ESTIMATION OF SOIL EROSION & SEDIMENT YIELD USING GIS

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By
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Candidate's Declaration

I hereby certify that work which is being presented in the Dissertation entitled **"ESTIMATION OF SOIL EROSION AND SEDIMENT YIELD USING GIS"** is in partial fulfillment of the requirement for the award of the Degree of Master of Technology and submitted to the Department of Water Resources Development and Management (WRD&M), Indian Institute of Technology Roorkee. This is an authentic record of my own work carried out during the period from July 2006 to June 2007 under the supervision and guidance of *Dr. S. K. Mishra*, Assistant Professor, WRD&M and *Dr. M. K. Jain*, Assistant Professor, Department of Hydrology (DOH), IIT Roorkee, Uttara Khand, India.

The matter presented in this dissertation has not been submitted by me for the award of any other degree.

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ABSTRACT

Problems associated with soil erosion, movement and deposition of sediment in watershed and catchment persist through the geologic ages in almost all parts of the earth. The situation is more aggravated in recent times with humankind's increasing intervention with the environment such as rapid transformation of virgin lands into agricultural use and also due to faulty agricultural practices, mismanagement and over exploitation of forests, over-grazing of pasture, mining, and developmental works but not accounting for counter mitigative measures. This environmental impact makes drainage network dry and consequently land slide problem commences and further increment in degradation and deterioration of watershed. At present, the quality of available data may be uneven. Land use planning based on unreliable data can lead to lots of expenditures and gross errors in results. Soil erosion research is a capital-intensive and time-consuming exercise. Global extrapolation on the basis of few data collected by diverse and unstandardized methods can lead to gross errors.

Soil Erosion involves the processes of detachment, transportation & accumulation of soil from soil surface due to either of raindrop impact and splash, the shearing force of flowing water, wind, sea waves or moving ice. During the process of erosion and transportation to downstream side, some part of the eroded material may get opportunity to deposit. The net amount of sediment flowing through the watershed is termed as sediment yield.

Empirical models such as Universal soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE) and Revised Universal Soil Loss Equation (RUSLE) are simple most commonly used soil erosion estimation models and are employed for quantitative assessment of soil loss. Soil erosion is a function of physical systems, such as climate, soil, crop and topography. Remote Sensing provides affordable and easy solution for capturing the authentic remotely sensed data. Voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of Geographic

Information Systems (GIS). In this case, GIS Software helped to a great extent for assessment of soil erosion and sediment yield inventory and for their result analysis.

In the present study, a GIS based method is proposed for computation of soil erosion and sediment yield due to rainfall. The proposed method was tested using data from Chaukhutia watershed. The ERDAS Imagine 8.5 and ArcGIS 9.0 software were used for catchment discretization into cell areas using grid networks, evaluation of catchment topographical characteristics and land use, computations and presentation of the results obtained.

Various thematic layers representing different factor of USLE were generated and overlaid to compute spatially distributed gross soil erosion maps for watershed using recorded rainfall for 18 years. A concept of transport limited accumulation was formulated and used in ArcGIS for generating maps for transport capacity. Using transport capacity maps, gross soil erosion was routed to the catchment outlet using hydrological drainage paths resulting in generation of transport capacity limited sediment outflow maps. Such maps give amount of sediment flowing from a particular grid in spatial domain. The pixel value of the outlet grid of transport limited sediment outflow maps thus computed give sediment coming out of the watershed. Comparison of observed and computed value of sediment yield revealed that the % error between observed and computed value of sediment yield range from -40% (over estimation) to +41% (under estimation). Larger errors in a few years are ascribed to uncertainties in the data. Nevertheless the accuracy obtained is considered satisfactory because even the more elaborate process-based soil erosion models are found to produce results with still larger errors (ASCE, 1975; Foster, 1982; Hadley *et al.*, 1985; Wu *et al.*, 1993; Wicks and Bathurst, 1996).

Further using the methodology presented, maps for deposition of sediment were also obtained. Such maps are helpful in identifying areas vulnerable to silt deposition in the catchment. Analysis of maps reveals that deposition of sediment resulted at grids where transport capacity was low, mostly by the sides of some of the stream reaches.

Superimposition of sediment deposition map over gross erosion map resulted in identification of areas vulnerable to soil erosion and deposition. Such maps are extremely important in planning conservation measures.

The method has the potential to assess impact of different land use scenarios and soil conservation measures on resulting sediment outflow scenario from the catchment. Therefore the present method is a useful tool in integrated environmental watershed management.

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SYMBOLS AND ABBREVIATIONS USED

.img	Image File
.shp	Shape File
AOI	Area of Interest
ANSWERS	Arial Non-Point Source Watershed Environment Response Simulation
C	Cover and Management Factor
cm	centimeter
CSWCRTI	Central Soil and Water Conservation Research and Training Institute
CREAMS	Chemical Runoff and Erosion from Agricultural Management Systems
DBMS	DataBase Management System
DEM	Digital Elevation Model
E	East
EMS	Electro-Magnetic Spectrum
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental System Research Institute
EUROSEM	European Soil Erosion Model
FID	Field Identification
GCP	Ground Control Point
GIS	Geographical Information System
ha	hectare
ha-m	hectare-meter
hr	hour
INFO	Information
IRS	Indian Remote Sensing Satellite
K	Soil Erodibility Factor
Km	Kilo meter
Km^2	Square Kilo meter
L	Slope Length Factor
LISS	Linear Imaging Self Scanner Sensor
Lit	Litre

LS	Topographic Factor
m	meter
mm	millimeter
m^2	Square meter
Max	Maximum
MJ	Mega Joule
Min	Minimum
MMF	Morgan Morgan and Finney
MUSLE	Modified Universal Soil Loss Equation
N	North
P	Erosion Control Practice Factor
R	Rainfall Erosivity Factor
RDBMS	Relational DataBase Management System
RF	Rain Fall
RMSE	Root Mean Square Error
RUSLE	Revised Universal Soil Loss Equation
S	Slope Steepness Factor
SDR	Sediment Delivery Ratio
SLEMSA	Soil Loss Estimator for Southern Africa
SOI	Survey of India
SRTM	Shuttle Radar Topography Mission
SY	Sediment Yield
t	ton
TIFF	Tagged Image File Format
TauDEM	Terrain Analysis Using Digital Elevation Model
TIN	Triangulated Irregular Network
TM	Thematic Mapper
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator
WERM	Watershed Erosion Response Model
WEPP	Water Erosion Prediction Project

1

INTRODUCTION

1.1. Outline

Over the last decade a widely stated objective in land resource management has been the adoption of strategies to ensure the sustainable use of land. The aims of any policy dealing with sustainable use of soils are to maintain soil quality, properties, processes and diversity. At the same time soil erosion continues to degrade the global land resource base with approximately 30 per cent of the present cultivated area having been substantially affected. According to National Commission on Agriculture (Anonymous 1976) 175 million hectares are degraded all over the world. The current rate of annual top soil loss in the world due to water and wind erosion ranging from 20 to 100 tones per ha. This is 16 to 100 times greater than the natural accumulation range, which is estimated at about one centimeter of topsoil formation in 200 years under normal Agricultural practices. Soil erosion rates have increased to such an extent that the material delivery from rivers to the oceans has increased to such an extent that the material delivery from rivers to the oceans has increased from just 8 billion tons to over 23 billion tons a year, the largest discharge of over 10 billion tones per year coming from Asian rivers alone. If the present trend in the erosion of fertile topsoil of over 23 billion tones per year continues, it will result in the loss of 30 per cent of global soil inventory by 2050.

In recent analysis of annual soil erosion rates in India, it was estimated that about 5334 million tones (1653 tones / ha) of soil is detached annually due to agriculture and associate activities alone. The country's rivers carry about 2052 million tones (626 tones / ha) of this, nearly 1572 million tones are carried away by the rivers into the sea every year and 480 million tones are being deposited in various reservoirs, resulting in the loss of 1 to 2 % of the storage capacity (Anonymous, 1976). Optimal use of soil and land resources to meet the needs of fast growing population is a fundamental issue and promising challenge for the national development.

1.2. Soil Erosion and Sediment Yield

The process of soil erosion involves the processes of detachment, transportation & accumulation of soil from land surface due to either impact of raindrop, splash due to rain impact, shearing force of flowing water, wind, sea waves or moving ice. Erosion due to water is an area of interest to hydrologists and sedimentologists. Various forms of soil erosion due to water are interrill, rill, gully & stream channel erosion. Rain drop plus sheet erosion jointly causes interrill erosion. Concentrated flow causes rill erosion. Gully erosion is an advanced stage of rill on account of head cutting at the gully head. Apart from rainfall and runoff, the rate of soil erosion from the area is also strongly dependent upon its soil, vegetation & topographic characteristics. During the process of erosion and transportation to downstream side, some part of the eroded material may get opportunity to deposit. The net amount of sediment flowing through the watershed is termed as sediment yield.

Deposition of sediment transported by a river into a reservoir reduces the reservoir capacity, thereby adversely affecting the water availability for power generation, irrigation, domestic & industrial use. Sediment deposition on river bed & banks causes widening of flood plains during floods. Control of upland erosion does not always reduce the sediment yield immediately, because of the increased erosivity of channel flow in the downstream. Soil erosion is a serious problem in Lesser Himalayas and foothill ecosystem. Sustainable use of mountains depends upon conservation and potential use of soil and water resources. High population growth has placed a demand on limited natural resources present in the hills. High rainfall coupled with fragile rocks, and high relief conditions in Himalayas are conducive to soil erosion. It is a prime threat to sustained land use for crop production in Himalayan ecosystem. Rapid increase in the developmental activities, mining and deforestation etc. are major factors contributing to soil erosion and thus leading to land degradation.

Empirical models such as Universal soil Loss Equation (USLE) (Wischmeier and Smith, 1965), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991b) and Soil Loss Estimator for Southern Africa (SLEMSA) (Elwell, 1978) as well as physical process based models such as Water Erosion Prediction Project (WEPP) (Nearing et al., 1989), Morgan, Morgan and Finney model (Morgan et al., 1984) and many others are employed for quantitative assessment of soil loss. The soil loss estimation applying these models indicates the severity of soil erosion under the present land use practices. It aims to identify lands under various kinds of erosion state that serves the basis for planning soil conservation work as well as land use planning. The formulation of proper watershed management programme for sustainable development requires an inventory of the quantitative soil loss erosion and the priority classification of watershed. A watershed with a higher rate of erosion needs to be given higher priority for soil conservation measures to be adopted. Sediment yield from a catchment is one of the main criteria for assessing the vulnerability of a watershed to soil erosion. However, this criterion requires continuous monitoring of sediment samples at the catchment outlet. Such data are hardly available in India and Nepal for small watersheds. Although the sediment yield from large catchment can be obtained from such observations, it is not possible to ascertain the vulnerability to soil erosion of small watersheds within a basin. A soil conservation programme is an expensive and cumbersome process, carried out in steps starting from the most vulnerable (highest sediment producing) region. Therefore, there is a need to assign relative priorities to different regions within a catchment. Development of effective erosion control plans requires the identification of areas vulnerable to soil erosion and quantification of the amounts of soil erosion from various areas. The empirically based USLE and newly revised RUSLE have been used in many countries since the late 1960s for estimation of soil erosion (Wischmeier and Smith, 1978). It is designed to estimate the long-term average annual soil loss for fields with specified cropping and management systems as well as rangeland (Renard et al., 1997).

The RUSLE estimates annual soil loss per unit area from rill and interill erosion caused by rainfall splash and overland flow, but not from gully and channel erosion. The RUSLE does not consider the runoff process explicitly, nor soil detachment, transport, and deposition individually (Renard et al., 1994). RUSLE is a field scale model, thus it cannot be directly used to estimate the amount of sediment reaching downstream areas because some portion of the eroded soil may be deposited while traveling to the watershed outlet, or the downstream point of interest. Williams and Berndt, 1977 modified the USLE to estimate sediment yield from single storm event. The modified model is referred to as Modified Universal Soil Loss Equation (MUSLE).

1.3. Background of the Study

A watershed is a land area which drains into a stream system, upstream from its mouth or other designated point of interest. Surface characteristic, soil depth, geological structures, topography and climate of the watershed play an interrelated role in the behavior of water, which flows over or through it. Watersheds are subjected to many types of modifications by human and natural activities. Erosion is a natural geomorphic process occurring continually over the earth's surface. The processes of erosion of soil from earth surface if largely depend on topography, vegetation, soil and climatic variables. These areas found to have pronounced spatial variability in a catchment due to the spatial variation of climatic factors and catchment heterogeneity. This is one of the reasons given for promoting the use of distributed information of catchment resources using a GIS. By using a GIS the catchment is discretized into sub-areas having approximately homogeneous characteristics and rainfall distribution. The technique of Geographical Information System (GIS) is well suited for quantification of heterogeneity in the topographic and drainage features of a catchment (Shamsi, 1996; Rodda *et al.*, 1999). The remote sensing and GIS techniques have been used for sediment and erosion ? medaling across the globe. The model simulates the dynamics of event runoff, soil detachment and transport processes. Jain and Kothyari (2000) demonstrated the utility of GIS and satellite data in identification of source areas and prediction of storm sediment yield from catchments. The concept of sediment delivery ratio with USLE was used in the study for Karso and Nagwa watersheds in Jharkhand. With the same watersheds and concept of sediment delivery ratio, Kothyari et al., (2002) estimated the temporal variation in sediment yield. Jain and Goel (2002) used these techniques for the assessment of vulnerability of 16 watersheds in the Western India to the soil erosion. The study was reported for catchment of Ukai dam in Gujarat. Keeping above in view, this study envisage estimation of soil erosion and sediment yield utilizing remotely sensed data and GIS using simple empirical models.

1.4. Objective of the Study

The aim and objective of the present study are as follows.

- To assess annual rate of soil erosion from a catchment using distributed information for topography, land use, soil etc using a GIS.

- To compute the transport capacity of discretized locations and route the transport limited sediment outflow from each of the discretized cells to the catchment outlet.
- To compare the simulated sediment yield with the observed sediment yield.
- To generate maps for sediment outflow from discretized cells.
- To analyze the rate of soil erosion/deposition maps and thus identification of areas vulnerable to soil erosion.

1.5. Scope of the Work

- To calculate Rainfall Erosivity factor, R from meteorological data
- To calculate Observed Sediment Yield from meteorological data
- To generate Digital Elevation Model (DEM) for the Watershed Study Area
- To generate Slope, Flow accumulation , Flow direction, and Watershed Network
- To generate Topographic factor LS Map
- To generate Land Use Map of study area using digital analysis of satellite data
- To create Soil Map and its characteristics Database from Satellite data in GIS Environment using ERDAS
- To generate Cover Management factor C Map
- To generate Support Practice factor P Map
- To generate Soil Erodibility factor K Map
- To generate map for sediment transport capacity
- To generate maps for transport limited soil accumulation by routing sediment outflow from each of the discretized cells using GIS
- To generate soil erosion/deposition maps for identification of vulnerable areas.

2

REVIEW OF LITERATURE

Review of literature reveals that there are slew of models available for estimation of soil erosion and sediment yield from watersheds. Most of these models can be grouped in to two broad categories. Models those based on empirical equations generally derived based on analysis of field data are commonly termed as empirical models. Simple methods such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975) or Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1991b), are quite frequently used empirical models for estimation of soil erosion from watersheds (Ferro and Minacapilli 1995; Ferro 1997; Kothyari and Jain, 1997; Ferro *et al.*, 1998; Stefano *et al.*, 1999, Jain and Kothyari, 2000, Kothyari et al., 2002).

The other category of models which use theoretical description of processes involved in the form of mathematical equations are termed as physically based models. These models are intended to represent the essential mechanisms controlling erosion and they incorporate the laws of conservation of mass and energy. Most of them use particular differential equations and generally require more input parameters than empirical models. Numbers of the physical based models are developed in recent past. Examples of physically based models available in literature for estimation of soil erosion are WEPP (Water Erosion Prediction Project, USA) (Nearing et al., 1989), EUROSEM (European Soil Erosion Model), SHESED (Wicks and Bathurst, 1996) and others. The power of physically based models is that they represent a synthesis of the individual components which affect erosion, including the complex interactions between various factors and temporal variability. The result is synergistic, the model as whole represents more than the sum of the individual pieces. The use of physically based models is limited for research use due to their complexity and non-availability of data required to use them. Therefore empirical models are more commonly in use for field evaluation and modellling for data scarce regions. The main aim of this work is to use a empirical model in distributed sense, therefore the review of literature is limited to empirical models only.

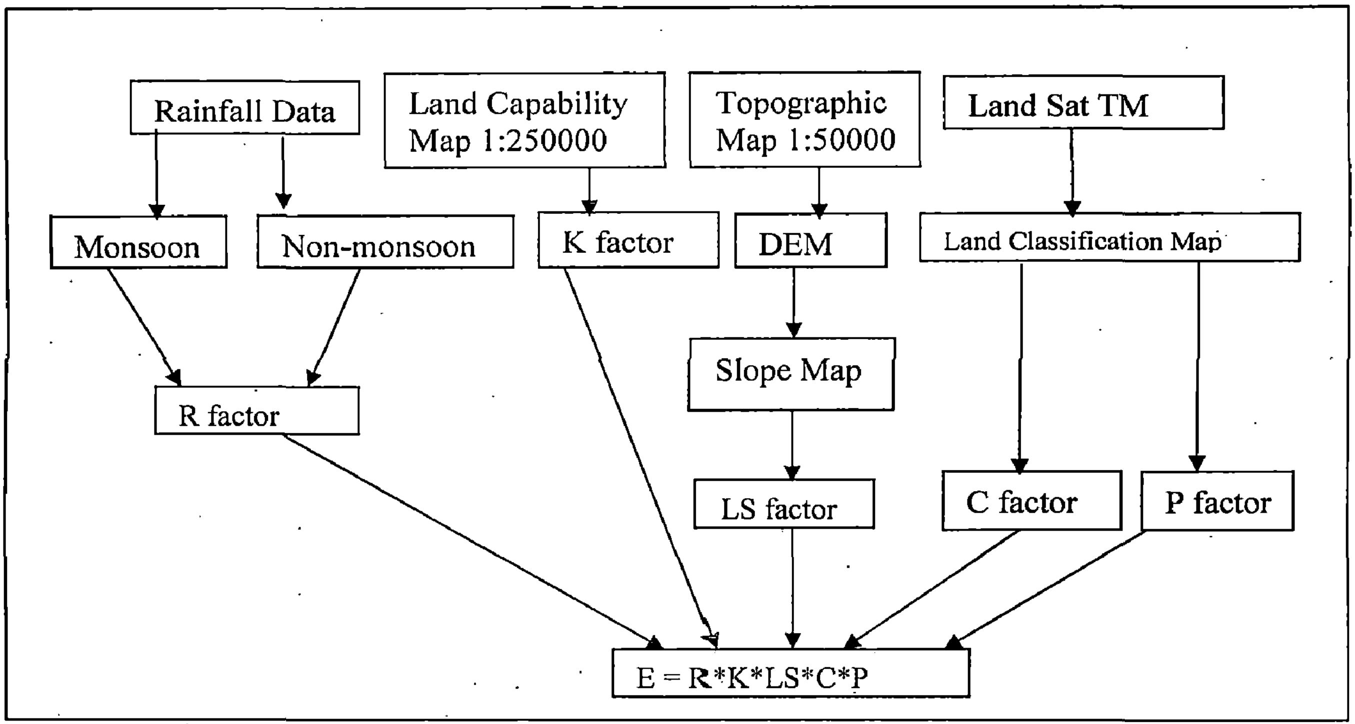
2.1 Empirical Sediment Yield Models

These are based on inductive logic and generally applicable only to those conditions for which the parameters have been calibrated.

