THESIS

SOIL EROSION ESTIMATION OF RIVER SOAN CATHMENT USING GIS AND SOIL EROSION MODELS

By

MUHAMMAD AHSAN
(2004-PG-WRE-12)

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University of Engineering and Technology, Lahore, Pakistan.

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ABSTRACT

Climatically major part of Pakistan falls in arid to semi arid zone, where the rains are seasonal and sporadic. Almost all hilly nullahs /hill torrents originating from the mountains of these areas receive non-perennial flows and pass through large tracts of fairly leveled and fertile land before they join the Indus Basin System. These hill torrents bring in flashy floods of shorter duration and higher magnitudes. Due to steep gradients, flood flows move with high velocity, which result in damages to standing crops, irrigation system, houses, roads etc, and some time human lives also. In fact, these hill torrents have lot of potential for agriculture produce to meet up the shortage of food and raw materials for agro based industries, if managed wisely.

Pothowar Hill Torrent one of the major hill torrent of Punjab Province. Pothowar area is one of the regions of Pakistan where the topography is classified as plateau along with intermittent gulleys and ravines; and as such no large canal system can be developed. The physical features of the area dictate the provision of local irrigation system for isolated small tract of land having topographic uniformity. Nevertheless the hill torrents flood flows are mostly wasted except those where storage arrangements have been provided. The plateau comprising the districts of Rawalpindi, Attock, Jhelum and Chakwal, forms about 40% of Punjab Barani (Rain fed) Tract (PBT). A small part of Gujrat District also forms part of Pothowar plateau.

Soil erosion assessment is a capital-intensive and time-consuming exercise. A number of parametric models have been developed to predict soil erosion at drainage basins, Soil erosion model used in this study is based on the methods explained by

Morgan (Morgan, 1986; Morgan and Finney, 1984). Some of the inputs of the model such as cover factor and to a lesser extent supporting conservation practice factor and soil erodibility factor can also be successfully derived from remotely sensed data. In this study, Land sat ortho data was used to identify the land use status of the Soan river basin. Based on maximum likelihood classifier, the area was classified into different land use classes namely, Barren land, Mixed Forest, Open shrub land, closed shrub land, River Bed. Digital Elevation Model (DEM) of soan river basin was used to generate slope maps, R factor, P factor are calculated from Rain fall data, The K factor map was prepared from the soil map and spatial extent was introduced from land use/ cover map. All these maps covering each parameter (R, K, S, C and P) were integrated to generate a composite map of erosion intensity based on the advanced GIS functionality. This intensity map was classified into different priority classes. Each class was analyzed individually in terms of soil type, average slope, drainage length, drainage density, drainage order, height difference, land use / land cover and average soil erosion to find out the dominant factor leads to higher erosion and to provide conservation measures.

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In the name of **ALLAH**, The Beneficent, The Merciful. “Holy art you, no knowledge have we except you have taught us”. **Al-Quran.**

First of all thanks to **Almighty ALLAH**, Who blessed me with sound health, talented teachers, sympathetic friends, prays of my parents and relatives with a sufficient opportunity to complete this study.

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The list of those who have helped the author during this study is long. But, their memories are printed on author’s heart with loving care. At different stages, different people were involved. Most of them could not do more than make a little effort to provide some help in the experimentation. Author prays that God bless them all a comfortable and productive life.

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Muhammad Ahsan

In the name of God

…Dedicated: *To my Father*
To my Mother
To all of them whom I owe what I am

TABLE OF CONTENTS

Table of Contents (Continued)

Table of Contents (Continued)

LIST OF FIGURES

List of Figures (Continued)

List of Figures (Continued)

LIST OF TABLES

Chapter I
INTRODUCTION

1.1 GENERAL

There is nothing in the world of nature, which is more important than deserves as much attention as that soil. Truly it is the soil that makes the world a friendly environment for mankind. It is the soil, which nourishes and provides for the whole of nature: the whole of creation depends on the soil, which is the ultimate foundation of our existence.

Problems associated with soil erosion, movement and deposition of sediment in rivers, lakes and estuaries persist through the geologic ages in almost all parts of the earth. However, the situation is aggravated in recent times with man's increasing interventions with the environment.

