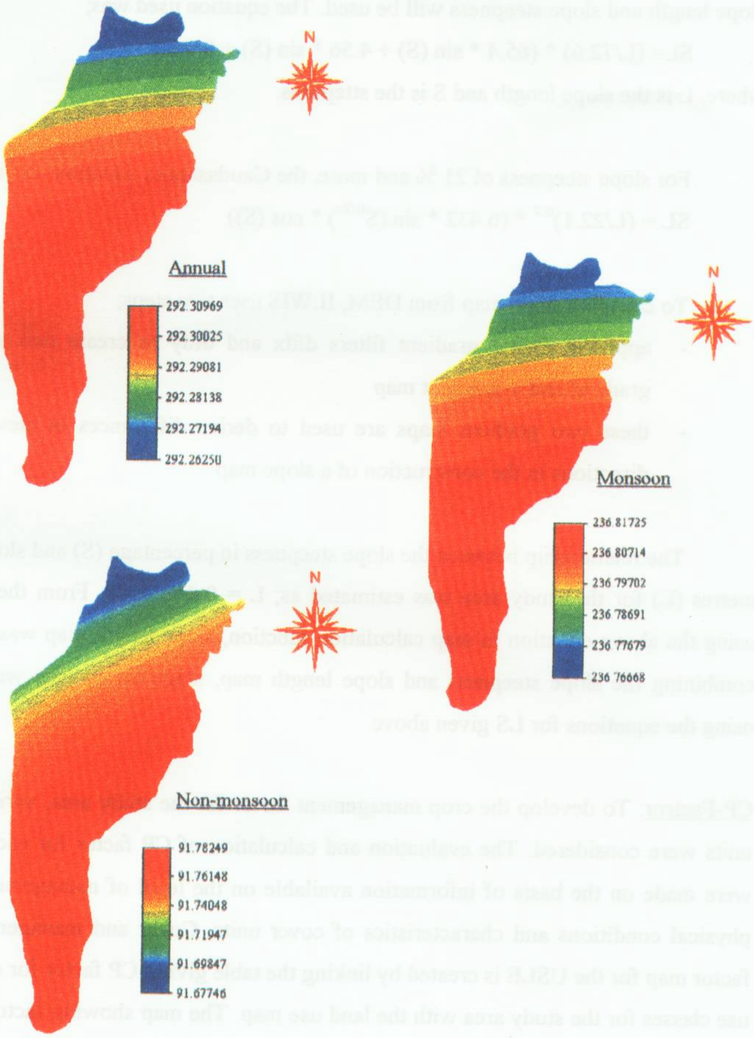


Figure 5. Annual and Seasonal Variation of R-Factor

SL-Factor: For slope steepness upto 21%, the original USLE formula for estimating the slope length and slope steepness will be used. The equation used was;

$$SL= (L/72.6) * (65.4 * \sin (S) + 4.56 * \sin (S) + 0.065)$$

where, L is the slope length and S is the sttepness.

For slope steepness of 21 % and more, the Gaudasamita equation was used;

$$SL = (L/22.1)^{0.7} * (6.432 * \sin (S^{0.79}) * \cos (S))$$

To calculate slope map from DEM, ILWIS uses two steps;

- applying digital gradient filters dfdx and dfdy to create two so called x-gradient and y-gradient map
- these two gradient maps are used to derive differences in elevation in all directions in the construction of a slope map

The relationship between the slope steepness in percentage (S) and slope length in metres (L) for the study area was estimated as; $L = 0.4*S + 40$. From the slope map, using the above equation in map calculation function, slope length map was created. By combining the slope steepness and slope length map, slope factor map was calculated using the equations for LS given above.

CP-Factror: To develop the crop management factor for the study area, various land use units were considered. The evaluation and calculation of CP factor for each cover unit were made on the basis of information available on the level of management practices, physical conditions and characteristics of cover units. Cover and management practice factor map for the USLE is created by linking the table giving CP factor for different land use classes for the study area with the land use map. The map showing factors LS, C and P for the watershed are given in table 4.

Table 4. CP Factor for Different Land Use Classes for the Study Area

Land Use Type	Farming Method	Tillage Practice	P factor	C factor
Agriculture (Crop) Land a. Double Crop b. Kharif Crop c. Rabi crop	Strip cropping with small grain and row crop	Spring Conventional Tillage	0.40	0.36
Barren Land	------	------	1.0	0.20
Stony Wasteland	-------	------	1.0	0.45
Shruby Land	------	-------	1.0	0.21
Water Body	-------	------	0.0	0.0

Figure 6 shows the variation of K, LS, and CP factor for the study area.

Potential Soil Loss Calculation: The rain erosivity, soil erodibility, and the slope factor as elements of USLE can be considered as naturally occurring factors determining the sheet and rill erosion processes (without considering management factors). By combining these factors, the potential erosion (tons/ha./year) for the study area was estimated. In ILWIS terms, the multiplication of the three maps showing the variation of R-factor, K-factor, and LS-factor, potential soil map was created.