USLE: Soil erosion is most frequently assessed by using Universal Soil Loss Equation (USLE) since early 60's. The equation was designed for interrill and rill erosion (Wischmeier and Smith 1978, Renard et al., 1991). Although the equation is described as universal, its database, though extensive, is restricted to slopes normally 0 to 17°, and to soils with a low content of montmorrilonite, it is also deficient in information on erodibility of sandy soils. In addition to the limitation of its database there are theoretical problems with the equation. Soil erosion cannot be adequately described merely by multiplying together six factor values ($E = R*K*LS*C*P$). There is considerable interdependence between variables (Morgan, 1995).

MUSLE: is one of the modified versions of the USLE. In MUSLE (Williams. 1975), the rainfall erosivity factor was replaced with runoff. The runoff factor includes both total storm runoff volume and peak runoff rate. Compared to USLE, this model is applicable to individual storms, and eliminates the need for sediment delivery ratios, because the runoff factor represents energy used in detaching and transporting sediment. The main limitation is that it does not provide information on time distribution of sediment yield during a runoff event.

RUSLE: is a revised version of USLE, intended to provide more accurate estimates of erosion (Renard et al., 1997). It contains the same factors as USLE, but all equations used to obtain factor values have been revised. It updates the content and incorporates new material that has been available informally or from scattered research reports and professional journals. The major revisions occur in the cover management factor, C, support practice factor, P, and slope length gradient factor, LS, factors. The C is now the product of four sub factors: prior land use, canopy cover, soil surface cover and surface roughness. A flowchart depicting process of using USLE based equations with GIS is shown in Fig. 2.1 as illustration.



FLOW CHART 2.1 Analysis of flow of USLE model using GIS

RUSLE is a computation method which may be used for site evaluation and planning purposes and to aid in the decision process of selecting erosion control measures. It provides an estimate of the severity of erosion. It will also provide quantifiable results to substantiate the benefits of planned erosion control measures, such as the advantage of adding a diversion ditch or mulch. For example, a diversion may shorten the length of slope used in calculating a LS factor. Also, the application of mulch will break raindrop impact and reduce runoff. The Revised Universal Soil Loss Equation (RUSLE) equation is as A = RK (LS) for bare ground conditions of graded areas of construction sites. The benefit of mulch can be predicted by multiplying the above by an appropriate cover or C-value. The benefit of a diversion ditch can be illustrated by comparing the original LS with the shorter slope length LS created when adding this practice:

$$E = R * K * LS * C * P \qquad (2.1)$$

Where, E is the computed soil loss in units of tons per hectare per year. R and K are same as in USLE. If the slope is concave, the LS factor will be slightly lower. If convex, then the LS will be slightly higher. C is the factor to reflect the planned cover over the soil surface. On construction sites where mulch or fabrics are used, the benefit derived from intercepting the erosive raindrop impact on the soil surface is calculated. Therefore, mulching can substantially reduce the predicted soil loss. P is the factor that represents management operations and support practices on a construction site.

MMF Model (Morgan et al., 1984): is another empirical model for predicting annual soil loss from field-sized area on hill slopes. The model separates the soil erosion process into two phases i.e. the water phases and the sediment phase. In the water phase annual rainfall is used to determine the energy of the rainfall for splash detachment and the volume of runoff, assuming that runoff occur whenever the daily rainfall exceeds a critical value representing moisture storage capacity of the soil-crop complex and that the daily rainfall amounts approximate an exponential frequency distribution. In the sediment phase, splash detachment is modeled using a power relationship with rainfall energy modified to allow for the rainfall interception effect of the crop. The model has been revised with new changes incorporated owing to the rise in data availability and difficulties in estimating certain parameters as in the original version. In the revised version, changes have been made to the way soil particle detachment by raindrop impact is simulated, which now takes account of plant canopy height and leaf drainage, and a component has been added for soil particle detachment by flow SLEMSA (Elwell, 1978): The Soil Loss Estimator for Southern Africa (SLEMSA) was developed largely from data from the Zimbabwe to evaluate the erosion resulting from different farming systems so that appropriate conservation measures could be recommended. Generally, the model looks like USLE and it has the same limitations as USLE. Empirical Models possess severe limitations. They cannot be universally applied. They are not able to simulate the movement of water and sediment over the land and they cannot be used on scales ranging from individual fields to small catchments.

2.2 REVIEW OF USLE' APPLICATIONS USING GIS

2.2.1. Gediz River Basin, Turkey

Fistikoglu & Harmancioglu (2002) used a GIS with USLE for Assessment of Soil Erosion for a small region (23 km^2) in the Gediz River Basin along the Aegean western coast of Turkey. The main focus of the study was to integrate a GIS with the USLE model for identification of rainfall based erosion and the transport of non point source pollution loads to the Gediz River, which discharges into the Aegean Sea along the western coast of Turkey. The study identified the gross erosion, sediment loads, and organic N loads within a small region of the

Gediz River basin. The results of the study have shown that GIS permits more effective and accurate applications of the USLE model for small watersheds provided that sufficient spatial data are available.

2.2.2. Island of Ishigaki in Okinawa Prefecture, Japan

Paringitand & Nadaoka (2003) studied Sediment yield modeling for small agricultural catchments: This paper discusses the application of remote sensing technique in the retrieval of vegetation and soil parameters necessary for the distributed soil loss modeling in small agricultural catchments and analyses the variation in erosional patterns and sediment distribution during rainfall events using numerical solutions of overland flow simulations and sediment equations, a method is proposed to account for the variability of associated vegetation cover based on their spectral characteristics as captured by remotely sensed data. This study lends a theoretical support and empirical evidence to the role of vegetation as a potential agent for soil erosion control.

2.2.3. Mkomazi River Catchment

Flugel et al (2003) used the catchment for the study on Integrating geographical information systems, remote sensing, ground truth and modeling approaches for regional erosion classification of semi-arid catchments in South Africa (KwaZulu /Natal; South Africa). With respect to water quality problems, the understanding of the dynamics of integrated soil erosion processes in river basins is of crucial importance. This study is on the delineation of response unit in the catchment. It was carried out within the framework of an interdisciplinary project aimed at developing and integrated water resources management system for water resources analysis in the catchment. Particular attention was focused on the identification of sediment source areas. For this purpose response unit concept was applied to delineate erosion. Spatially distributed input data from the catchment were derived by remote sensing technique and geographical information systems analysis. Taking into account the high amount of sediments produced by gully erosion, not considered in USLE type models, Special attention was focused to gully erosion, a dynamic gully erosion model.

2.2.4. Banha Watershed in Upper Damodar Valley (UDV)

Sarangi & Bhattacharya (2000) used the watershed for the study on use of Geomorphologic Parameters for sediment yield Prediction from watershed. The watershed parameters which represent its morphology were grouped under four deferent categories. They are steepness component, shape component, drainage component, and geological component. In that study, judiciously selected representative parameter from each group was mathematically associated with runoff rate to develop a multiple regression equation for sediment yield prediction. The sediment yield model thus developed was validated .The silt flow rate was expressed as a function of runoff rate, relative relief, form factor and drainage factor. Its performance was found satisfactory based on appropriate statistical test as mentioned above. Therefore it can be concluded that the representative of geomorphologic parameters under different groups can be associated with runoff rate to predict the sediment concentration in the outflow from a watershed under study.

2.2.5. Sub-Watershed Sitlarao in Doon Valley

Jain et al (2001) used the watershed for the study on Estimation of Soil Erosion for a Himalayan Watershed Using GIS Technique. The sub-watershed belongs to Asan River System, which is a tributary of Yamuna River. The area covers about 52 km^2. The fragile ecosystem of the Himalayas has been an increasing cause of concern to environmentalists and water resources planners. The steep slopes in the Himalayan along with depleted forest cover, as well as high seismicity have been major factors in soil erosion and sedimentation in river reaches. Prediction of soil erosion is a necessity if adequate provision is to be made in the design of conservation structures to offset the ill effects of sedimentation during their lifetime. In the study soil erosion has been carried out using two different models, namely Morgan, Morgan and *Finney and Model USLE (Wischmeir & Smith, 1978)* in GIS environment. GIS platform provides a faster and better method for spatial modeling and gives output maps that can be understood better. The MMF separates the soil erosion process into a water phase and a sediment phase. In the sediment phase, soil erosion is considered due to detachment of soil particles from the soil mass by raindrop impact (splash detachment) and transport of those particles by overland flow. Results from both erosion models vary for some of the land use / soil units. The study showed that forested areas show less soil loss compared to unprotected areas like fallow lands, which contribute to high soil loss.

2.2.6. Tons Watershed in Asan Catchment

Kumar and Sharma (2005) used the watershed for the study on Soil erosion risk assessment based on MMF model using remote sensing and GIS. Soil erosion is a serious problem in lesser Himalayas and foothill ecosystem. High rainfall coupled with fragile rocks, and high relief prevalent in Himalayas is conducive to soil erosion. MMF model has been used to assess average annual soil loss in the study for soil erosion risk assessment. The loss was found highest from the area under open scrub and lowest from that under dense forest cover. The study indicated that nearly 40 per cent of watershed is subjected to severe erosion risk. The assessment of soil erosion is of great significance for land use planning and watershed management in hilly region. Remote sensing and GIS application helped to identify the spatial patterns of soil loss present in the watershed. The study revealed that highest soil loss is from open scrub and lowest from dense forest cover.

2.2.7. Ukai Catchment

Jain & Goel (2002) used the catchment for the study on assessing the vulnerability to soil erosion of the Ukai Dam catchments using remote sensing and GIS. The investigation of basins for planning soil conservation requires a selective approach to identify smaller hydrological units, which would be suitable for more efficient and targeted conservation management programme. It is pointed out that in India sediment yield data are generally not collected for smaller catchments and it becomes difficult to identify the most vulnerable areas for erosion that can be treated on a priority basis. An index based approach, based on the surface factors mainly responsible for soil erosion, is suggested in this study. These factors are soil type, vegetation, slope and various catchment properties such as drainage density, Form factor, etc. Satellite data are used to evaluate the topography and morphology related indices. The integrated effect of all the parameters is evaluated to find different areas vulnerable to soil erosion.

2.2.8. Birantiya Kalan Watershed

Chakraborty et al (2004) used the watershed for the study on Satellite Remote Sensing Application in Assessing Soil Erosion of a Watershed. The IRS data of LISS-II sensor for two year Rabi season, 1988 and 1996 were used for the study. The USLE was applied with ARC / INFO-GIS to predict the soil erosion status of the watershed. The crop factor in the USLE was derived from satellite data. Though the erosion potential was found to be below the permissible limit for both the years, it was higher in 1996. The grid based surface modeling for soil erosion with satellite remote sensing data as major input was found to be rational and realistic in predicting and monitoring of runoff and soil erosion of this remotely located watershed, where it is difficult to get actual field observations. The study showed that there has been non-perceptible improvement in the land use and vegetation status. Also there has been an increase in soil erosion in the post-treatment (1996) relative to pre-treatment (1988) periods notwithstanding the adoption of various soil and water conservation measures.

2.2.9. Nagwa and Karso Catchments in Bihar (India)

Jain & Kothyari (2000) used the catchment for the study on Estimation of soil erosion and sediment yield using GIS. The catchment area for Nagwa and Karso are 70 and 28 km^2 respectively. The soils were classified into three categories viz. clay loam, very fine sandy loam and sandy loam. The objective of this paper study were to use GIS for the discretization of the catchments into small grid cells and for the computation of such physical characteristics of these cells as slope, land use and soil type, all of which affect the processes of soil erosion and accumulation of soil in the different sub-areas of a catchment. GIS methods were used to partition the sub-areas into overland and channel types, to estimate the soil erosion in grid cells and to determine the catchment sediment yield by using the concept of sediment delivery ratio. The USLE has been employed to produce realistic estimates of surface erosion over areas of small size (Wischmeier & Smith, 1978). The values for the factors K, C and P were estimated for different grids in overland and channel regions as per Wischmeier & Smith (1978) using the classified satellite data for land cover and soil. The gross amount of soil erosion for each cell during a storm event was generated by multiplying the term KLSCP with the R factor for the corresponding storm event .The eroded sediment was routed from each cell to the catchment outlet using the concept of sediment delivery ratio.

2.2.10. Lawyers Creek Watershed

Fernandez (2001) used the watershed for the study on Predicting Erosion and Sediment Yield using GIS. Because of increasing concerns on water quality and aquatic habitat, the need to quantify, and predict sediment yield at a watershed level has become important. Models for sediment yield provide invaluable information when applied to those areas lacking of data, for guiding data collection programs, and for predicting future impacts of agricultural activities, land-use, stream stabilization, and flood control practices. The aim of study was to develop a methodology using Geographic Information System (GIS) and computer modeling to estimate the spatial distribution of soil erosion and sediment yield in the Lawyers Creek Watershed. Soil loss erosion and the sediment yield for the Lawyers Creek Watershed were estimated based on the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.*, 1997).The use of GIS facilitated data manipulation and output display and allowed the erosion and sediment yields models to be applied for individual cells. The watershed was discretized into homogenous grid cell units. RUSLE was applied to assess long-term mean annual soil erosion. Different scenarios were proposed to analyze the effect of cropping and management practices on average annual soil . The agricultural lands in the Lawyers Creek Watershed presented greater erosion rates while the forestlands had lower values. A reduction in soil erosion up to 25 % resulted when a combination of control practices were included. Sediment yield obtained in the main channel reflected the erosion severity in the watershed.

2.2.11. Goodwin Creek Basin

Molnar & Julien (1998) used the basin for the study on Estimation of Upland Erosion using GIS, Computers & Geo Sciences. The extent of sheet and rill erosion is controlled by factors such as climate, topography, soil type, and land use. Erosion rates in upland areas depend on erosive forces from raindrop impact and runoff, and on soil resistance to detachment and transport. Numerous physical processes are involved in the detachment of soil and its subsequent transport down slope, and this complexity makes it difficult to evaluate upland erosion factor R indirectly accounts for variations in rainfall intensity duration-frequency, specific to different geographic locations. The Goodwin Creek watershed in Mississippi was used in the analysis because it has been extensively monitored by the United States Department of Agriculture. GRASS is a tool that can be used in aggregating GIS data and in performing calculations on raster values of individual cells. The original GIS raster maps were used in establishing the required parameters were: (1) a digital elevation map (DEM) generated by the United States Geological Survey; (2) a soil map generated by the Soil Conservation Service; and (3) a land use map developed by the Agricultural Research Service in Oxford, Mississippi. The average annual value of the rainfall erosivity factor, R, was estimated from an iso-erodent map of R factors for the United States (Wischmeier and Smith, 1965). The usefulness of GIS for the analysis of physical processes in large watersheds is demonstrated in this study of upland erosion. Large databases describing watershed characteristics were analyzed for Goodwin Creek (21.6 km^2). It is determined that the effect of grid resolution on the slope steepness factor, S, plays a major role. As grid size increases, slope values for individual cells decrease, which ultimately leads to an underestimation of soil loss.

3

STUDY AREA AND DATA USED

3.1. General

The Chaukhutia watershed located in Almora and Chamoli districts of the State of Uttarakhand has been selected for the present study. This watershed is the most upstream sub-watershed of Ramganga reservoir catchment. Ramganga River is a tributary of Holy River Ganges. It originates from sub Himalayan region in the district of Chamoli. After traveling a course of about 425 km., the river RamGanga gets merged in the Ganges near Fatehpur in the State of Uttar Pradesh. In order to harness the potentialities of RamGanga River, the Government of Uttar Pradesh constructed a dam across it at Kalagarh in the district of Pauri Garhwal in Uttara Khand at a site which is about 3km. upstream from the place where this river enters in the plains. The RamGanga river catchment, upstream to Kalagarh dam, comprises of an area of about 3,134Sq. Km. The sub Himalayan region where the RamGanga dam is situated is known by the name of Shiwalik ranges. Index map of the study watershed is shown in Fig. 3.1.

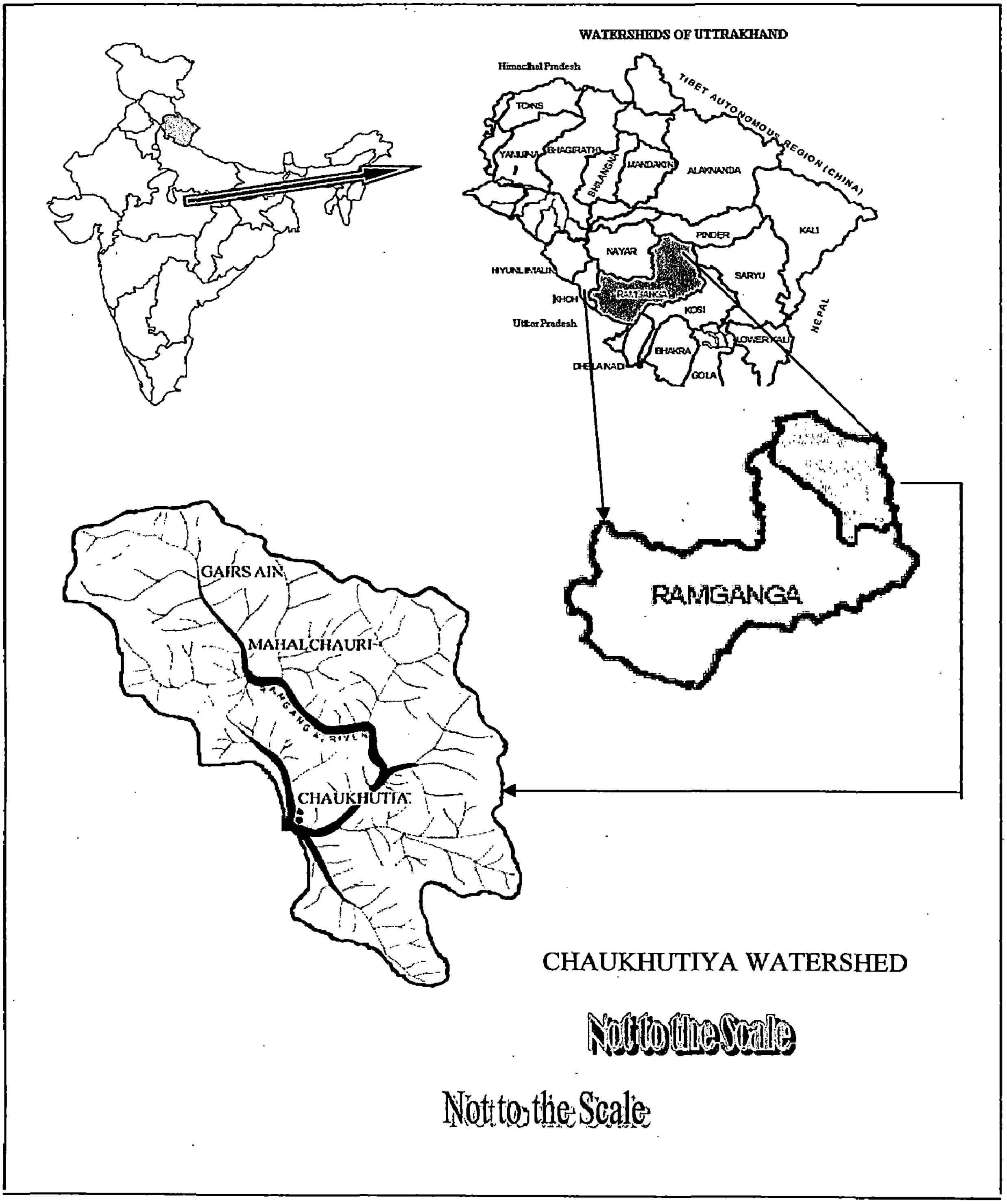


Fig. 3.1 Layout Map of Chaukhutiya Catchment

3.2 Geographic Location

Chaukhutia watershed is upper catchment of RamGanga River comprising of an area of **572 Sq. Km**. Geographically the entire boundary of Chaukhutia watershed is situated between latitudes of **29^{0}46'35" to 30^{0}06'11"** North and longitudes of **79^{0}11'23" to 79^{0}31'21"**East. The area is covered in Survey of India, Toposheet no, **53N4, 53N8, 53O1, 53O5** and **53O9,** all available in the scale of 1:50,000. Small townships of Chaukhutia and Dwarhat are situated in Chaukhutia watershed and these townships come under Almora district. Other small townships situated in Chaukhutia watershed are Gairsen and Mehalchauri which comes under Chamoli district.