1.2 SOIL EROSION

Soil erosion is universally recognized as a serious threat to human beings. Soil erosion has geomorphological, pedological, ecological, social, and economical impacts. The soil is natural resource, which can be considered nonrenewable on a historical time scale. Soil erosion is one of the major causes of soil degradation. The loss of the regional soil resource is insidious, and the resource once lost is lost forever. The recent GLASOD (Global Assessment of Soil Degradation) survey has indicated that more than 10^9 ha of the land surface of the earth are currently experiencing serious soil degradation as a result of water erosion. Worldwide up to 75 billion tones of topsoil are eroded every year and 85% of world's agricultural soils are affected by erosion.

The United States has been one of the leaders in soil conservation efforts in the world. Soil erosion estimates taken from the 1992 National Resources Inventory indicates that average annual soil loss from row crop-agricultural land is greater then 6 tons/acre-years due to water and wind erosion, whereas average crop yield is 4 tons/acre-year of corn cropland. In other words, on the average, more soil is lost than corn produced on cultivated corn cropland in United States.

Some of the soil lost is shifted from one position on the landscape to another, which will eventually result in reduction of productivity for the portion of land. Indeed, the most essential function of the soil is food production. In many parts of the world, in particular the arid and semi arid areas arable land is wasted by erosion forcing farmers to abandon their land, meanwhile the sediment, which is leaving the field, is finding its way to streams and lakes. By assuming that 1.2 tones of freshly deposited sediment occupy one cubic meter, it means that the total losses of the world reservoir volume are 1.7 – 4.2 billion cubic meter per year, same as 0.03-0.07 % per year of the 6000 km^3 of estimated world reservoir storage.

There is strong link between the occurrence of sediment transport and flooding events. Erosion is directly depending on the occurrence of overland flow, which adds to the peak discharge of streams. Measures that reduce erosion may therefore as well be helpful in reducing the peak discharge in streams and flooding problems. The awareness of the necessity of taking action against erosion goes hand in hand with the occurrence of severe events and with the severity of the resulting damage.

1.3 SEDIMENT YIELD

Surface erosion and mass movements within a watershed produce sediment available for transport. The actual amount of eroded material passing a given point in a watershed (usually the outlet) within a given amount of time is termed sediment yield. Sediment yield, usually expressed as tones per unit area of the basin per year. It always less than the total erosion due to sediment storage during transport, and is highly variable because of measurement difficulty, the temporal variability of hydrological processes, and changes in land management practices in the basin from one year to the next.

Sedimentation in the reservoirs is one of the principal factors, which threaten the longevity of reservoirs. Sedimentation reduces the storage capacity of reservoirs and hence their ability to conserve water for various intended purposes.

Estimates of sediment yield have important economic consequences. In many developing countries like Pakistan the estimated reservoir life is very limited. According to White (1988), examples of predicted sediment yield in Asia tend to be between two and sixteen times lower than actual measured rates, with the consequence that actual reservoir life is greatly reduced. Pakistan's important Warsak Reservoir - built in 1960 - is now completely silted up. The water's silt burden has caused serious wear on all rotating parts of the reservoir's hydroelectric generating station, and the main powerhouse structure is suffering from alkali-aggregate reaction. With the correct knowledge of the sedimentation process going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedules can be planned for optimum utilization of water. Sand, silt and clay and other insoluble materials transported by flowing water of streams, either as suspended matter or as bed load present problems of vital importance in many projects for flood control, soil conservation, irrigation, water power development, etc; sometimes complete loss of important engineering works may be experienced due to filling of reservoirs by sediment.

Indus River is 2737 km long, and has a drainage area of 966,000 km^2.Tarbella Dam stores 13.5 km^3 and Manchar Lake stores about 0.7 km^3. In 1981 and 1983, the Indus carried 53.4 and 57.9 km^3 of water and 91.9 and 37.2 million tons sediment respectively.