The K, LS, and CP factors were combined together to generate a map of KLSCP, which is independent of storm events in the watershed. This represents the erosion potential of the area or watershed topography, from which storm erosion can be computed by adding appropriate R-factor.

Figure 7 shows RKLS and KLSCP maps for the study area.

Expected Soil Loss (A) Calculation: The actual soil loss was estimated by multiplying the maps of R, K, LS, and CP factors. By comparing actual and potential soil loss, the effect of management practices can be understood. By comparing both the maps, the cause of the increased erosion might be detected and improved management actions could be proposed to prevent further degradation.

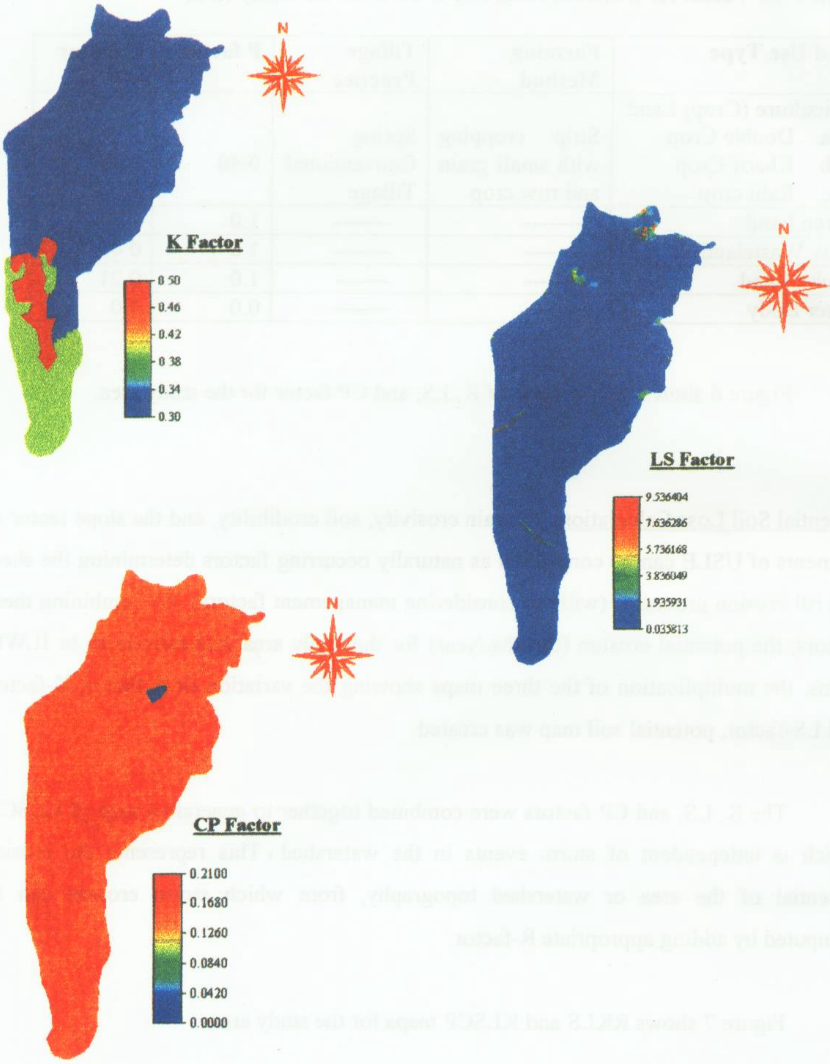
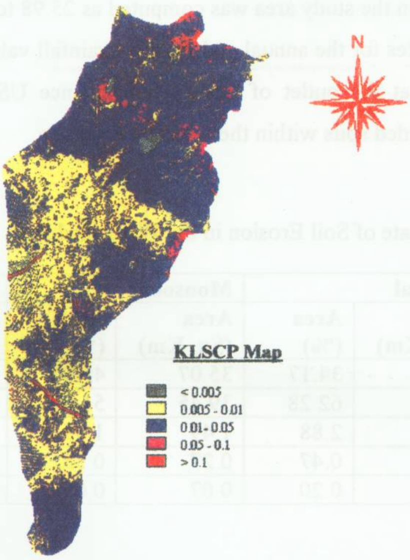


Figure 6. K, LS, and CP Factors for the Study Area



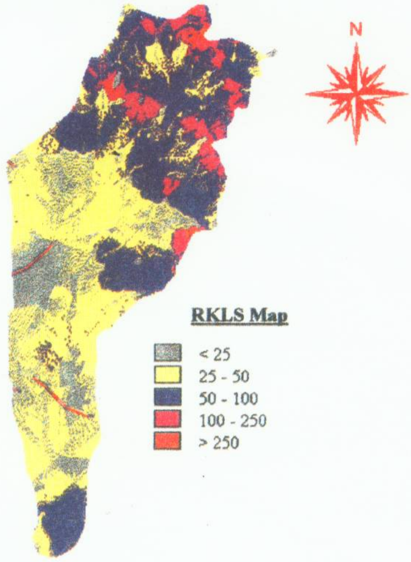


Figure 7. Erosion Potential Maps for the Study Area

The actual annual and seasonal soil loss maps were shown in figure 8. The average soil loss from the study area was computed as 25.98 tons/hect/year. Table 5 gives the actual erosion rates for the annual and seasonal rainfall values. This will not represent the sediment yield at the outlet of the watershed since USLE will not calculate the deposition of the eroded soils within the watershed surface.