3.3 Climate

The Chaukhutia watershed lies in Sub Himalayan zone of Western Himalaya. The variation in altitude influences the climate of the watershed. The climate of this watershed varies from sub-tropical in the lower region to sub-temperate and temperate in upper region with a mean annual temperature of 24.5^{0}C and a mean minimum temperature of 17.3^{0}C. Most of the rainfalls are received during July and August. Winter rainfall occurs during the month of December to February.

3.4 Geology

Chaukhutia watershed consists of crystalline and sedimentary rocks of calcareous zone. Crystalline occurs as vast sequence of low to medium grade metamorphic associated with coarse to medium grained granites. A thin zone of porphyritic rocks exposed along the

Almora fault is known as Chaukhutia Quartz Porphyry. These rocks are highly crushed and fine grained with porphyro-blasts of quartz and feldspar, and also show development of schistose structure. Sedimentary rocks of Calc zone is found north of Dwarahat around Dhunagiri hill and RamGanga valley near Mehalchauri. South of Mehalchauri north-east trending open faults of large wavelength are superimposed by the tight isoclinical folds trending north-west. A series of gently plunging open folds of 27.432 m to 36.576 m wavelength are exposed in the RamGanga valley south-east of Mehalchauri. Tightness of folds increases in upper level and assumes a recumbent to overturned posture towards Chaukhutia. Regional trend of folds is from north to north-west which are reoriented and refolded near the contact with Almora crystalline.

3.5. Topography

The Chaukhutia watershed is hilly catchment of the river RamGanga. The maximum and minimum elevations within this watershed are **3098.95 m** and 939.05m above mean sea level respectively. The outlet is situated at an elevation of **939.053 m** in south-western boundary of the watershed as shown in location/index maps. This watershed consists mostly of rolling and undulating topography having very steep irregular slopes.

3.6. Land Resources

In terms of land resources, the Chaukhutia watershed is covered with Forest, Pasture, Agriculture, Settlement, Fallow/Rocky/Waste lands, River and Road.

3.6.1. Forest Land

Forest land of Chaukhutia watershed is dominated by dense mixed jungle mainly having Pine and Banj. Chir, pine (Pinus Roxburghii) and broad-leaved Banj (Quercus Leuchotrichophora) are the major forest species. Most of the forest areas are under Reserve Forest. The forest cover of Chaukhutia watershed is about 49% of the total area of this watershed. Forest area of this watershed is under the jurisdiction of Divisional Forest Office (Soil Conservation), Ranikhet, Almora, Uttara Khand.

3.6.2. Pasture Land

The Chaukhutia watershed consists of pasture land having an area of about 16.00% of the total area of this watershed.

3.6.3. Agriculture Land

Agriculture land in this watershed consists of hill-slope cultivation, level terrace cultivation and valley cultivation. The percentage of agriculture land area is about 12.41% of the total area of this watershed.

3.6.4. Settlement

The area covered by urban and rural settlements in this watershed is about 8.19% of the total area of this watershed. Mostly settlement is along Ranikhet – Badrinath state highway which crosses the Chaukhutia watershed from its southern boundary to northern boundary. In addition to this the area of different types of road is about 2.98% of the total area of this watershed.

3.6.5. Other Land Types

Within the other land the area of water bodies is about 4.83% and the area of Fallow/Rocky/Waste land is about 6.57% of the total area of this watershed.

3.7. Soil Type

The soils in Chaukhutia watershed vary in texture, depth and slope. Soil map of the Chaukhutia watershed was available from National Bureau of Soil Survey and Land Use Planning, Govt. of India. The whole catchment of Chaukhutiya has been divided into seven map segmental units viz. 14, 13, 18, 36, 38, 45, and 48 and the texture of all soil map units are respectively classified as thermic fine loamy to loamy skeletal soils, thermic to coarse loamy soils, thermic skeletal to coarse loamy soils, thermic coarse to fine loamy soils, loamy skeletal to fine loamy soils, thermic coarse to fine loamy soils, and thermic sandy skeletal soil. The depth of top soil of catchment ranges from very shallow to deep soil. The erosion potential of topsoil varies slight to moderate to severe. The slope of general terrain varies from steep to very steep. The texture of topsoil surface of catchment varies from loamy to sandy. The drainage condition of the catchment is naturally excessively drained. The stoniness of catchment is mixed with general soil ranging from slight to strong.

Table 3.1 DETAILS OF SOIL SERIES OF CHAUKHUTIA WATERSHED

DETAILS OF SOIL SERIES OF CHAUKHUTIA WATERSHED								
SN	Map Unit	Texture	Depth	Erosion	Slope	Surface	Drainage	Stoniness
1	**14**	Thermic fine loamy to loamy skeletal soils	Moderately shallow	Moderate	Moderate	Loamy	Excessively drained	Slight
2	**23**	Thermic to coarse loamy soils	Shallow to moderately shallow	Severe to moderate	Steep	Loamy to sandy	Excessively drained	Strong to moderate
3	**28**	Thermic skeletal to coarse loamy soils	Moderately deep to moderate shallow	Moderate	Moderate steep to steep	Loamy	Excessively drained	
4	**36**	Thermic coarse to fine loamy soils	Moderately deep	Moderate to slight	Moderate steep	Loamy	Excessively drained	Strong to moderate
5	**38**	Thermic loamy skeletal to fine loamy soils	Moderately shallow deep to moderate deep	Moderate to slight	Steep to moderate steep	Loamy	Excessively drained	Strong to moderate
6	**45**	Thermic coarse to fine loamy soils	Moderately deep to deep	Moderate to slight	Moderate	Loamy	Well drained	
7	**48**	Thermic sandy skeletal soil	Very shallow	Very severe	Very steep	Sandy	Excessively drained	Strong

3.8. Tributaries

The length of RamGanga river course up to Chaukhutia outlet is about 37 km. There are two major streams those confluences at Chaukhutia. These are Kurhlar Gad which is about 14 km long and this stream flows from south-east direction of Chaukhutia and Khachyar Gadhera which is about 41 km. long and this stream flows from north direction of Chaukhutia. In addition to these two major streams, several other minor streams are present in the study catchment.

3.9. Rainfall

The significant portion of total precipitation in the form of rainfall in the watershed occurs mainly during the four months of the monsoon i. e. from June to September with a mean annual total precipitation of 1388.7 mm. In fact, the monsoon contributes about 74.2% of the total annual rainfall. Total annual rainfall varies from 967.9 mm (1981) to 1985.1 mm (1998). Mean monthly rainfall varies from 6.9 mm in the month of November to 344.3 mm in the month of July. The entire hydro-meteorological characteristics of the watershed are characterized by the high precipitation generating peak monsoon flows and low precipitation during the dry season resulting in low flows. These figures are based on the rainfall data at Chaukhutia which were collected from RamGanga Dam Division, Kalagarh (Pauri Garhwal) under *the Department of Irrigation, Government of Uttar. The mean monthly rainfall at* Chaukhutia watershed outlet-cum-rain gauge site and daily rainfall recorded are given in Appendix A.

3.10. Observed Sediment Yield

There is a stream gauge station for measuring runoff and sediment outflow from Ramganga River at Chaukhutia Site. Geographic location of this stream gauge station is having latitude of $29^0 53'10''$ and longitude of $79^0 20'40''$ and this is situated at an altitude of 939.05 m above mean sea level. Daily sediment data from January 1973 to December 1990 was collected from irrigation department, site office Kalagarh. The daily sediment yield data was aggregated to annual series and used in present investigation.

4

METHODOLOGY

Apart from rainfall and runoff, the rate of soil erosion from an area is also strongly dependent upon its soil, vegetation and topographic characteristics. In real situations, these characteristics are found to greatly vary within the various sub-areas of the catchment. Therefore, a catchment can be discretized into various smaller homogeneous units before making the computations for soil loss. The grid based discretization is found to be most reasonable procedure in both the process based models as well as in the other simple models (Beven, 1996; Jain and Kothyari 2000). Therefore, for present study, the grid based discretization procedure has been adopted. Grid size to be used for discretization should be small enough so that the grid encompasses a hydrologically homogeneous area.

The methods such as the Universal Soil Loss Equation (USLE) have been found to produce realistic estimates of surface erosion over small size areas (Wischmeier and Smith, 1978). Therefore, soil erosion within a grid (or cell) is estimated as per the USLE.

4.1 THE UNIVERSAL SOIL LOSS EQUATION

The Universal Soil Loss Equation is an empirical equation previously designed for the computation of average soil loss in agricultural fields in USA, but these days it has globally been accepted as most popular model for erosion prediction and conservation planning technology. The equation predicts the losses from sheet and rill erosion under specified conditions. It computes the soil loss for a given site, as product of six potential parameters, whose most likely values at particular location can be expressed numerically (Wischmeier and Smith 1978; Renard et al., 1991) as;

$$E = R * K * LS * C * P \qquad (4.1)$$

Where, E is computed soil loss per unit area, expressed in the (tone / ha / yr)

R is rainfall erosivity factor, (MJ*mm / ha*hr)

K is soil erodibility factor, (tone*ha*hr / ha*MJ*mm)

L is slope length factor, (dimensionless)

S is slope steepness factor, (dimensionless)

C is cover and management factor, (dimensionless)

P is support practice factor, (dimensionless)

4.1.1 Rainfall Erosivity Factor, R

Wischmeier and Smith (1958) after evaluation of correlations between soil erosion and a number of rainfall parameters, defined the R factor as the product of rainfall energy and maximum 30-min intensity divided by 100 for numerical convenience, known as the EI_{30} index. On an annual basis, the EI_{30} value is the sum of values over the storms in an individual year. Calculations of rainfall energy require an algorithm relating energy to some measurable parameter. Up to an intensity of 3 in / hr, rainfall energy increases with storm intensity as a result of the fact that the drop size and fall velocity increase with intensity. Above 3 in / hr, the drop size reaches its maximum size and energy remains constant. Wischmeier and Smith (1958) proposed that rainfall energy is related to intensity by

$$E_i = (200 + 87 \log_{10} I_i) P_i \qquad (4.2)$$

Where,

E_i = Kinetic energy of the i^{th} rain increment, J/m^2

I_i = Average intensity of rainfall intensity in the i^{th} increment, cm/hr

P_i = Depth of rainfall in the i^{th} increment, cm

$$R = \sum Erosion\ index = \sum_{i=1}^{n} \left(\frac{E_i I_{30}}{100} \right) \quad in \quad \frac{MJ - mm}{ha - hr} \tag{4.3}$$

$E = \sum E_i$ = Kinetic energy of rainfall, J/m^2

I_{30} = Maximum intensity of rainfall during a continuous period of 30 minutes, mm/hr

n = Number of rainstorms per year

R = Rainfall Erosivity Factor

Rambabu et al (1979) have developed rainfall intensity-duration-return period relationships for Indian conditions, which can be used with fair accuracy. The relationships are explained below, where T is the return period (20-25 yr) and t, the duration of rainfall.

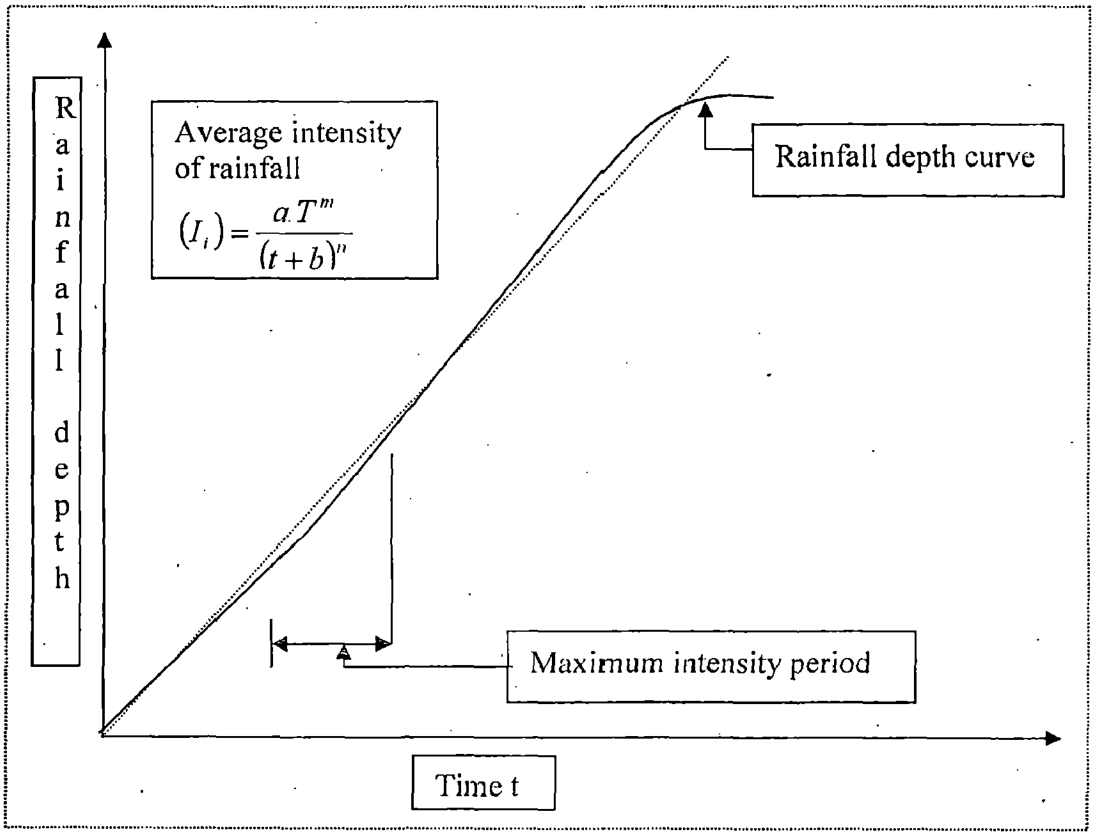


Fig. 4.1 Rainfall Intensity-Duration-Return Period Relationships for Indian Condition

Table 4.1: Data for intensity-Duration-Return Period Relationships for India

Zone	a	b	m	n
North	5.914	0.500	0.152	1.013
East	6.933	0.501	0.135	0.88
Centre	7.465	0.75	0.171	0.96
West	3.97	0.15	0.165	0.733
South	6.31	0.50	0.152	0.947

The selection of maximum intensity of rainfall for duration of 30 minutes by Wischmeier and Smith (1978) was based on extensive experimental results. Incidentally, this value has been found to be equally applicable to many parts of India, including Dehradun, by the Central Soil and Water Conservation Research and Training Institute, Dehradun (CSWCRTI). In some tropical and subtropical countries of Asia and Africa, it has been reported that the kinetic energies of individual storms, at intensities 25 mm/hr. are more appropriate for correlating the soil loss. By using this method, only the *EI* values are required to be considered and not the EI_{30} values.

4.1.2 Soil Erodibility Factor K

A number of studies of soil erodibility have been made with the USLE. In the USLE, K is assumed to be constant throughout the year. Tables of K values are available from local Soil Conservation Service Offices for most soils in the U.S. In the absence of published data, a widely used relationship for predicting erodibility is a nomograph by Wischmeier et al. (1971), which was developed from data collected on 55 mid-western agricultural soils. Soil erodibility in the nomograph is predicted as a function of five soil and soil profile parameters:

- Percentage silt (MS; 0.002-0.05 mm).
- Percentage very fine sand (VFS; 0.05-0.1 mm).
- Percentage sand (SA; 0.1-2 mm).
- Percentage organic matter (OM).
- Structure (S_1).
- Permeability (P_1).

It is important to note that the size ranges given here are not standard for some particle classifications. Codes for structure and permeability are given in USDA soil survey manuals (Soil Conservation Service, 1983) available for most countries in the U.S. and in some foreign countries. An analytical relationship for the nomograph by Wischmeier et al. (1971) is given by following regression equation.

$$K = \frac{2.1 * 10^{-4}(12 - OM)M^{1.14} + 3.25(S_1 - 2) + 2.5(P_1 - 3)}{100} \tag{4.4}$$

Where K is soil erodibility in tons per acre per unit rainfall index (tons. acre. hr/hundreds .acre. ft. tonsf. in), OM is the percentage organic matter, P_1 is the permeability index, S_1 is the structure index, and M is a function of the primary particle size fractions given by

M = (% MS + % VFS).(100 - % CL),

Where % CL is percentage clay (<0.002 mm) and other terms are defined as above.

The soil erodibility factor K (t*ha*hr / ha*MJ*mm) has been estimated using table values based on the soil textural information given by Haan (1994).

4.1.3 Length and Slope Factors, LS

For computation of LS factor, in a grid based descretized area as shown in Fig. 4.1, the minimm cell area of about 0.01 km^2 is required to have a representative estimate of LS factor for use in the USLE (Wischmeier and Smith, 1978; Panuska *et al.*, 1991). With this area the maximum permissible length is 141 meters.(Panuska *et al.*, 1991) However, cell size smaller than this are to be used for soil loss estimation using GIS. An equation was derived based on unit stream power theory by Moore and Burch (1986), Moore and Wilson (1992) for estimating the LS factor in cells smaller than the plots of Wischmeier and Smith (1978). The factor LS in present study is therefore computed for overland grids by using the stated equation of Moore and Wilson (1992) given as below

$$LS = \left[\frac{A_s}{22.13}\right]^n \cdot \left[\frac{\sin\beta}{0.0896}\right]^m \tag{4.5}$$

Where, A_s is the specific area ($=A/b$), defined as the up slope contributing area for overland grid (A) per unit width normal to flow direction (b); β is the slope gradient in degrees; $n = 0.4$; and $m = 1.3$. For channel grid areas, the value of A is considered to be equal to the value of the threshold area corresponding to the channel initiation. The use of Eq. (4.5) in the estimation of the LS-factor allows the introduction of the three-dimensional hydrological and topographic effect of converging and diverging terrain on soil erosion (Panuska *et al.*, 1991; Mendicino, 1997).