1.4 FACTORS AFFECTING SOIL EROSION

The brief description of the major factors affecting the soil erosion are listed below

(1). Climatic Factor

- Rain intensity (raindrop impact)
- Glaciers

(2). Topographic Factors

- Basin slope
- Basin size
- Slope length
- Land slides

(3). Soil Characteristics

- Hydraulic properties of soil (rate of infiltration)
- Roughness of soil (Manning's n)
- Detachability of soil by raindrop impact
- Detachability of soil by overland flow
- Moisture content of the soil
- Sediment particle diameters

(4). Land use type

- Surface vegetation
- Canopy cover
- Ground cover
- Crop residues
- Canopy height

(5). Geology/Lithology

- Type of crust material
- Tectonic activity (Volcanoes and Earth quakes)

(6). Human activity

- Agricultural economic development
- Deforestation
- Cropping management
- Cattle grazing
- Road construction
- Urban and rural roads
- Construction equipments

1.5 CONSEQUENCES OF SOIL EROSION

Erosion is a complex natural process that has often been accelerated by human activities such as land clearance, agriculture, construction, surface mining and urbanization. The accelerated erosion rate has both environmental and economic impacts that have resulted in extensive damage and expense. In Pakistan water erosion is a serious problem, particularly in the hilly and mountainous regions and the Photohar plateau. Its severity has increased tremendously because of faulty land use, unscientific management, cutting of trees and excessive grazing.

The negative consequences of uncontrolled forest exploitation in Pakistan are ever more obvious. They include serious soil erosion and sedimentation, desertification of once-productive upland areas, the silting up of waterways in the plains (making them more prone to flooding). The decline in tree cover has already resulted in a large reduction in watershed and reservoir efficiency. Efforts at watershed management should lengthen the life of the projects, such as the Mangela and Tarbella Reservoirs; yet reports indicate that, even in these cases sedimentation is occurring at a rate which could render them inoperative in as little as forty years (*http://home.alltel.net/bsundquist1/se4g.html* accessed October 20th, 2004).

1.5.1 Loss in Fertility of Agricultural Land

Soil productivity refers to the capacity of a soil to produce a certain yield of crops with optimum management. Soil erosion is the most serious tool of destruction of land in rain fed areas. It has been the cause of low agricultural production, disinterest of farmers in their land. The erosion has resulted in aggravated productivity decline and environmental pollution.

Erosion degraded lands are both hungry and thirsty. The fertility mainly lies in topsoil. The loss of productive topsoil and available nutrients, which accompany erosion, reduces the productive capacity of soil. Their productivity loss occurs not only due to fertility depletion but also because of moisture stress.

Soil fertility is only one of a number of factors that determine the magnitude of crop yields. The other soil parameters, which are directly/indirectly related with its productivity, consist of soil texture, soil depth, water characteristics (water holding capacities, water infiltration rates), biological activities etc. All these soil parameters are negatively affected due to erosion, which consequently impair its productivity. (Dr. Muhammad Shafiq, 2003).

(a) Deterioration of soil structure

The soil structure plays an important role in crop production. While loss of favorable structure frequently results from soil erosion, make the exposure of harsh cloddy/dense sub-soil. Yield reduction as a result of this may be permanent. They can be brought back only by good soil management and use of large quantities of organic and inorganic fertilizers. However, it will take a long time

(b) Water losses

Water is vital for crop/plant production. In rain fed areas, rainfall is the main source of water. Studies have indicated that a severely eroded soil was not only lower in organic mater and nitrogen but also lost more rainfall by runoff than did less eroded soils. This phenomenon may be attributed to low water holding capacities and infiltration capacity of eroded soils.

(c) Soil depth

The depth of soil is an important factor in crop yields. Soil degradation because of soil erosion reduces soil depth. Furthermore, exposed sub-soil is dense with very poor infiltration rate and water holding capacities, which further enhances surface runoff and soil loss with very poor crop yields. Exposure of sub-soil also restricts root system, plants face moisture, and nutrient stresses.