Table 5 Estimated Rate of Soil Erosion in the Watershed Area

Rate of Erosion (Tons/Ha)	**Annual**		**Monsoon**		**Non monsoon**	
	Area (Sq. Km)	**Area (%)**	**Area (Sq. Km)**	**Area (%)**	**Area (Sq. Km)**	**Area (%)**
< 5	26.09	34.17	35.07	45.94	67.28	88.12
5 – 25	47.55	62.28	39.45	51.67	8.20	10.72
25 – 50	2.20	2.88	1.49	1.95	0.83	1.09
50 – 100	0.36	0.47	0.27	0.35	0.03	0.04
> 100	0.15	0.20	0.07	0.09	0.00	0.00

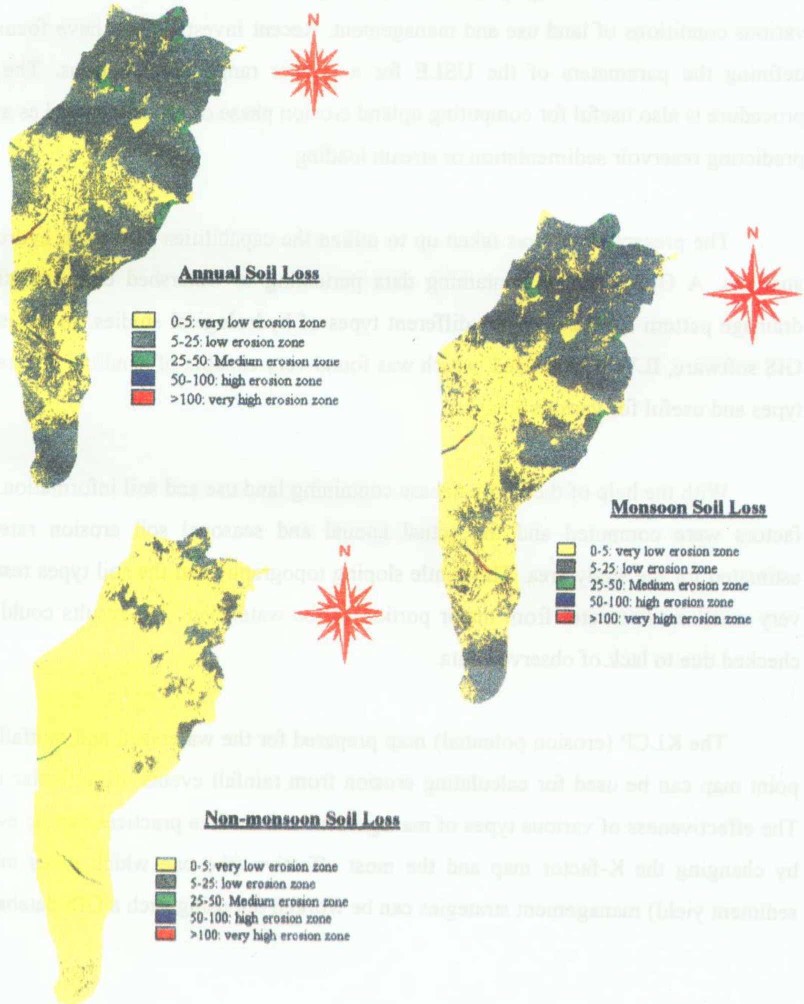


Figure 8. Annual and Seasonal Soil Loss Maps

7.0 CONCLUSION

The USLE is a highly useful tool for predicting sheet and rill erosion under various conditions of land use and management. Recent investigations have focussed on defining the parameters of the USLE for a greater range of conditions. The USLE procedure is also useful for computing upland erosion phase of sediment yield as a step in predicting reservoir sedimentation or stream loading.

The present study was taken up to utilize the capabilities of GIS in hydrological analyses. A GIS database containing data pertaining to watershed characteristics and drainage pattern can be used for different types of hydrological studies. In this study, a GIS software, ILWIS, was used, which was found very capable of handling different data types and useful for various analyses.

With the help of the GIS database containing land use and soil information, USLE factors were computed and the actual annual and seasonal soil erosion rates were estimated for the study area. The gentle sloping topography and the soil types resulted in very small erosion rates from major portion of the watershed. The results could not be checked due to lack of observed data.

The KLCP (erosion potential) map prepared for the watershed and rainfall station point map can be used for calculating erosion from rainfall events of particular interest. The effectiveness of various types of management and surface practices can be evaluated by changing the K-factor map and the most effective (the one which gives minimum sediment yield) management strategies can be worked out using such a GIS database.

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