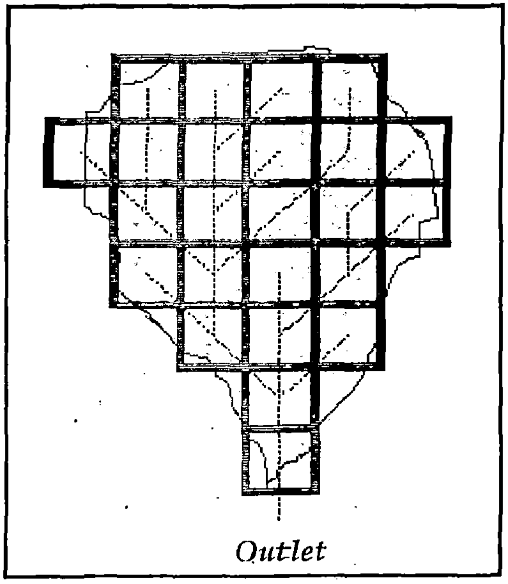


Fig. 4.2 Schematic showing discretized grid cells in a catchment

4.1.4. Cover and Management Factor, C

The cover and management factor is the ratio of soil loss from an area with specified cover and management to that of an identical area in tilled continuous fallow. Vegetative cover dissipates the impact force of raindrops on the soil surface, and protects the soil from splash erosion by modifying the value of volume, drop size, Coefficient of distribution, impact velocity and kinetic velocity of rainfall. The canopy cover is primarily responsible for effectiveness of the vegetative cover. The quality of the cover depends on the foliage characteristics, plant height and the area covered by the vegetation, whereas the leaf area index, height and density of the canopy, foliage characteristics, and the area covered by different species are affected by the type of vegetation. Splash erosion is caused not only by the direct impact of raindrops on the bare soil surface, but also by the through fall of raindrops from the canopy cover. A dense vegetative cover provides a high protective cover to the ground surface, but a higher height of the canopy , namely from pines, etc. imparts a high terminal velocity to drops of the through fall, which caused heavy soil erosion by splash on the soil surface. The crop cover-management factor C accounts for the effects of cover, crop sequence, and productivity level, length of growing season, tillage practices, residue management, and expected time distribution of erosive events. Based on experimental investigations, values for C factor have been tabulated for many cover conditions (ex. Haan, et al., 1994).

4.1.5. Support Practice Factor, P

The conservation practice factor, P, by definition is the ratio of soil loss from any conservation support practice to that with up and down slope tillage. It is used to evaluate the effects of contour tillage, strip cropping, terracing, subsurface drainage, and dry land farm surface roughening. A bare fallow land surface causes maximum soil erosion especially when it is cultivated up and down the slope or in other words, cultivated across the contours of the land surface. When a sloping land is put under cultivation, it needs to be protected by practices that will attenuate the runoff velocity, so that much less amounts of soil are carried away by the runoff water. P is always ≤ 1.0. In areas with more than one type of practice in use, a weighted value of P as per the area under each practice is considered and *P* is the *support practice factor-the ratio of soil loss with a support practice like contouring, strip-*cropping, or terracing and down the slope. Based on experimental investigations, values for P factor have been tabulated for many management conditions (ex. Haan, et al., 1994).

4.2 Sediment Transport and Outflow

Use of Eq. (4.1) produces the estimate of gross soil erosion in each of the discretized grids of the catchment. Gross amount of soil erosion for each grid area during a year can be generated by multiplying the term *KLSCP* with the *R*-factor for the corresponding year. The eroded sediment from each grid follows a defined drainage path – as shown in Fig. 4.2 for a particular cell – to the catchment outlet. The rate of sediment transport from each of the discretized cell depends upon the transport capacity of the flowing water (Meyer and Wischmier, 1969). The sediment outflow from an area is equal to soil erosion in the cell plus contribution from upstream cells if transport capacity is greater than this sum. However if transport capacity is less then amount of sediment excess of transport capacity get deposited and sediment load equal to transport capacity is discharged to next downstream cell. The concept is shown schematically in Fig. 4.3 (after Meyer and Wischmier, 1969).

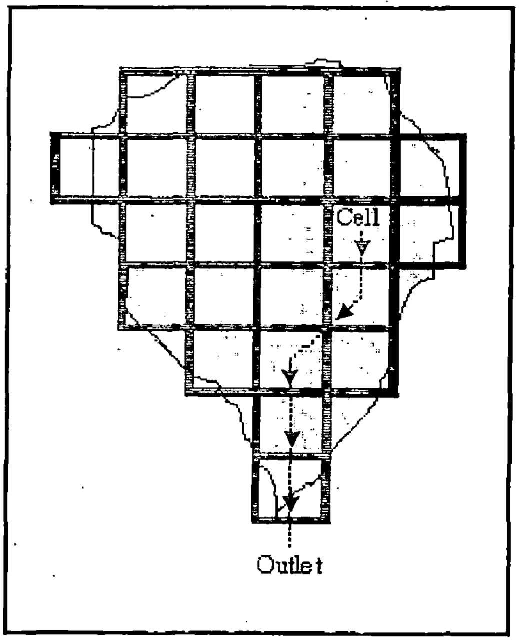


Fig. 4.3 Schematic showing a flow path

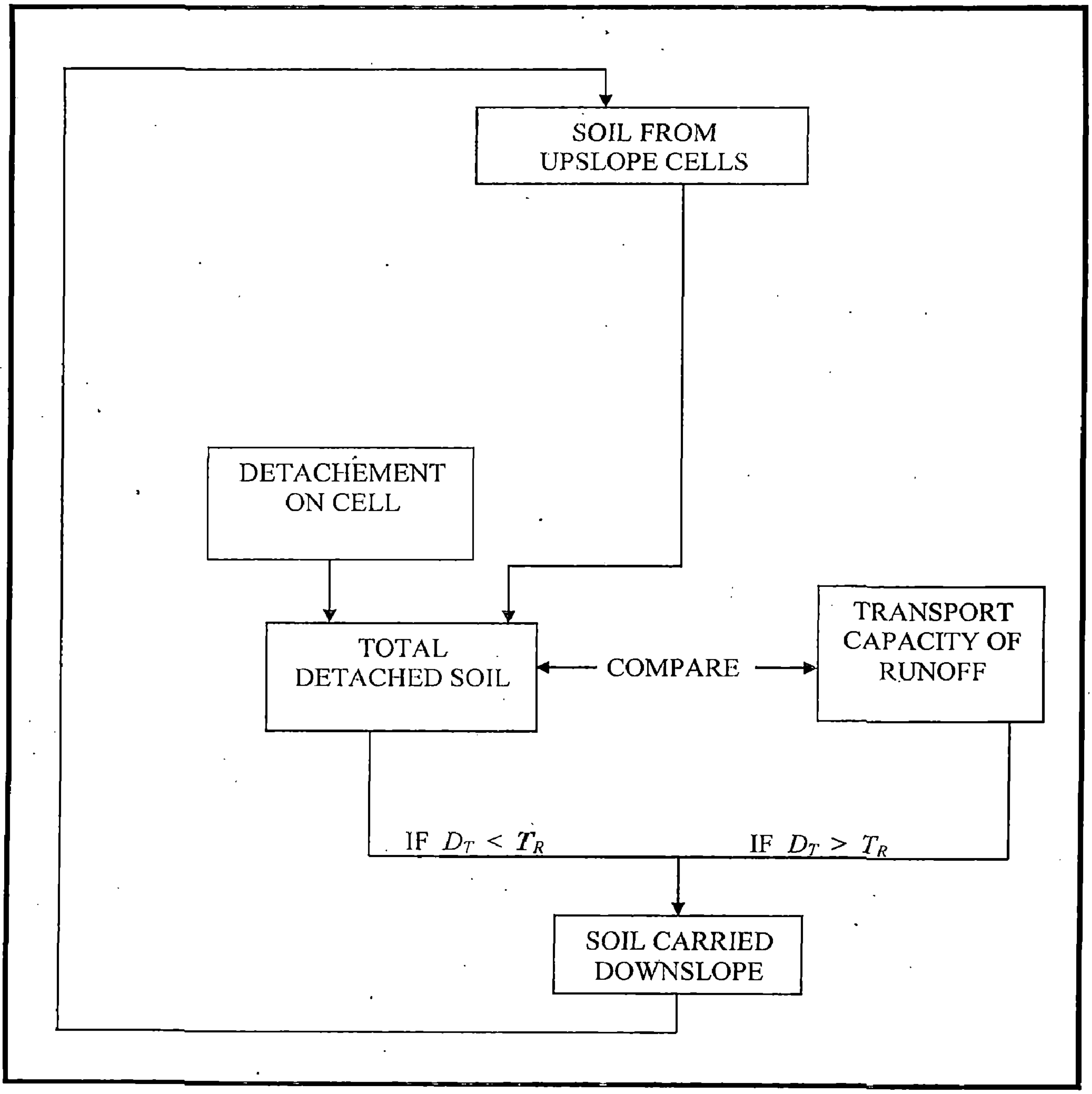


FIG. 4.4 CONCEPTS OF MATHEMATICAL MODELLING OF THE PROCESS OF SOIL EROSION BY FLOW OF WATER (Meyer and Wischmeier, 1969)

4.2.1 Mean Annual Sediment Transport Capacity

The rate of transport of the sediment is governed by the transporting capacity of the flowing water. Most geomorphologic models assume that overland flow is transport limited accumulation and flux is mainly predicted by the following equation

$$Q = K * L^{m} * S^{n} \tag{4.6}$$

with L the upslope distance (m) and S the local slope gradient (m m^{-1}). For three-dimensional landscapes (Kirkby and Chorley, 1967; Carson and Kirkby, 1972), this equation becomes:

$$Q = K * S^{n} * A^{m} \tag{4.7}$$

Where A is the upslope contributing area per unit of contour length. Prosser and Rustomji (2000) made a review on the constants m and n, and found that the median value obtained in experimental studies is 1.4 for both constants. This concept was further studies by Verstraeten et al. (2007) and based on their hypothesis following equation for mean sediment transport capacity was proposed and the same is adopted in this study.

$$TC = K_{TC} * R * K * A^{1/4} * S^{1/4} \tag{4.8}$$

Where TC is transport capacity (kg/m^2/yr). K_{TC} is the transport capacity coefficient and reflects vegetation component within the transport capacity and S the slope gradient.

4.2.2 Transport Limited Accumulation

Sediment is routed along the runoff pattern towards the river (Fig. 4.1 & 4.2), taking into account the local transport capacity, TC of each pixel. If the local TC is smaller than the sediment flux, then sediment deposition is modeled. This approach assumes that sediment transport is not necessarily restricted to a transport limited system. If the TC is higher than the sediment flux, then sediment transport will be supply limited. Thus, by introducing the K_{TC}, transport capacity coefficient, a more realistic representation of overland flow sediment transport can be simulated. Because much sediment is being routed to these locations from the steeper hill slopes adjoining the thalwegs, it faces high sedimentation rates because the transport potential will also be rather low. The predicted sediment delivery values need to be interpreted as sediment delivery towards the complete length of the river in the catchment. The model produces different maps of erosion, sediment transport and sediment deposition rates, whereby a distinction is made between gross erosion, net erosion, total sediment deposition and net sediment deposition. Consequently, different total values of erosion and soil loss can be defined. For grid based discretization system transport limited accumulation can be computed as:

$$T_{out} = \min(E + \sum T_{in}, T_C) \qquad (4.9)$$

$$D = E + \sum T_{in} - T_{out} \qquad (4.10)$$

Where E=Annual Gross Soil Erosion

Tc=Transport Capacity

Tin = Sediment inflow from upstream cells

Tout= Sediment Outflow from the cell

D= Deposition in cell

5

PREPARATION OF DATABASE

Computation of soil erosion and sediment yield using method outlined in Chapter 4.0 require spatial data for DEM, soil and landuse. In subsequent paragraphs generation of this database is discussed.

5.1. DEM Generation

Digital Elevation Model is sampled array of elevations (z) that are regularly spaced intervals in the x & y directions. The various input data are

- Topographic map
- Data collected by GPS, Total Station
- Stereo Photographs / aerial photographs
- Stereo Satellite images
- Different radar images (LIDAR, IFSARE)

There are two ways to generate DEM

- Through raster data by Interpolation
- Through vector data by TIN

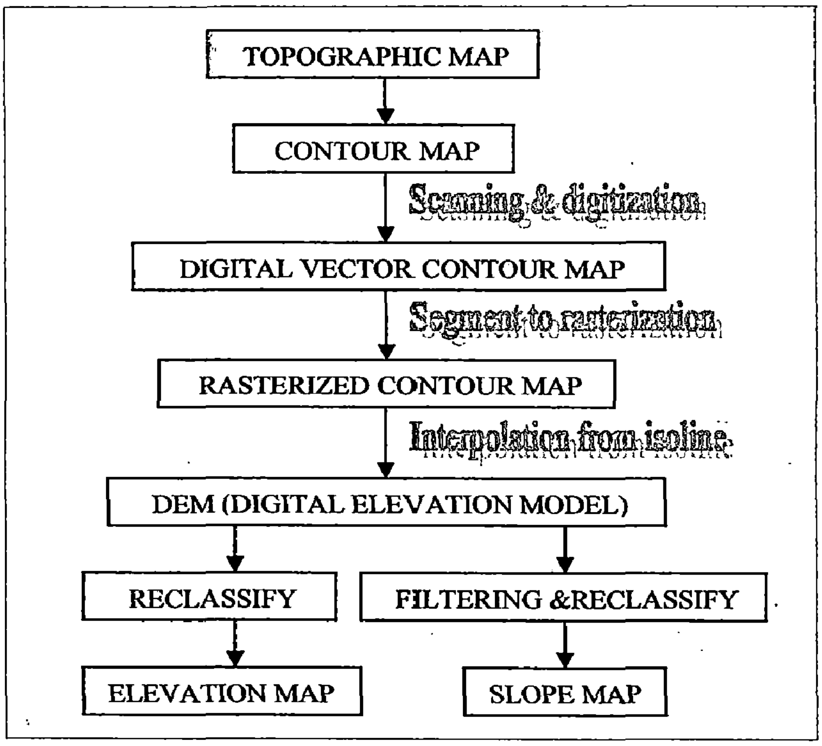
5.2. Generation of DEM and Drainage network

Add Registered Topographic maps in Polyconic projection system to the Arc Map window in Arc GIS. Create a shape file assigning the same coordinate system as that of registered Toposheet (By importing it). Digitize all the contours of the toposheet. Add "Contour Elevation" as new field to its attribute table and fill up all the contour elevation values against each digitized contour by highlighting them. Repeat above steps for all available toposheets in which study areas lies.

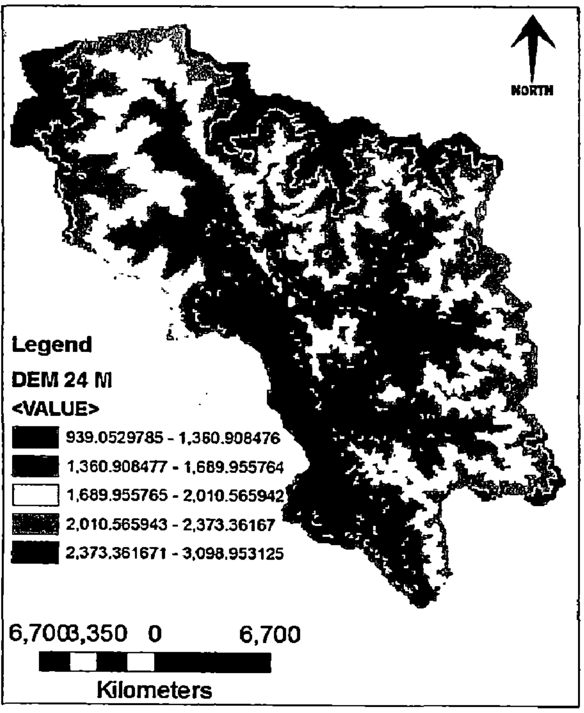
Then Open Arc Toolbox and go to

- 3D Analyst Tools
- Raster Interpolation
- Topo to Raster

Topo to Raster dialog box will be open in which we can add all the digitized Contour layers by changing attribute field to "Contour Elevation" and the tool interpolate contours into DEM of desired pixel size. For the present study a pixel size of 24m was selected. Following flowchart 5.1 a DEM of the study catchment was generated. Generated DEM is shown in Fig. 5.1. Fig. 5.2 shows generated drainage network for the watershed.



FLOW CHART 5.1 DEM & Slope Generation



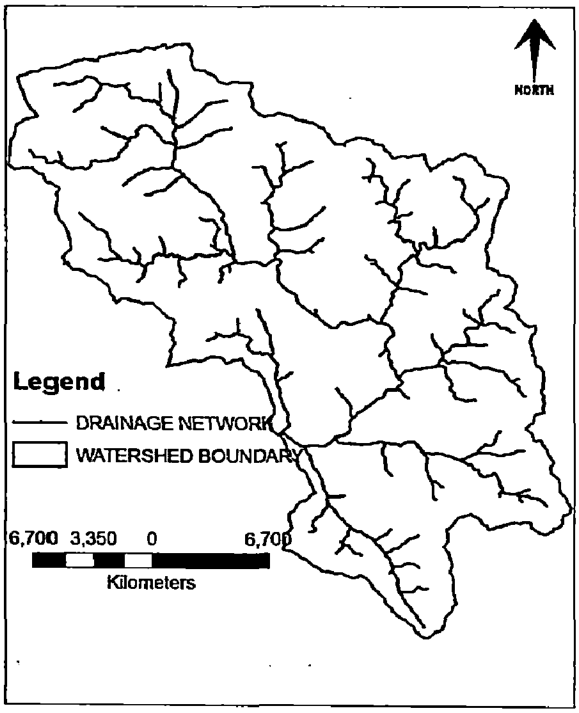


Fig. 5.1 DEM of Chaukhutiya watershed

Fig. 5.2 Drainage network

5. 3. Land Use / Land Cover Classification

Satellite data of IRS LISS III sensor was geo-referenced and classified in order to obtain land use/land cover map of the study watershed. In this study unsupervised classification has been carried out to prepare the land use / land cover maps. In unsupervised classification clustering of data is done for given input number of clusters. These clusters are then reclassified into desired number of classes using merging operation. The Chaukhutia sub-catchment has been classified into following seven major land use / land cover classes after merging different clusters. Classified landuse map of the Chaukhutia watershed is shown in Fig. 5.3.

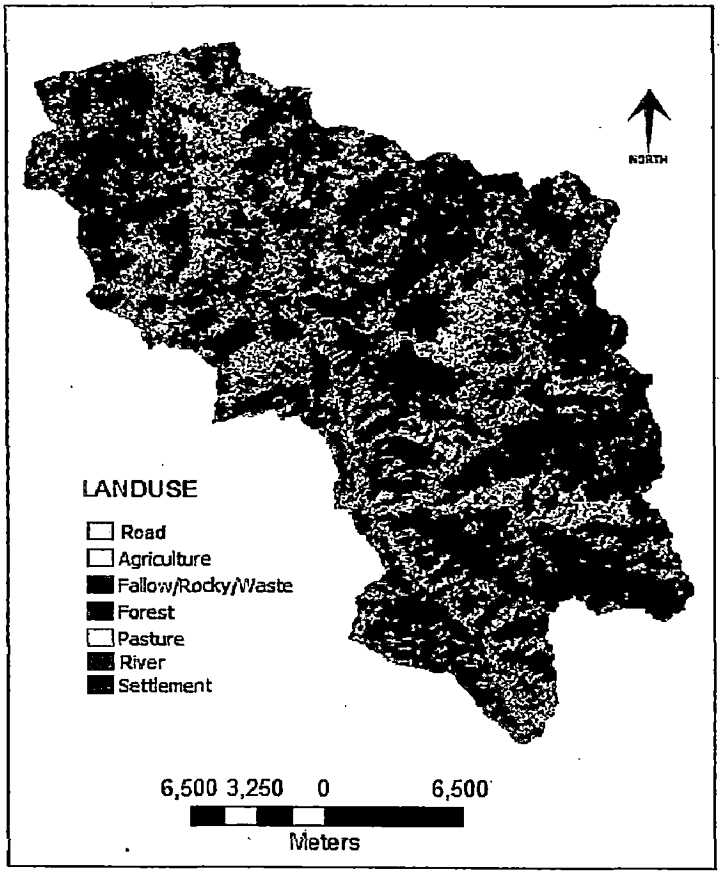


Fig. 5.3 Classified Landuse map of Chaukhutia watershed.