(d) Water quality

The role of sediment in chemical pollution is depends upon the particle size of sediment, and the amount of particulate organic carbon associated with the sediment. The chemically active fraction of sediment is usually cited as that portion which is smaller than 63 mm (silt + clay) fraction. For phosphorus and metals, particle size is of primary importance due to the large surface area of very small particles. Phosphorus and metals tend to be highly attracted to ionic exchange sites that are associated with clay particles and with the iron and manganese coatings that commonly occur on these small particles. Many of the persistent, bioaccumulation and toxic organic contaminants, especially chlorinated compounds including many pesticides, are strongly associated with sediment and especially with the organic carbon that is transported as part of the sediment load in rivers. Measurements of phosphorus transport indicate that as much as 90% of the total phosphorus flux in rivers can be in association with suspended sediment.

Chlorinated compounds and other chlorinated pesticides are very hydrophobic and are not, therefore, easily analyzed in water samples due to the very low solubility of the chemical. For organic chemicals, the most important component of the sediment load appears to be the particulate organic carbon fraction, which is transported as part of the sediment (Dr. Muhammad Shafiq, 2003).

Water quality parameters that reflect the level of sediment yield are turbidity and suspended solids. An increase in the concentration of suspended solids may destroy water supplies for human, animal, and other wildlife consumption, as well as feeding and nesting habitats. Implementation of erosion control features consistent with sound construction operations can minimize the adverse impacts associated with increased sediment yield.

1.5.2 Depletion of Reservoirs Capacities

Sedimentation in the reservoirs is one of the principal factors, which threaten the longevity of reservoirs. Sedimentation reduces the storage capacity of reservoirs and hence their ability to conserve water for various intended purposes. Estimates of sediment yield have important economic consequences. In many developing countries like Pakistan the estimated reservoir life is very limited. According to White (1988) examples of predicted sediment yield in Asia tend to be between two and sixteen times lower than actual measured rates, with the consequence that actual reservoir life is greatly reduced. Pakistan's important Warsak Reservoir - built in 1960 - is now completely silted up. The water's silt burden has caused serious wear on all rotating parts of the reservoir's hydroelectric generating station, and the main powerhouse structure is suffering from alkali-aggregate reaction.

The world's dams are losing 1% per year of their capacity due to built up silt, the United Nations Environment Program reported on the International Conference on Freshwater. A capacity of 1500 km^3 of a total of 7000 km^3 could be lost by 2050 (Rodney White, 1999).

Earlier figures by the World Bank also claimed a loss of 1% per year (i.e. 66 km^3/ year). Replacing this lost storage by building new reservoirs could cost $10-$13 billion/ year, assuming enough new reservoir sites could be found. If sediments had to be dredged out of existing reservoirs, the cost would climb to $130-$200 billion/ year (K. Mahmood, 1987).

With the correct knowledge of the sedimentation process going on in a reservoir, remedial measures can be undertaken well in advance and reservoir operation schedules can be planned for optimum utilization of water.

Many of the world's reservoirs are suffering significant reductions in storage capacity as a result of sedimentation, experts said at the International Conference on Freshwater in Bonn. Unless action is taken, 20% of reservoir capacity will be lost over the coming decades, the UN Environment Program warned. Sedimentation rates are now 8 times higher than in the mid-1960s.

1.5.3 Rise in River Bed Level

Erosion occurs on upstream of rivers and deposition on the lower reaches, which reduce the bed slope of the rivers; it reduces the flow velocity and raises the river elevation, which aggravates the flood events. To prevent localities from flood then we need high embankment heights, which increase the maintenance cost.

China's Yellow River-bed rises about 10-cm/ year in North China Plain, now 6-10 m above surrounding plain. Erosion is causing riverbed levels in Terai (Nepal) to rise by 6-12 inches/ year (15-30 cm/ year). The bed of the Bramaputra River rose 5.5 inches in past 5 decades. Bed of Ganges (Ganga) is rising 7-8 cm/ years (*http://home.alltel.net/.html* accessed October 20th, 2004).

1.5.4 Damage to the Environment

Damage to the quality of watercourses, lakes and rivers through excess inputs and increased chemical loading. Increased run off and sedimentation causes greater flood hazard downstream. Sediment in rivers damaging the spawning grounds of fishes and deposition of sediment onto roads, neighboring properties and into drains.

1.6 EFFECTS ON PAKISTAN

In the Pakistan and other arid and semi-arid areas there is a delicate seasonal balance between available moisture and vegetation cover. The slightest change in this balance can begin a chain reaction of removal of cover, surface sealing, decreased infiltration, increased surface runoff, less soil moisture available for plant growth etc. With the removal of vegetation, surface soils are quickly removed by the impact of intense rainstorms and are readily transported by surface runoff. Flow concentrates into rills, rills into gulley, gulley into stream bank erosion; until large quantities of material are being transported as either suspended sediment or bed load. Within a very short time all the nutrient bearing soil horizons are removed, leaving pavements of rock fragments or other large particles, which are too heavy to remove by raindrop impact and surface runoff.

Countries are characterized by a continental type of climate, which is arid and semi-arid. There is an extreme variation in temperature depending on the topography of the Pakistan, which experiences an overall deficiency in rainfall. One fourth of the country's land area, which is suitable for intensive agriculture, is seriously subjected to wind and water erosion, salinity/sodicity, water logging, flooding and loss of organic matter. Watersheds in upper Indus and its tributaries suffer from unfavorable soil and moisture regimes. Accelerated surface erosion due to deforestation in the catchments is reducing the life of Tarbela and Mangla reservoirs.

There is a serious problem of desertification in many parts of the country. Northern mountains of Pakistan are the major source of water for Tarbela and Mangla

Dams. However, due to heavy soil erosion, caused by deforestation in the catchments, these reservoirs are silting up, thus reducing the capacity of power generation and availability of irrigation water.

1.7 DESCRIPTION OF STUDY AREA

Soan river is situated in Pothowar plateau hill torrent area, and is located between longitude 71º45’ to 73º35’ and latitude 32º45’ to 33º55’. Soan River is one of the left bank tributaries of Indus, lies in Rawalpindi, Attock and Jehlum. Lai Nallah originates from Margala hills in Islamabad and outfalls into Soan River. The Soan river rises from the Southern slopes of the Shivalik range also known as Solasinghi range in the tract to the East of the Beas gap across the Southern periphery of the Kangra valley. It joins the boundary of Himachal Pradesh and Punjab. It enters the plains near Chirah, up to Chirah it drains an area of about 137 sq-miles. This varies in elevation from 2200 feet to 7500 feet. In the plains Soan river flows in a southwest direction to join Indus River at about 10 miles up stream of Kalabagh. In plains it is fed by its major tributaries (Ling, Korang, Lai Nalah, Sil River) and flows smoothly with a gentle gradient of about 6 feet/mile. Its gradient is not very steep and the slopes of the Soan catchment vary from gentle to steep. In the summer the discharge drops drastically, while during monsoon it is in spate.

1.7.1 Physiographic

Physiographical area can be divided into two landforms namely, weathered rock plains and mountains & hills. The weathered rock plain is a complex of calcareous loamy

& clayey soils, gullied/bad land and rough broken land. Mountains and hills comprise mountainous lands with some soil cover and with little soil cover.

1.7.2 Climate

Area lies in semi arid to sub-humid zone of climatic region with hot summers and cold winters. The average rainfall at Murree in the north-eastern part, where the major torrents originate, is over 1,500 mm whereas that of Tamman in the South-Western part of the area is 295mm. About 60% of annual rainfall occurs during the Monsoon season and abut 40% in the remaining period. Generally the rainfall intensity goes on decreasing gradually from north-east to south-west. The average annual rainfall covering the plateau is estimated at 675 mm a year. All the streams have steep gradients and bring flash-flows, which are charged with high-silt content.

1.8 PROBLEM STATEMENT

Soil erosion by water is considered as one of the major threats for sustainable land management. Effective land management to prevent soil loss requires prediction for large areas. Erosion of the earth's surface creates serious problems in agriculture and water resources management by the removal of fertile soil and its subsequent deposition in reservoirs. Sediment yield decreases useable storage capacity and thus reduces life of reservoirs. Soil erosion is a natural process; human activities such as construction or vehicular disturbance can substantially increase or decrease the rates of erosion, sediment transport and deposition. Increased erosion and sedimentation can create hazardous conditions, destroy water quality and cause other environmental damage, which requiring costly repairs.