5.4. Soil Map

The soil map of the present study area was digitized using GIS Software 9.0 version after scanning hardcopy soil map of the Chaukhutia watershed was available from National Bureau of Soil Survey and Land Use Planning, Govt. of India. The digitized polygon map was then rasterized at 24 m grid cells by using GIS Arc Toolbox.

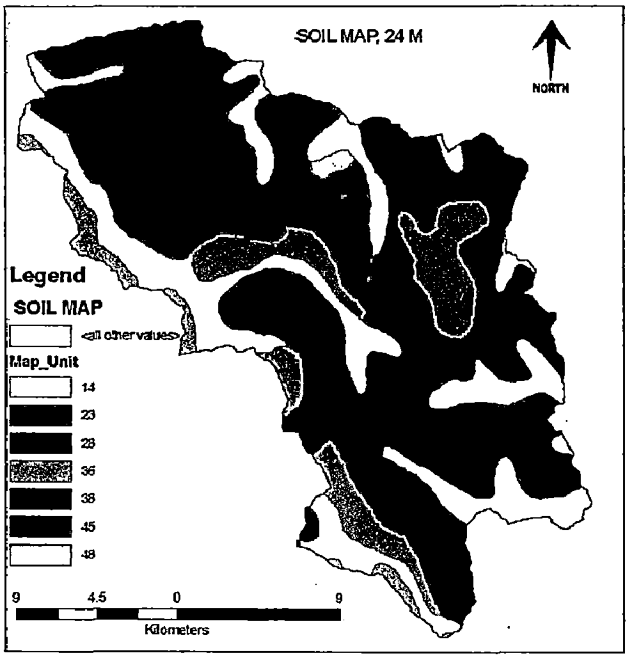


Fig. 5.4 Soil Map of Chaukhutia watershed

6. RESULTS AND DISCUSSION

The present study envisages generation of soil erosion in spatial domain which requires generation of different factor maps in spatial domain.

6.1. Computation of rainfall erosivity factor, R

The daily rainfall data from year 1973 to 1990 except for year 1974 for Chaukhutia catchment was available. The kinetic energy of daily rainfall was calculated using equation (4.2). I_{30} was calculated as per concept given by Rambabu et al 1979 for Indian condition. Then rainfall erosivity factor, R was calculated using equation (4.3). The output of R-values for eighteen years i.e. from 1973 to 1990 is presented in Table 6.1.

Table 6.1 Computed rainfall erosivity factor

Year	$R(\frac{MJ*mm}{ha*hr})$	**Year**	$R(\frac{MJ*mm}{ha*hr})$
1973	4451.11	1982	2211.67
1974	*	1983	2878.17
1975	4047.36	1984	1382.54
1976	3617.62	1985	2071.04
1977	4736.04	1986	4852.98
1978	3431.31	1987	3016.28
1979	1710.64	1988	4843.55
1980	3313.94	1989	3031.21
1981	1716.98	1990	5589.18

* Data not available

6.2. Computation of soil erodibility factor, K

The soil map of Chaukhutia catchment dominantly consists of seven categories of soils. The soil erodibility factor, K is dependent on soil profile and the response of the soil to the erosive action of rainfall. The soil erodibility (K) factor identifies the inherent susceptibility of a soil to erode under a standard condition, based on a multivariate nomograph of values for soil structure, permeability, organic matter, and percentage of sand and silt fractions. The soil erodibility factor K (t*ha*hr / ha*MJ*mm) for different type of soil is adopted from Haan et al., (1994). The K factor values are presented in Table 6.2.

Table 6.2. K factor for Soil

Type of soil	K (t*ha*hr / ha*MJ*mm)
Thermic fine loamy to loamy skeletal soils	0.020
Thermic loamy skeletal to fine loamy soils	0.023
Thermic to coarse loamy soils	0.032
Thermic sandy skeletal soils	0.042
Thermic coarse to fine loamy soils	0.049
Thermic skeletal to coarse loamy soils	0.057
Thermic coarse to fine loamy soils	0.057

The K factors presented in Table 6.2 were added in the attribute of soil theme's table of Soil Map by opening ERDAS. The output K factor map is presented in Fig.6.1

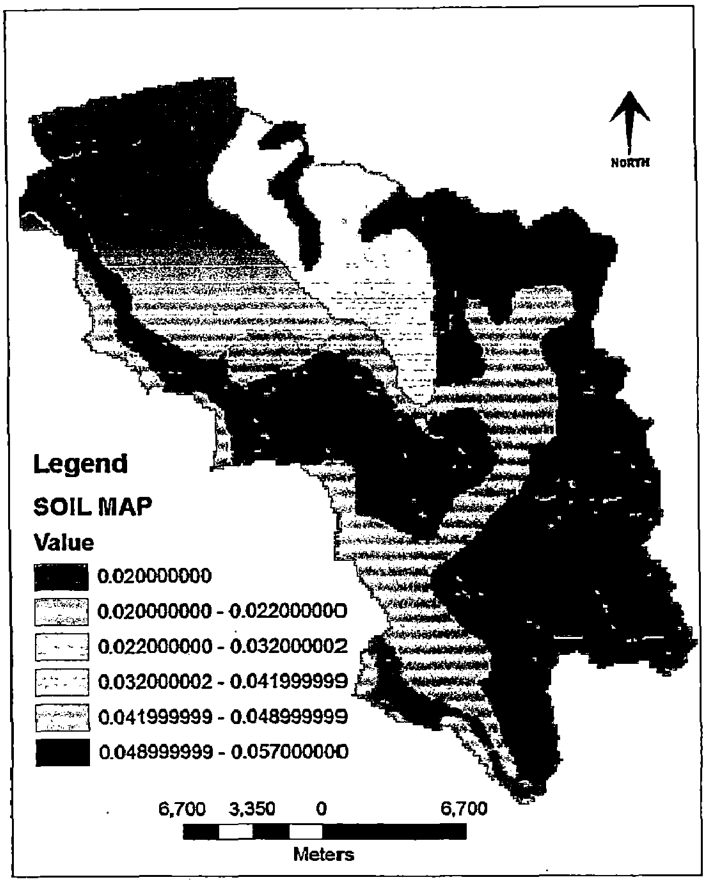


Fig. 6.1 K-Factor Map

6.3. Computation of Topographic factor, LS

These DEMs were further analyzed to remove pits and flat areas to maintain continuity of flow to the catchment outlets. Using Eq. (4.5). The slope length and gradient factors are linked and therefore calculated together where Flow Accumulation is a grid theme of flow accumulation expressed as number of grid cells. The output LS factor is presented in Fig. 6.2.

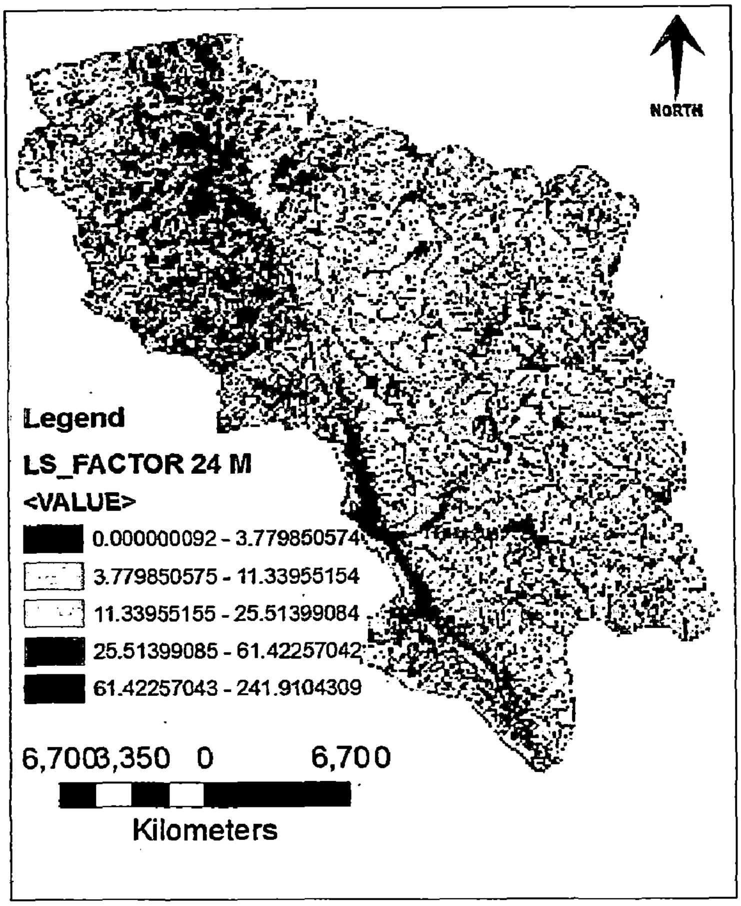


Fig. 6.2 LS-Factor Map

6.4. Computation of Cover and Management factor, C

The Chaukhutia catchment has been divided into 7 major coverage's namely cropland, pasture, and forest, road, settlement, rocky and fallow lands. Vegetation cover and cropping systems have a large influence on runoff and erosion rates. Soil erosion can be limited with proper management of vegetation, plant residue and tillage. The crop management factor can be determined with the use of land cover data. A lower c- value represents a cover type that is more effective at defending against soil erosion. The factor C for different type of land cover is taken from Haan et al., (1994) and is presented in Table 6.3.

Table6.3. C factor and P factor related to Land use / Land cover

Land use / Land cover	C factor	P factor
Agriculture	0.34	0.9
Fallow	0.13	1
Undisturbed Forest	0.003	1
Pasture	0.20	1
River	0.13	1
Road	0.13	1
Settlement	0.13	1

C-factor field is added as a field values of given classes of Land use Map by ERDAS 8.5.Version. The map of C Factor is presented in Fig 6.3.

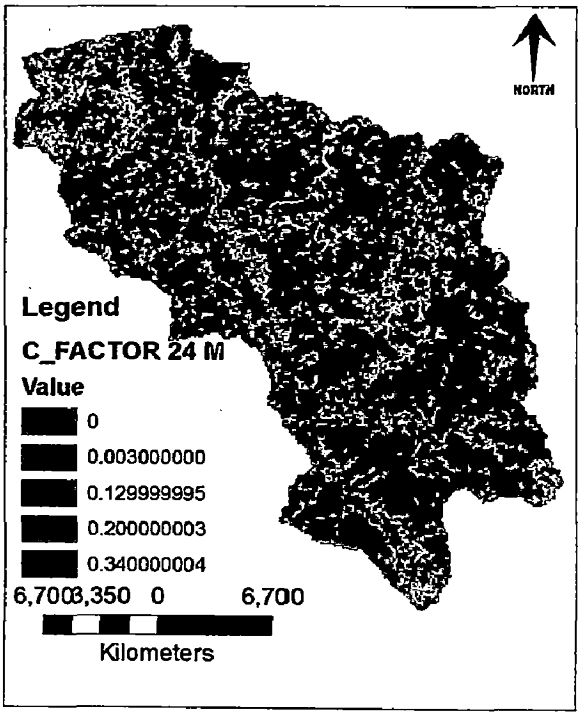


Fig. 6.3 C-Factor 24 m Map

6.5. Computation of Support Practice Factor, P

The Chaukhutia catchment has been divided into 7 major coverage's namely cropland, pasture, and forest, road, settlement, rocky and fallow lands. The conservation practices factor takes into account the effects of support and practice management measures which work to reduce the effects of soil erosion. A lower P-value represents a more effective conservation practice. The P factor can be obtained from tables or using the USLE program given information about land use and management. The factor P for different type of land cover is taken from Haan et al., (1994) and is presented in Table 6.3. P factor values are added in the attribute field of land use Map by ERDAS 8.5.Version. The P factor map is presented in Fig.6.4

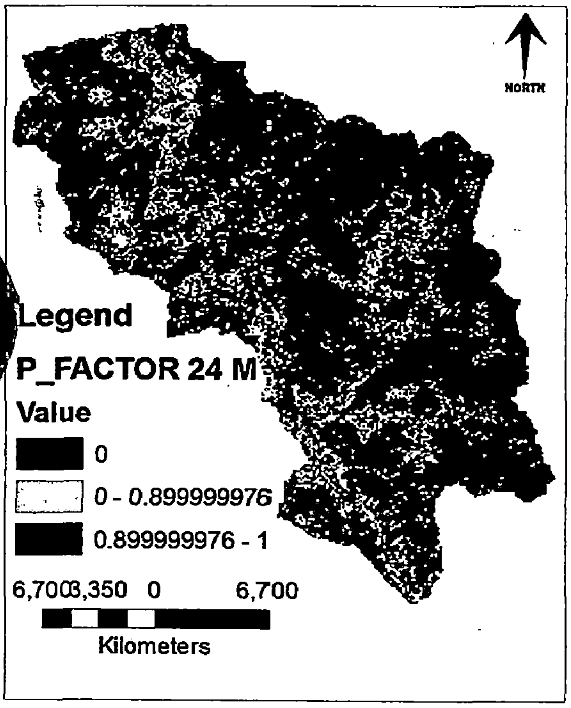


Fig 6.4P-Factor 24 m Map

6.6. Generation of the erosion potential maps

The land use, soil, slope steepness and management parameters are main factors governing soil erosion potential at particular location to the erosive power of rainfall erosivity. The maps for values of the USLE parameters viz, K, LS, C and P were integrated by GIS Raster Calculator to form a composite map of watershed system. The map of composite parameters KLSCP represents the soil erosion potential of different grid cells. A high value of this term indicates a higher potential of soil erosion in the cell and vice versa.

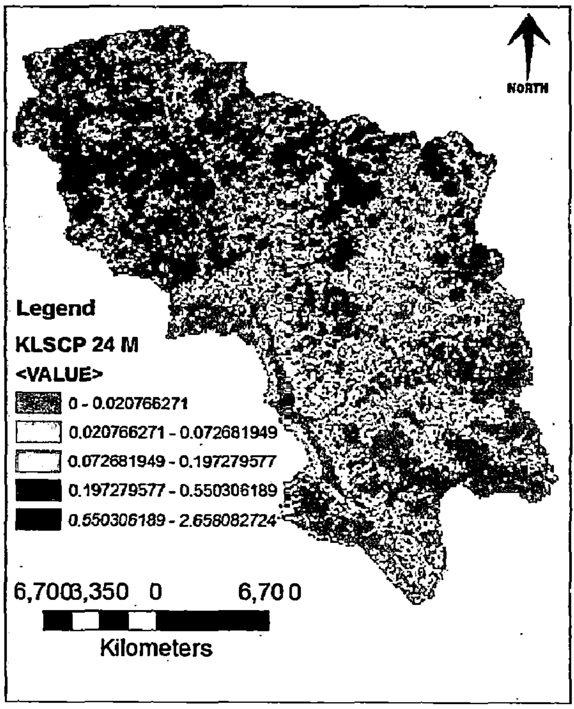


Fig 6.5 KLSCP Map

6.7. Estimation of Gross Soil Erosion of Chaukhutiya Watershed

Assessment of gross soil erosion of Chaukhutiya catchment has been calculated using Arc GIS Raster Calculator. The layers of topographic factor (LS), C factor, Soil Erodibility Factor, K, and Support Practice factor P were overlaid. Then evaluated values of LS, K, C and P maps were multiplied by values of R, rainfall erosivity factor presented in Table 6.4 from years 1973 to 1990 to respectively estimate the total soil loss in tones per annum for whole catchment. Multiplication of R factor into KLSCP factor map resulted in maps of gross erosion for different years. Figs. 6.6 to 6.15 present gross soil erosion for some of years. Total computed values of gross soil erosion were obtained by summing value of pixels within the catchment to arrive at total gross erosion in the watershed. The value of total gross erosion for all years is given in Table 6.4.

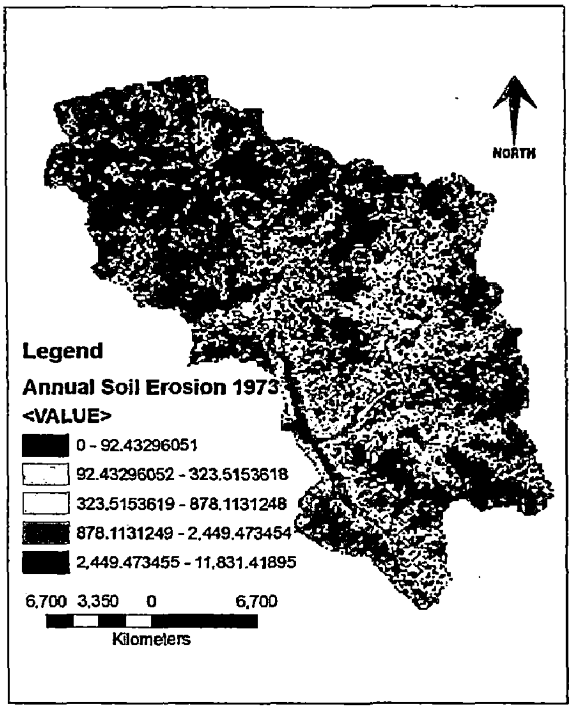


Fig6.6 Gross Soil Erosion 1973 Map

Comp.GSE= 2789489 tones

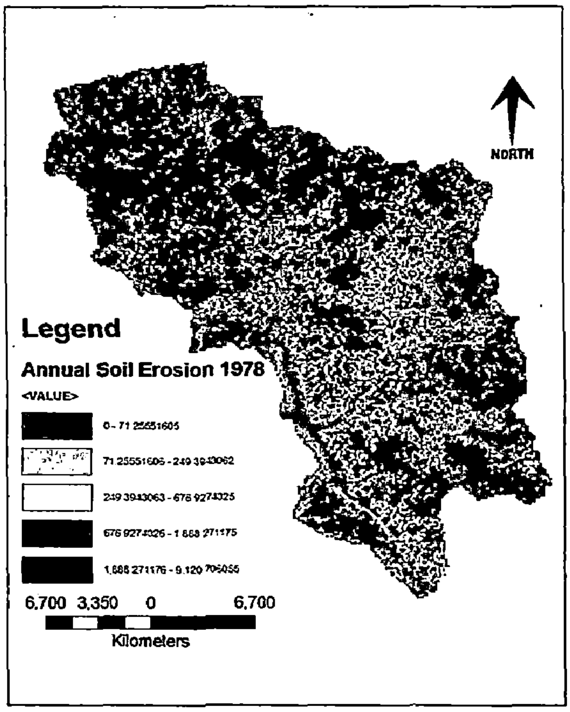


Fig6.7 Gross Soil Erosion 1978 Map

Comp.GSE= 2154161 tones

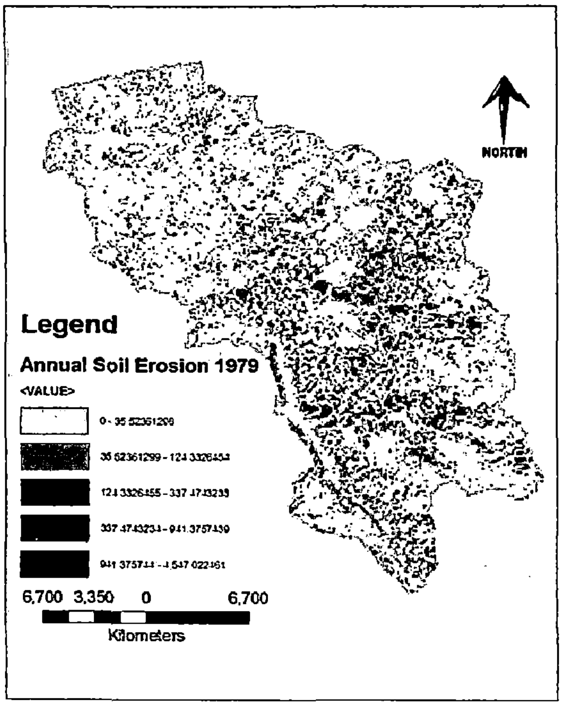


Fig6.8 Gross Soil Erosion 1979 Map

Comp.GSE= 1058097 tones

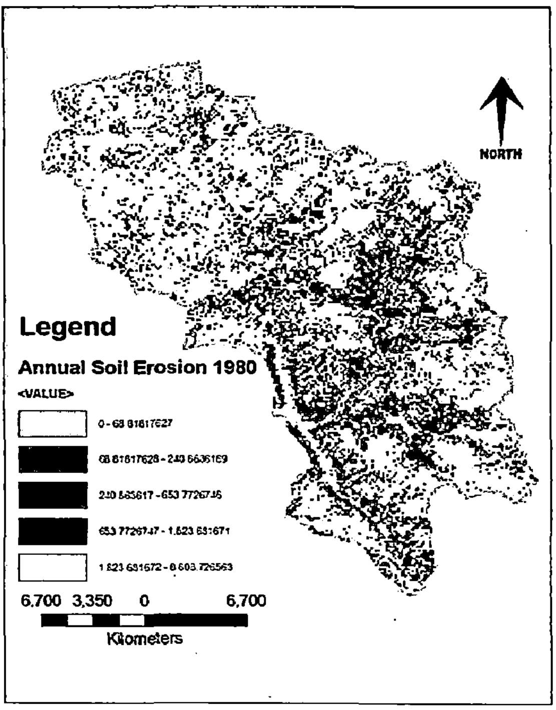


Fig6.9 Gross Soil Erosion 1980 Map

Comp.GSE= 2144234 tones

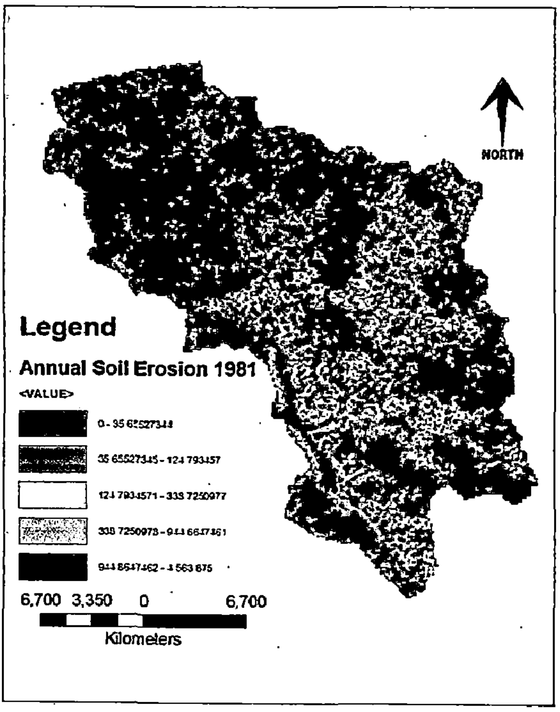


Fig6.10 Gross Soil Erosion 1981 Map

Comp.GSE= 1058100 tones

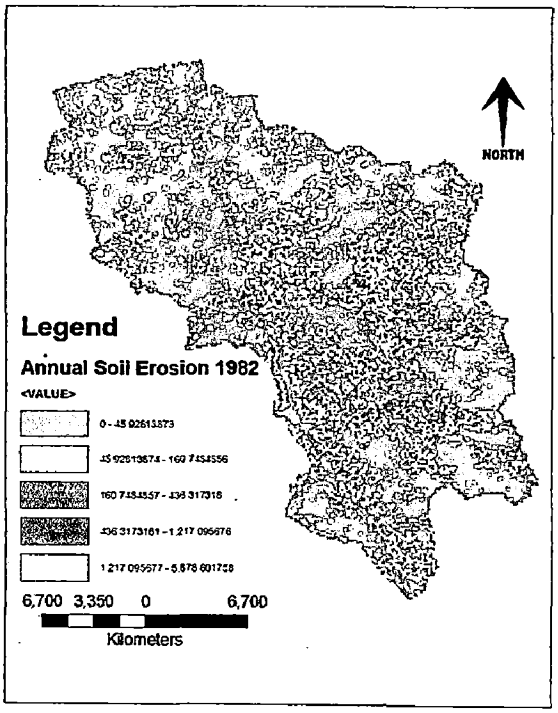


Fig6.11 Gross Soil Erosion 1982 Map

Comp.GSE= 1368009 tones

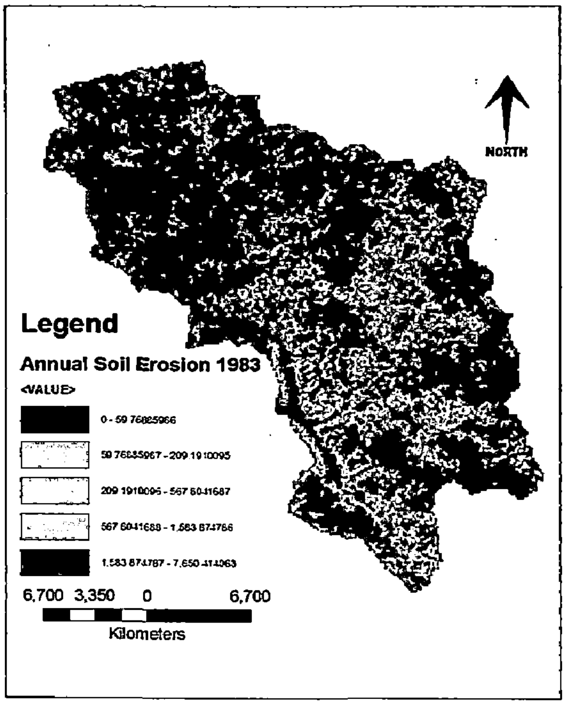


Fig6.12 Gross Soil Erosion 1983 Map

Comp.GSE= 1780280 tones

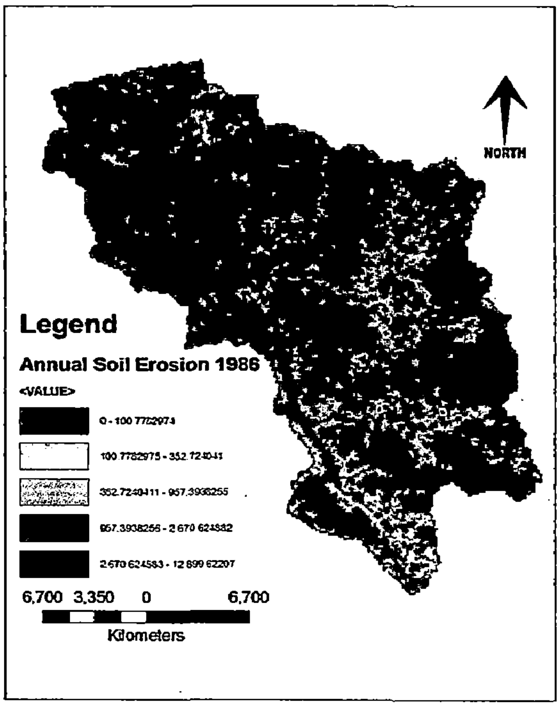


Fig6.13 Gross Soil Erosion 1986 Map

Comp.GSE= 3146862 tones

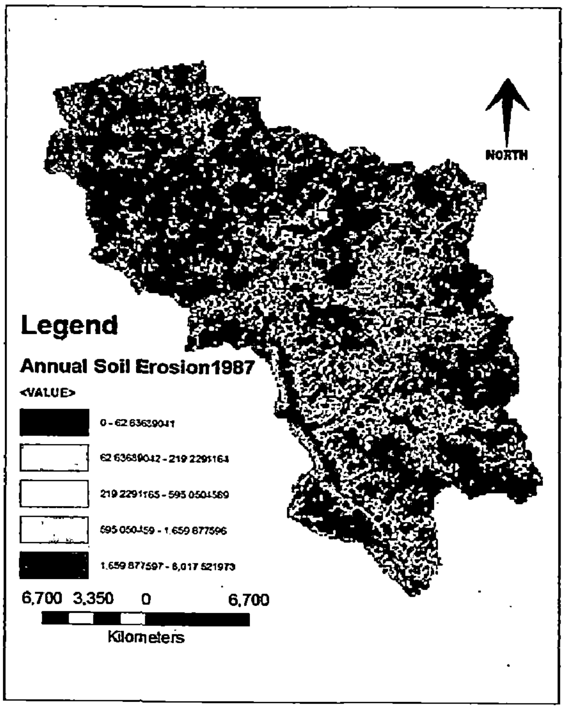


Fig6.14 Gross Soil Erosion 1987Map

Comp.GSE= 1894073tones

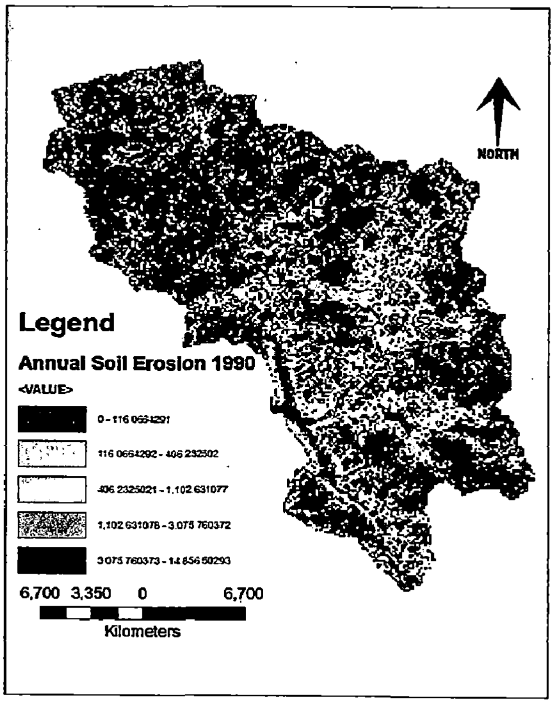


Fig6.15 Gross Soil Erosion 1990 Map

Comp.GSE= 3504234 tones

6.8. Computation of spatial distribution of transport capacity, transport limited accumulation and erosion deposition maps

As reported earlier, all erosion produced in a grid cell does not find opportunity to get transported to the outlet. Therefore to convert gross erosion into spatial distribution of sediment yield, annual transport capacity of each grid was computed using Eq. (4.8). The parameter K_{TC} appearing in Eq. (4.8) was taken as unity at the beginning and then calibrated using observed data for 5 years. The calibrated value of K_{TC} equal to 0.005 gave close match between observed and computed sediment yield and adopted for all other years. Fig. 6.16 & 6.17 shows transport capacity maps for year 1973 and 1990 respectively as illustration.

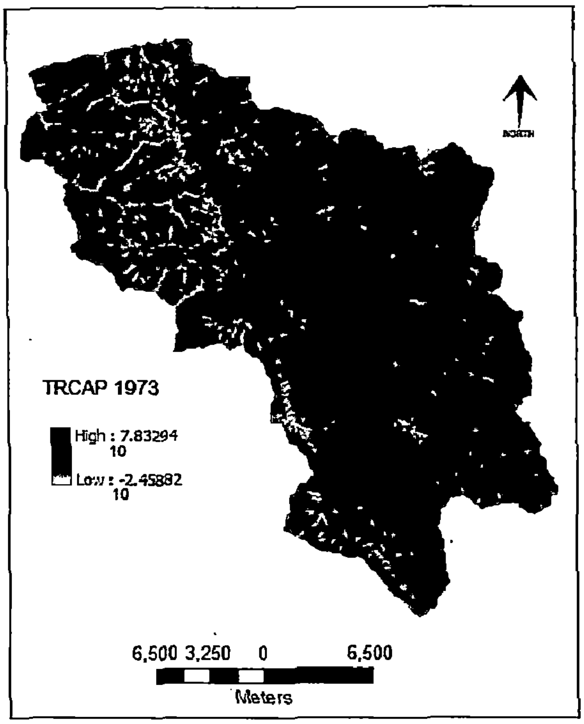


Fig6.16 Transport Capacity Map

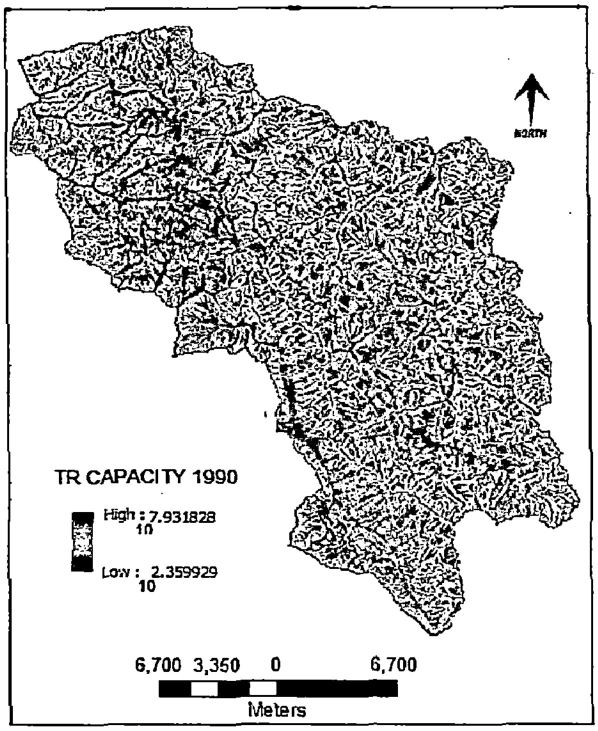


Fig6.17 Transport Capacity Map

Using Eq. (4.9) the gross erosion from each grid was routed downstream to generate map of accumulated sediment yield limited by transport capacity. Such maps give amount of sediment transported from the system at every grid. These maps are useful in knowing value of sediment flowing out of the catchment at any location. Transport limited sediment outflow maps were prepared for all 18 years. Fig. 6.18 & 6.19 depicts transport limited sediment outflow maps for year 1973 & 1990 respectively as illustration.

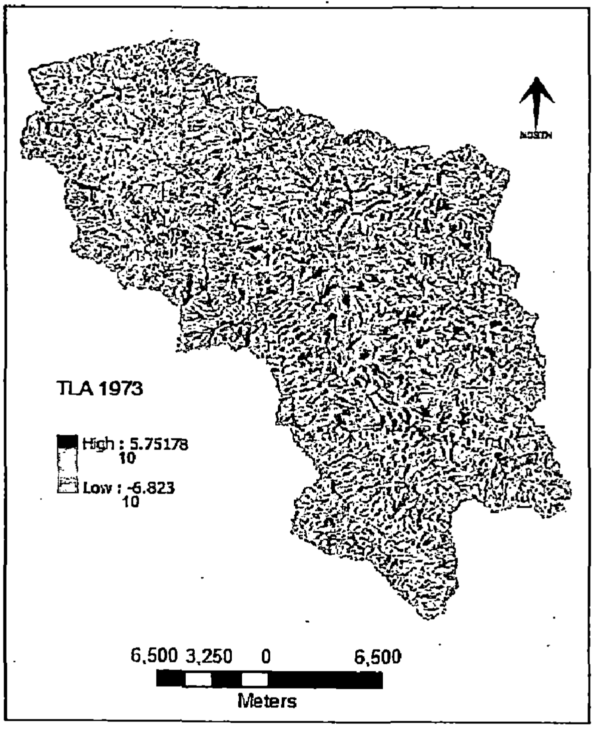


Fig6.18 Obser.GSY= 2789489 tone

Comp.GSY= 565679 tones

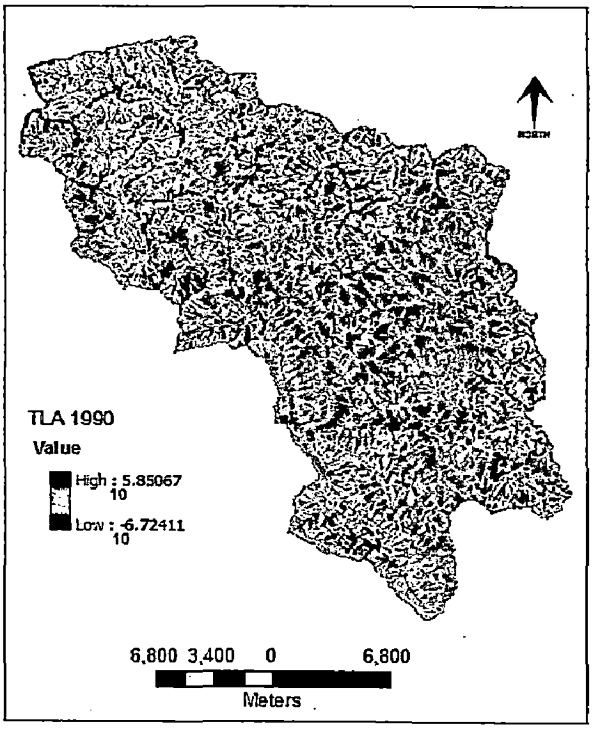


Fig6.19 Obser.GSY= 41397 tone

Comp.GSY= 54119 tones

The pixel value of the outlet grid of transport limited sediment outflow maps computed above give sediment coming out of the watershed. These values are tabulated in Table 6.4. As can be seen from Table 6.4 the model over estimate sediment yield for some years and underestimate for some years. Overall the % error between observed and computed value of sediment yield range from -40% (over estimation) to +41% (under estimation). Larger errors in a few years are ascribed to uncertainties in the data. Nevertheless the accuracy obtained is considered satisfactory because even the more elaborate process-based soil erosion models are found to produce results with still larger errors (ASCE, 1975; Foster, 1982; Hadley *et al.*, 1985; Wu *et al.*, 1993; Wicks and Bathurst, 1996).