Also the development of all other sector like livestock rearing, fisheries, industries etc is also dependent upon the availability of water .Flood flows of hill torrent of the area are the only potential source which can be managed for economic utilization and socio-cultural development.

It is therefore important to minimize the damages to soil conservation measures. Such planning may seem difficult for large areas but geographic information systems (GIS) can provide the tools to assess the erosion risk, evaluate various disturbance alternatives and spatially optimize conservation measures.

1.9 OBJECTIVES

The main objectives of the study are:

- Analysis of land use parameter including (land cover, Soil type, topography and vegetation cover)
- To identify sediment generated areas
- Application of Soil Erosion models for sediment yield estimation.
- To provide guidelines for soil conservation practices for the study area.

1.10 UTILIZATION OF RESEARCH

The research will be utilized in assessing soil erosion risk of similar catchments, as GIS provides better results for the estimation of sediment yield; also this Research will be utilized to improve soil conservation measures in Soan catchment area. The mitigation measures will be more enhanced because of accurate identification of problem by advance GIS techniques.

Chapter II
LITERATURE REVIEW

In this chapter various types of soil erosion, history of soil erosion research and various soil erosion modeling approaches to estimate soil erosion and sediment yield has discussed. Moreover a detailed discussion is given for the Universal Soil Loss Equation USLE including assessment of its factors.

2.1 TYPES OF SOIL EROSION

Erosion is the gradual wearing away of land by water and wind. Soil erosion is a naturally occurring process on all lands. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss every year.

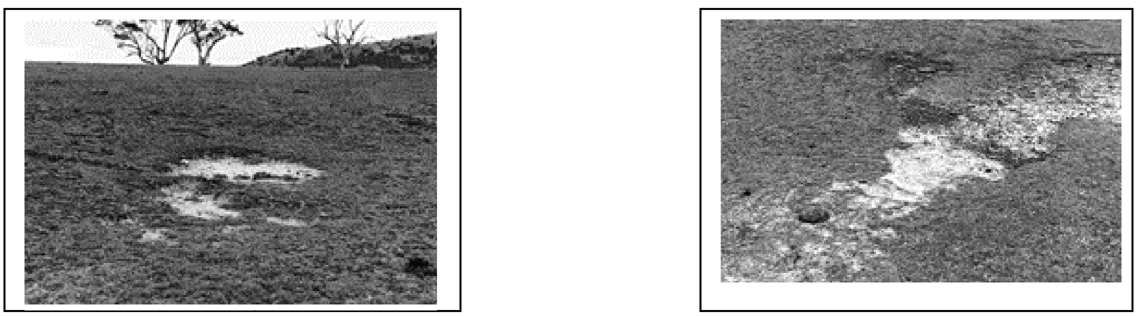
Soil Erosion is a slow process that continues relatively unnoticed, or it may occur an alarming rate causing serious loss of top soil. The loss of soil from farm land may be reflected in reduced crop production potential, lower surface water quality and damaged drainage network. Soil erosion can be explained into following types:

2.1.1 Sheet Erosion

Sheet erosion involves the removal of a uniform thin layer of soil by raindrop splash or water run-off. This thin layer of topsoil often disappears gradually, making it difficult to monitor because the damage is not immediately perceptible. This insidious process is often overlooked until the subsoil is exposed.

Loss of the finest soil particles, to which the bulk of plant-available nutrients and organic matter adhere, affects the productivity of the land. Erosion may also result in removal of seeds or seedlings and reduce the soil's ability to store water for plants to draw upon between rainfall events. Soil deposited off-site through this type of erosion causes crop and pasture damage, water-quality deterioration and stream, dam, lake and reservoir sedimentation.

Generally, repeatedly cultivated soils, fallow soils or soils that are bare through overgrazing by stock or pest animals are particularly vulnerable for sheet erosion.



a) Early stage of sheet erosion

b) Sheet erosion in action displaying fine sediment runoff leaving coarser material

Fig 2.1 Phenomenon of Sheet erosion.

2.1.2 Gully Erosion

Once rills are large enough to restrict vehicular access they are referred to as gullies or gully erosion. Major concentrations of high-velocity run-off water in these larger rills remove vast amounts of soil. This results in deeply incised gullies occurring along depressions and drainage lines.

Removal of topsoil and subsoil by fast-flowing surface water creates abrupt deep and wide gullies, of two different kinds: scour gullies and head ward erosion. In scour gullies, run-off water concentrated in rills or depressions removes soil particles through sluicing the washing effect of running water on loose grains.

Material commonly moved is the size of fine to medium sand or may be derived from slaking, when large aggregates disintegrate upon wetting. Scour gullies are often associated with gently undulating landscapes. In head ward erosion the gully extends upstream as a result of waterfall undercutting and gravitational slumping of the gully head. It is often associated with (although not confined to) steeper landscapes. In both cases gullies may widen through lateral erosion, where water undercutting causes subsequent slumping of the sides. Gully sides may also be subject to splash, sheet or rill erosion.

Impacts of Gully Erosion and Potential Problem Areas

Gully erosion means the loss of large volumes of soil. Deep wide gullies, sometimes reaching 30m deep, severely limit the use of the land, while off-site deposition of soil causes water-quality decline in streams or rivers and sedimentation of dams and reservoirs. Large gullies disrupt normal farm operations, creating access problems for vehicles and stock.

Gully erosion often occurs on lower slopes, but can form quite high in the landscape in particularly susceptible areas. Areas commonly affected have dispersible subsoils when exposed.

Fig 2.2 Gully erosion.

2.1.3 Rill Erosion

Rill erosion often occurs with sheet erosion and is commonly seen in paddocks of recently cultivated soils following high-intensity rainfall. It is easily identified as a series of little channels or rills up to 30 cm deep.

If rainfall exceeds infiltration, a surface film of water forms (see sheet erosion). Rill erosion results from a concentration of this surface water into deeper, faster-flowing channels, which follow depressions or low points through paddocks. The shearing power of the water can detach, pick up and remove soil particles making these channels the preferred routes for sediment transport. Rill erosion is often described as the intermediate stage between sheet and gully erosion.

Impacts of Rill Erosion and Potential Problem Areas

The loss of topsoil and nutrients reduces productivity greatly, as the remaining subsoils are often much less fertile. Also related soil deposition off-site causes sedimentation of streams, dams and reservoirs, resulting in water-quality deterioration and damage to aquatic habitats.

Rill erosion is common on agricultural land devoid of vegetation and so is often seen in cropping areas after tillage. Following intense rainfall cultivated topsoils overlying denser cohesive subsoils often exhibit rill erosion. Texture-contrast (duplex) soils are susceptible, as are poorly managed pasture areas where overgrazing occurs.

a) Rill in a recent cultivated paddock

b) A surface film of water forming on recent cultivated paddock

Fig 2.3 Rill erosion.

2.1.4 Tunnel Erosion

Water scouring or seeping through susceptible subsoil can form underground channels. Tunneling often accompanies poor vegetative cover, sheet erosion and increased surface run-off. Tunnel erosion is initiated by water moving into and through dispersive sub soils. It often results from water accumulating and moving along cracks or channels or into rabbit burrows and old tree root cavities. Tunnels require an adequate gradient to initiate the runoff speed necessary to drive free water through the soil. As the tunnel increases in size, parts of the tunnel roof collapse resulting in potholes and gullies.

Such erosion leads to loss of productive capability, deposition of infertile subsoils in lower more fertile landscapes and high sediment loads in streams or rivers. In the worst cases tunnels provide a hazard by collapsing restricting safe access and forming gullies. It occurs generally on cleared hilly terrain with an average rainfall of 300-650 mm, particularly on erodible soil.

Fig 2.4 Tunnel erosion.

2.1.5 Channel Erosion

Channel erosion occurs in watercourse channels and streams and includes both streambed and stream bank erosion. Channel erosion is the direct removal of banks and beds by flowing water. Typically, it occurs during periods of high stream flow. It is sometimes confused with gully erosion as this has similarities with seasonal or ephemeral streams. Erosion of stream or riverbanks through lateral (side) erosion and collapse often causes high sediment loads in creeks and rivers. The problem is often initiated by heavy falls of rain in catchments with poor vegetation cover, causing excess run-off. The resultant high volume and velocity runoff will concentrate in the lower drainage lines or streams within catchments. When the stress applied by these stream flows exceeds the resistance of the local soil material, stream bank and stream bed erosion occurs.