Table6.4. Comparison of output results

Year	$R(\frac{MJ*mm}{ha*hr})$	**Observed GSY(t)**	**Computed GSE(t) by USLE**	**Computed GSY(t) using TLA**	**% error**
1973	4451.11	436847	2789489	565679	-22.77
1974	*	*	*	*	0
1975	4047.36	558067	2541314	787141	-29.10
1976	3617.62	*	2263358	702322	0
1977	4736.04	430557	2268175	621088	-30.67
1978	3431.31	632971	2154161	667341	-5.15
1979	1710.64	753047	1058097	533680	41.10
1980	3313.94	782208	2144234	666902	17.29
1981	1716.98	212706	1058100	297788	-28.57
1982	2211.67	649553	1368009	633600	2.52
1983	2878.17	547775	1780280	586550	-6.61
1984	1382.54	497457	855115	366944	35.57
1985	2071.04	*	1280820	367048	0
1986	4852.98	76048	3146862	97659	-22.12
1987	3016.28	34822	1894073	58660	-40.64
1988	4843.55	175883	3146870	246236	28.50
1989	3031.21	20067	3749799	27094	-25.93
1990	5589.18	41397	3504234	54119	-23.51

*Data Not Available

Using Eq. (4.10) map for deposition of sediment is obtained. Such maps are helpful in identifying areas vulnerable to silt deposition in the catchment. Fig. (20) and (21) depicts sediment deposition maps for year 1973 and 1990 as illustration. As can be seen from these figures, deposition of sediment resulted at grids where transport capacity was low, mostly by the sides of some of the stream reaches. Superimposition

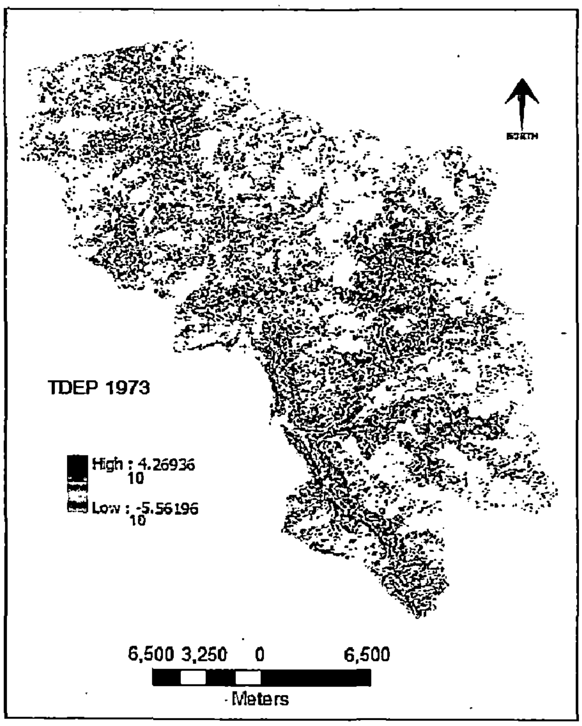


Fig6.20 Total deposition 1973 Map

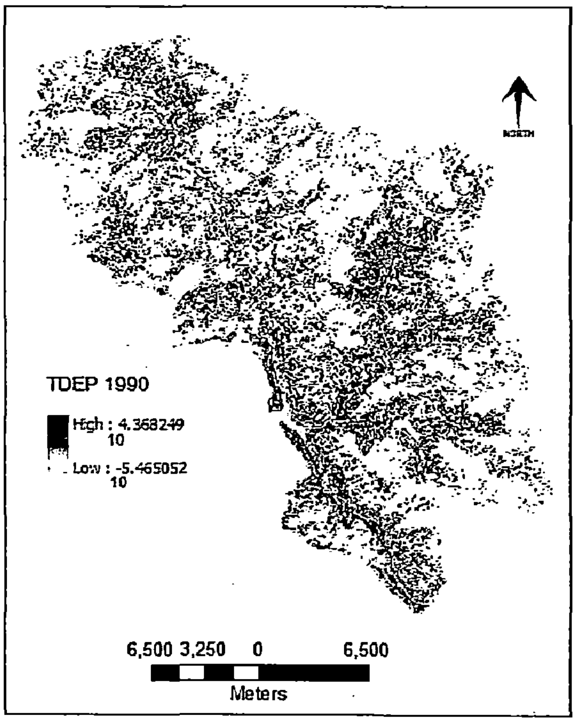


Fig6.21 Total deposition 1990 Map

of sediment deposition map over gross erosion map resulted in identification of areas vulnerable to soil erosion and deposition. Such maps are extremely important in planning conservation measures. Fig. (6.22) and (6.23) depicts erosion/sediment deposition maps for year 1973 and 1990 as illustration.

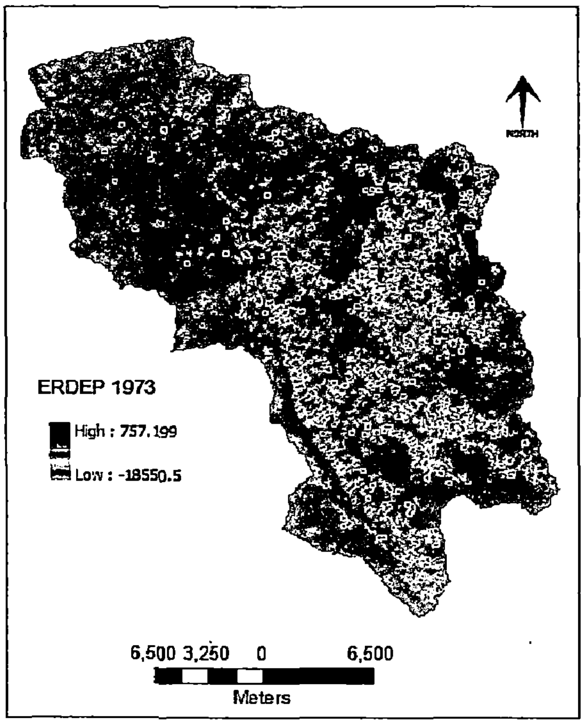


Fig6.22 Erosion/deposition 1973 Map

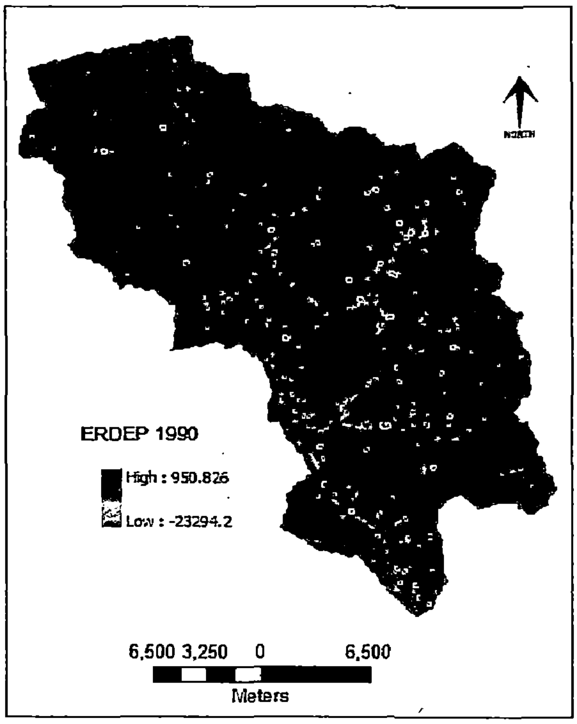


Fig6.23 Erosion/deposition1978 Map

7. SUMMARY AND CONCLUSIONS

Scientific management of soil and water is very important to arrest erosion and enhancing the agricultural production. Soil erosion is the major cause of the loss of fertility, diminishing crop production and land degradation. The deterioration of soil in study area can be controlled effectively by adopting the watershed treatment measures if spatial distribution of soil erosion is known.

Erosion is a natural geomorphic process occurring continually over the earth's surface. The processes of erosion of soil from earth surface if largely depend on topography, vegetation, soil and climatic variables. These areas found to have pronounced spatial variability in a catchment due to the spatial variation of climatic factors and catchment heterogeneity. This is one of the reasons given for promoting the use of distributed information of catchment resources using a GIS. By using a GIS the catchment is discretized into sub-areas having approximately homogeneous characteristics and rainfall distribution. The remote sensing and GIS techniques have been used in this study for generation of spatial information, catchment discretization, data processing and making computations.

Various thematic layers representing different factor of USLE were generated and overlaid to compute spatially distributed gross soil erosion maps for watershed using recorded rainfall for 18 years. A concept of transport limited accumulation was formulated and used in ArcGIS for generating maps for transport capacity and using transport capacity maps, gross soil erosion was routed to the catchment outlet using hydrological drainage paths resulting in generation of transport capacity limited sediment outflow maps. Such maps give amount of sediment flowing from a particular grid in spatial domain. The pixel value of the outlet grid of transport limited sediment outflow maps thus computed give sediment coming out of the watershed. Comparison of observed and computed value of sediment yield revealed that the % error between observed and computed value of sediment yield range from -40% (over estimation) to +41% (under estimation). Larger errors in a few years are ascribed to uncertainties in the data. Nevertheless the accuracy obtained is considered satisfactory because even the more elaborate process-based soil erosion models are found to produce results with still larger errors (ASCE, 1975; Foster, 1982; Hadley *et al.*, 1985; Wu *et al.*, 1993; Wicks and Bathurst, 1996).

Further using the methodology presented, maps for deposition of sediment were also obtained. Such maps are helpful in identifying areas vulnerable to silt deposition in the catchment. Analysis of maps reveals that deposition of sediment resulted at grids where transport capacity was low, mostly by the sides of some of the stream reaches. Superimposition of sediment deposition map over gross erosion map resulted in identification of areas vulnerable to soil erosion and deposition. Such maps are extremely important in planning conservation measures.

The method has the potential to assess impact of different land use scenarios and soil conservation measures on resulting sediment outflow scenario from the catchment. Therefore the present method is a useful tool in integrated environmental watershed management.

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APPENDIX A

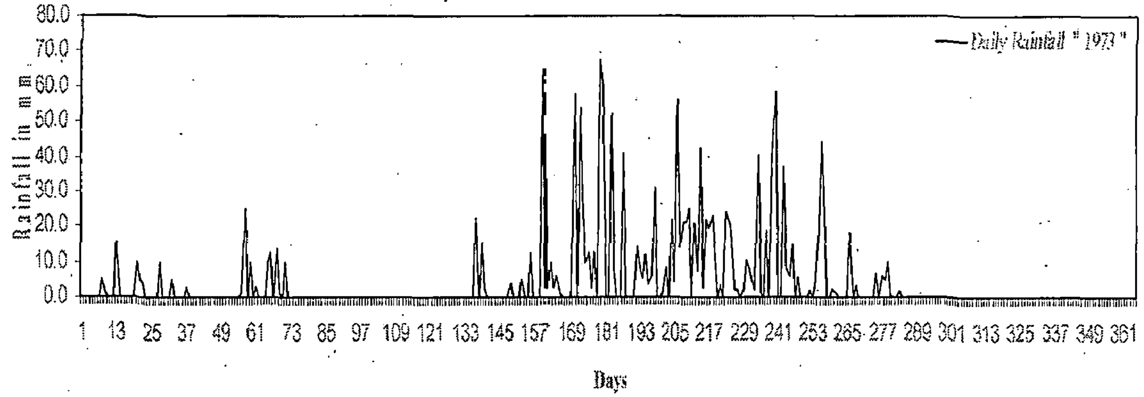

Fig.1 Daily rainfall data recorded at Chaukhutia 1973

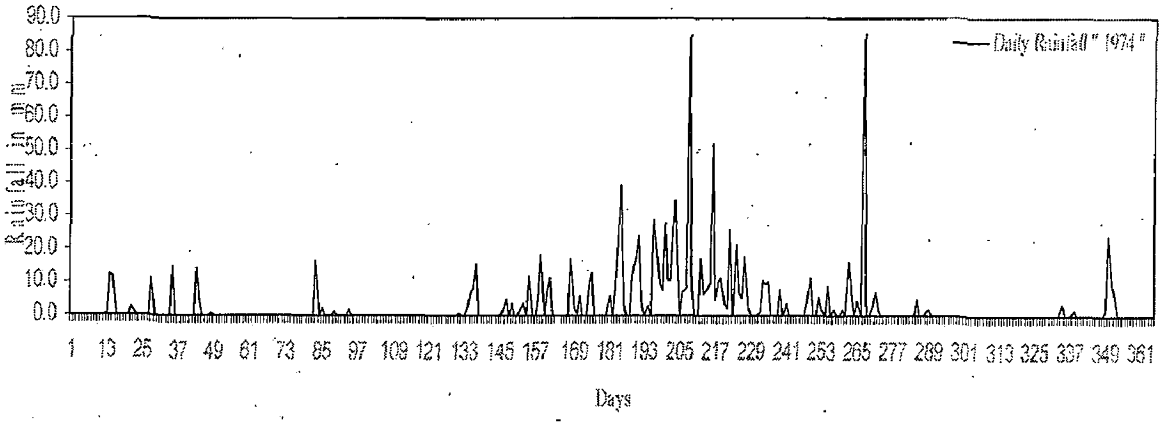

Fig.2 Daily rainfall data recorded at Chaukhutia 1974

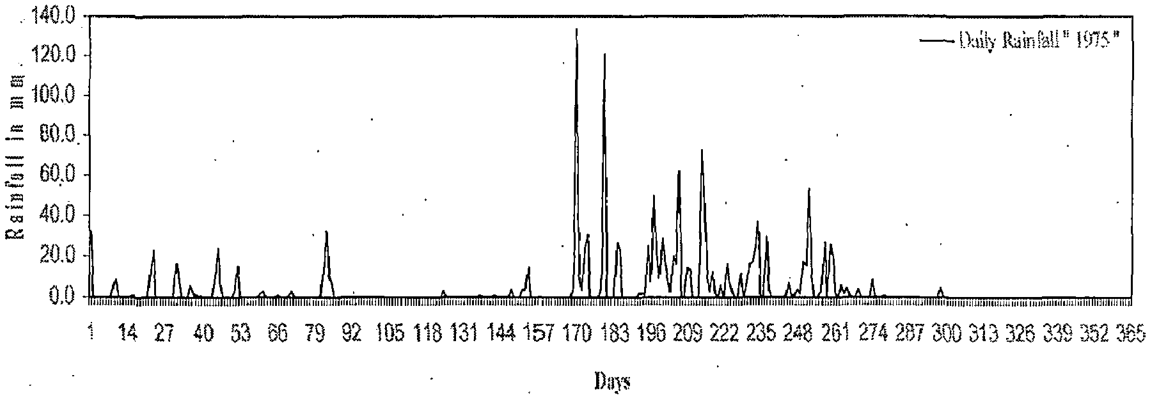

Fig.3 Daily rainfall data recorded at Chaukhutia 1975

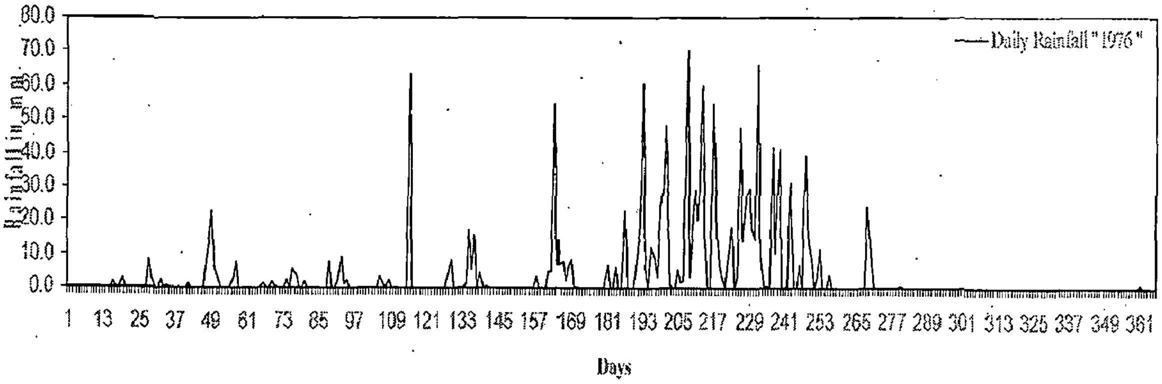

Fig. 4 Daily rainfall data recorded at Chaukhutia 1976

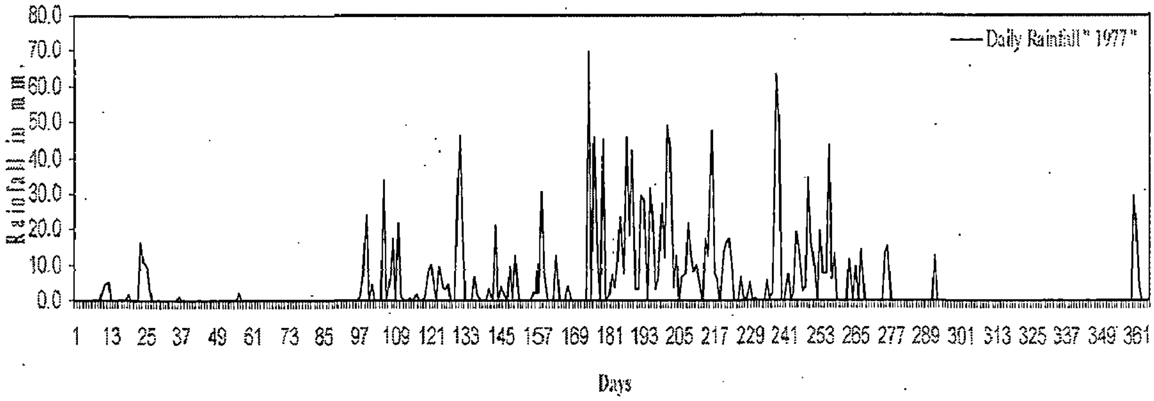

Fig.5 Daily rainfall data recorded at Chaukhutia 1977

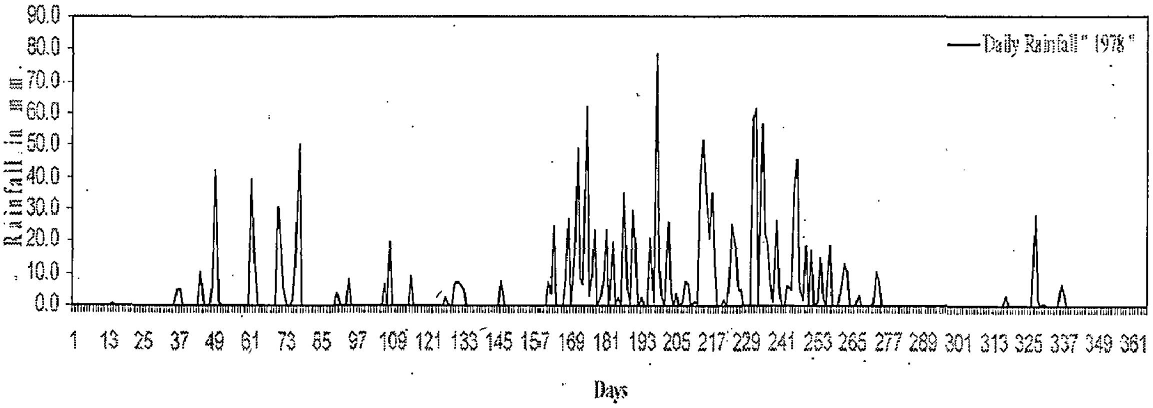

Fig.6 Daily rainfall data recorded at Chaukhutia 1978

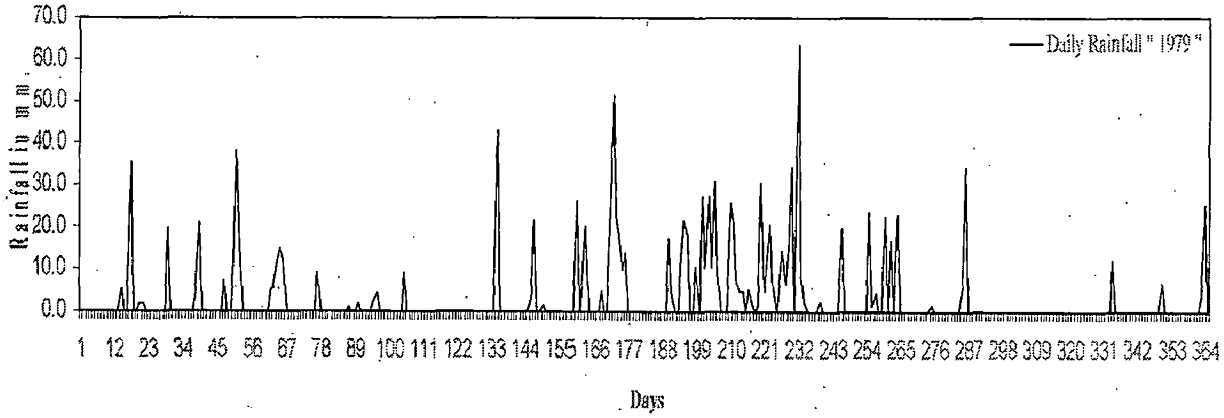

Fig.7 Daily rainfall data recorded at Chaukhutia 1979

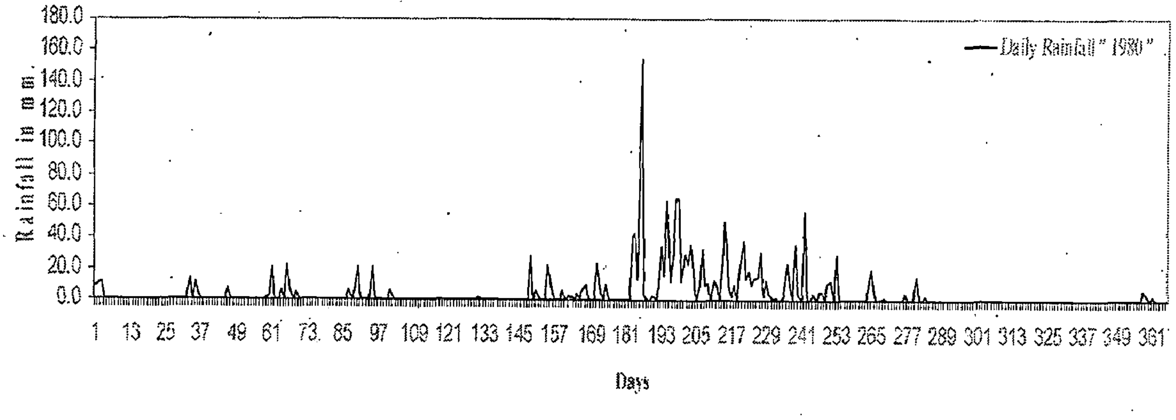

Fig. 8 Daily rainfall data recorded at Chaukhutia 1980

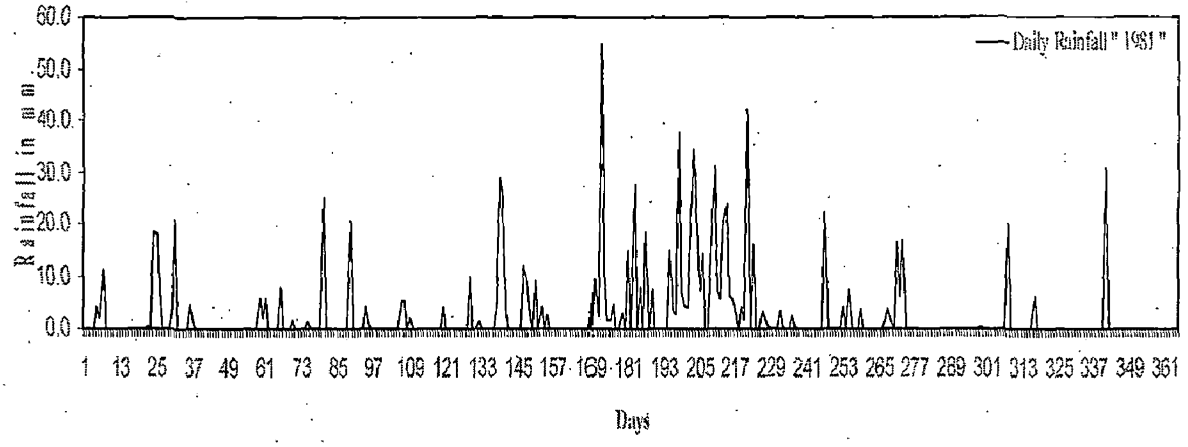

Fig.9 Daily rainfall data recorded at Chaukhutia 1981

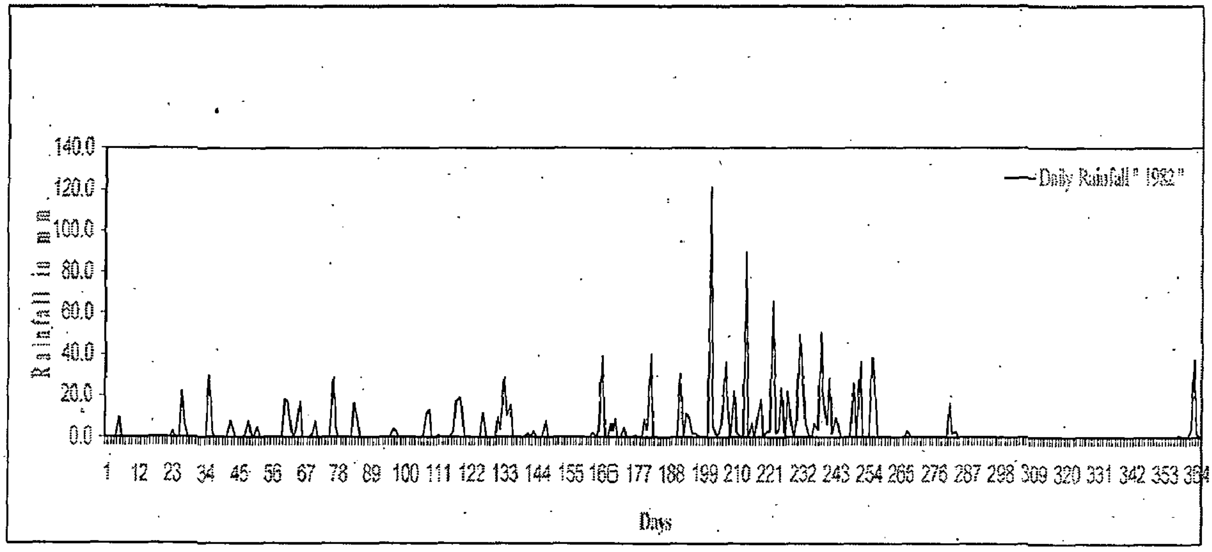

Fig. 10 Daily rainfall data recorded at Chaukhutia 1982

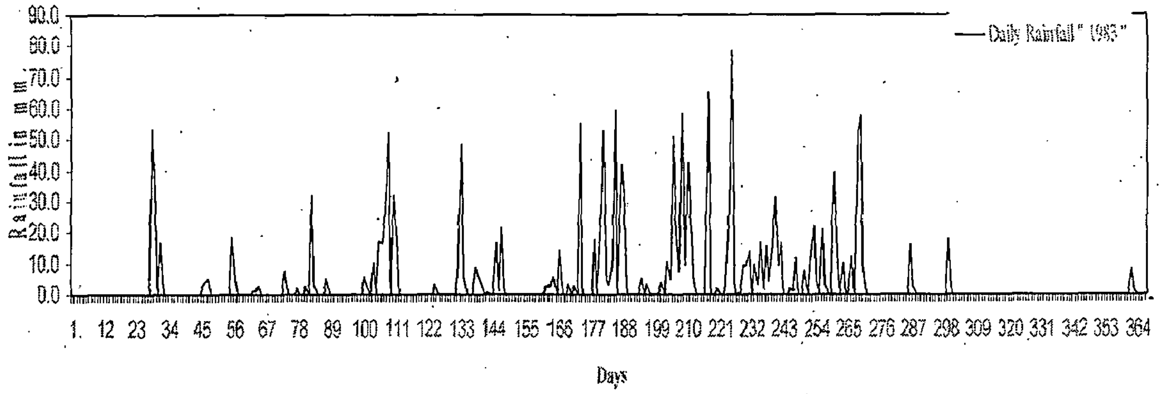

Fig.11 Daily rainfall data recorded at Chaukhutia 1983

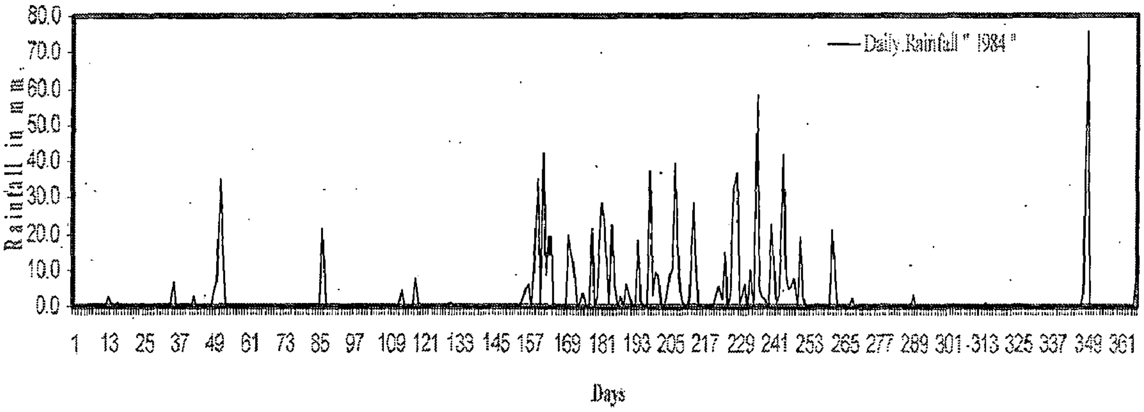

Fig. 12 Daily rainfall data recorded at Chaukhutia 1984

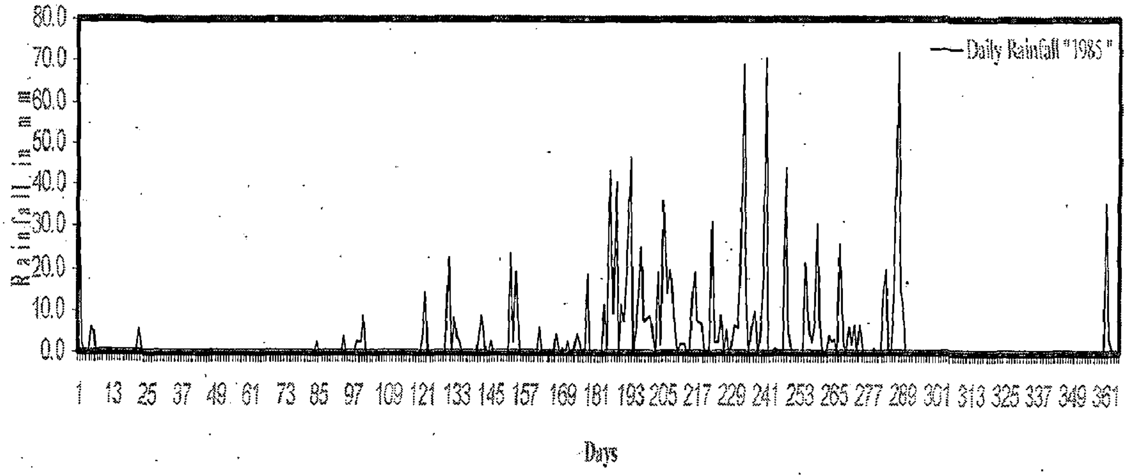

Fig.13 Daily rainfall data recorded at Chaukhutia 1985

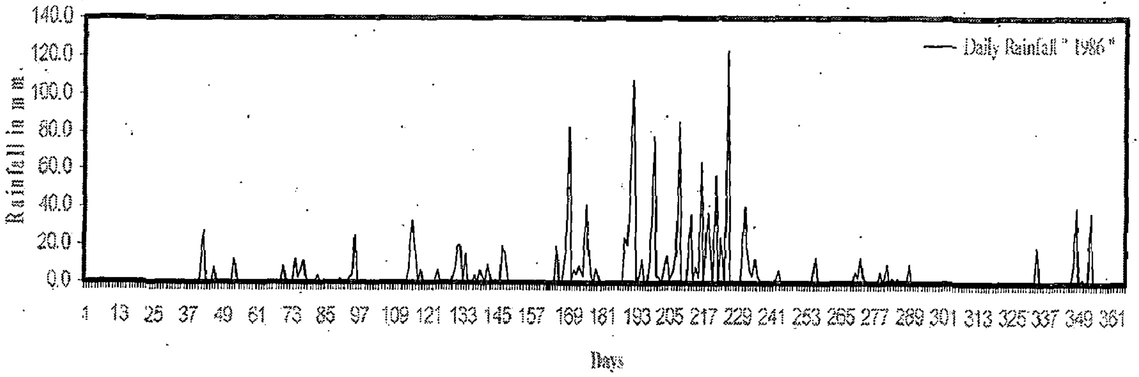

Fig.14 Daily rainfall data recorded at Chaukhutia 1986

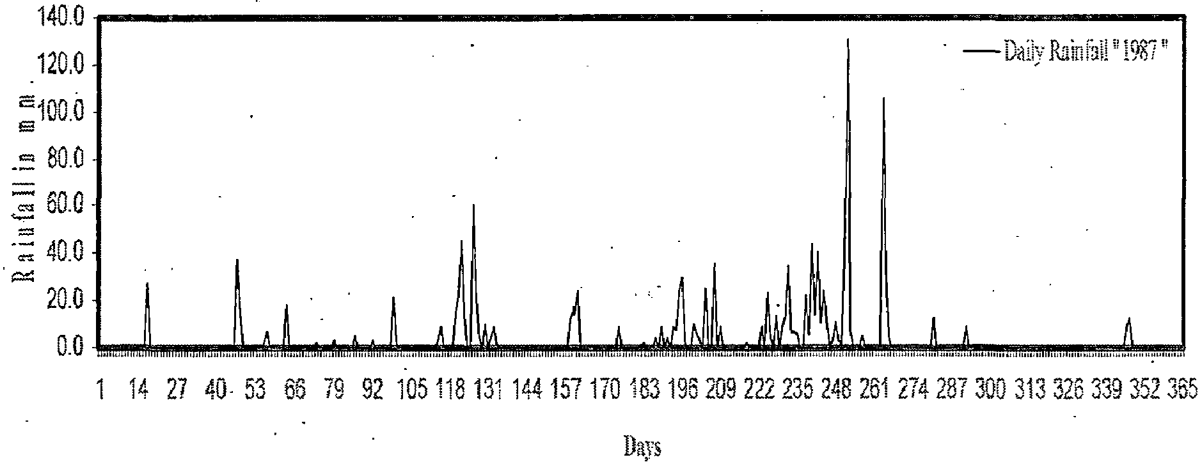

Fig.15 Daily rainfall data recorded at Chaukhutia 1987

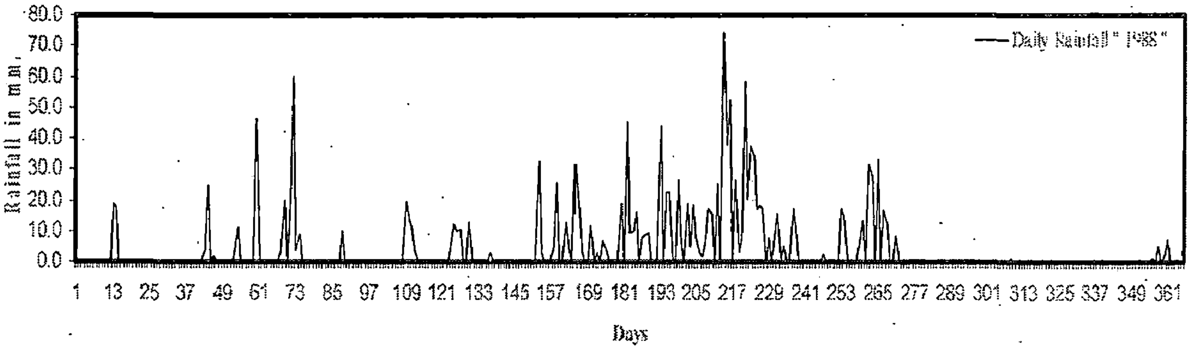

Fig. 16 Daily rainfall data recorded at Chaukhutia 1988

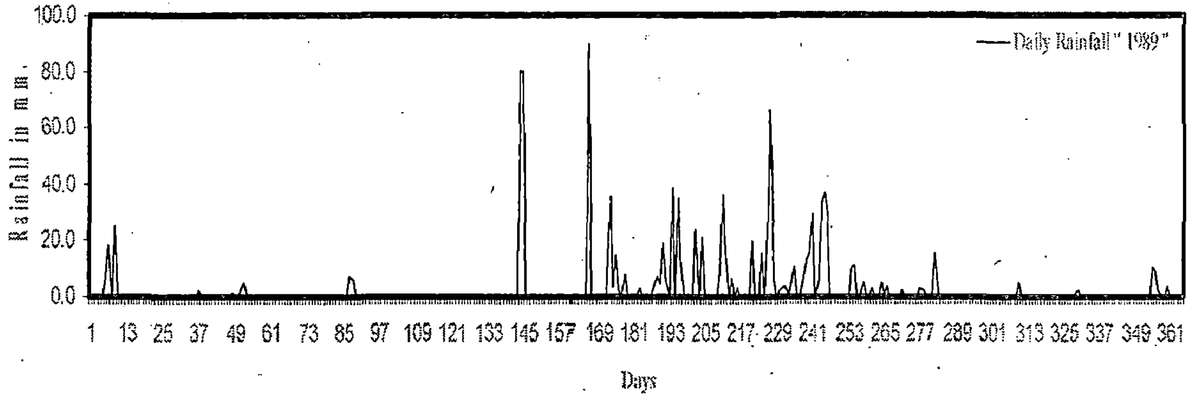

Fig.17 Daily rainfall data recorded at Chaukhutia 1989

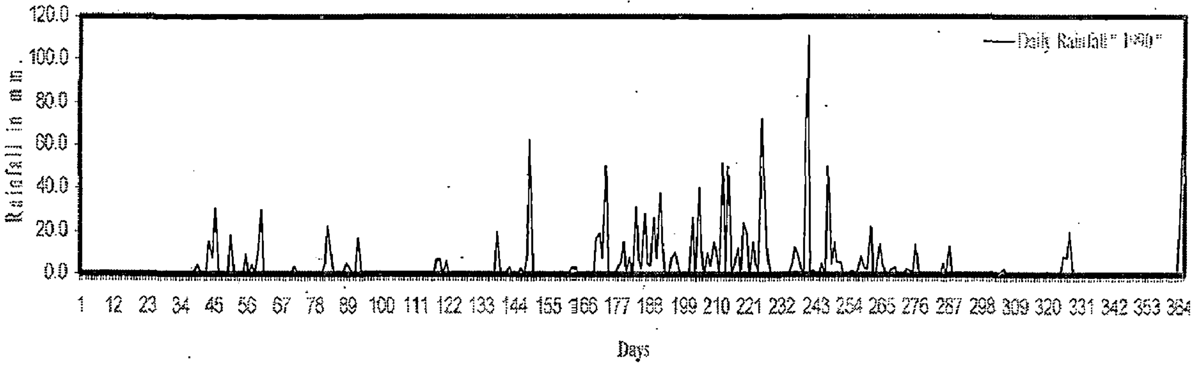

Fig.18 Daily rainfall data recorded at Chaukhutia 1990