As the sediment load increases, fast-flowing streams grind and excavate their banks lower in the landscape. Later, the stream becomes overloaded or velocity is reduced, and deposition of sediment takes place further downstream or finally in dams and reservoirs

In addition to loss of productive land due to bank erosion and bed erosion, dramatic changes in the course of a river or creek often restrict access on properties. Subsequent deposition of soil causes problems on productive land downstream and sedimentation in reservoirs. Other problems include reduction in water quality due to high sediment loads, loss of native aquatic habitats, damage to public utilities (roads, bridges and dams) and maintenance costs associated with trying to prevent or control erosion sites.

Catchments with little vegetation cover and steep gradients will often have high rates of water run-off that result in high-velocity stream flows. Stream straightening, dredging or realignment to accommodate roads or rail lines leads to increased stream power and velocity, which in turn will increase the energy applied to stream banks. The erosive impact of these high-velocity stream flows will depend on the stability of the bank material. For instance, sand will erode more easily than gravel and silt will erode more easily than sand.

Creeks or streams may change direction or cut new channels very rapidly in storms, while over longer periods they may change course. Sediments deposited in lower-flow periods may obstruct the natural flow of streams or ultimately fill reservoirs.

Fig 2.5 Channel erosion.

2.1.6 Wind Erosion

Wind erosion is the movement and deposition of soil particles by wind. Wind erosion is highly visible. Although it is a problem, water erosion is generally much more severe.

Wind erosion occurs when soils bared of vegetation are exposed to high-velocity wind. When its velocity overcomes the gravitational and cohesive forces of the soil particles, wind will move soil and carry it away in suspension.

The process sorts soil particles, removing the finer material containing the organic matter, clay and silt through suspension and leaving the coarser, less fertile material behind. Wind erosion mainly affects inland farming (especially cropping) areas with annual rainfall below 375 mm per year and having predominantly sandy soils with low levels of organic matter.

Fig 2.6 Wind Erosion.

2.2 STUDIES ON SOIL EROSION

Research on soil erosion and its effect on agricultural productivity started in 1930s. During 1940 and 1956, research scientists began to develop a quantitative procedure for estimating soil loss in the Corn Belt in the United States. Several factors were introduced to an early soil loss equation, in which slope and practice were primarily considered. It was recognized that a soil loss equation could have a great value for farm planning and the Corn Belt equation could be adapted for other regions.

In 1946, a group of erosion specialists held a workshop in Ohio to reappraise the factors previously used and added a rainfall factor. U.S. Department of Agriculture, Agricultural Research Service (ARS) established the National Runoff and Soil Loss Data Center at Purdue University in 1954 to locate, assemble, and consolidate all available data throughout the United States. More than 10,000 plot-years of basic runoff and soil loss data were then collected from U.S. federal-state cooperative research projects in 49 U.S. locations.

Based on the data assembled at the Data Center and previous studies, Wischmeier, Smith, and others developed the Universal Soil Loss Equation (USLE). USLE has become the major conservation-planning tool, which is used in the United States and other countries in the world.

2.3 UNIVERSAL SOIL LOSS EQUATION (USLE)

Universal Soil Loss Equation was developed by (U.S. Department of Agriculture) scientists Wischmeier and D. Smith. The Universal Soil Loss Equation is a simplified model to estimate soil erosion and was found to be most commonly used throughout the literature because of its simplicity (Bahr, 1999). USLE has been the most widely accepted and utilized soil loss equation for over 30 years.

Universal soil loss equation is most commonly used regression model for predicting soil erosion. Different reports indicate that about 250,000 individual soil loss measurements from small field plots at 45 research stations while developing this model. Although USLE was developed in United States, but it has been widely used throughout the world. The reason of this wide spread use of USLE is that it seems to meet the requirements of research better than any other available tool (Risse et al.1993).

2.4 FACTORS OF UNIVERSAL SOIL LOSS EQUATION (USLE)

Five major factors are used to calculate the soil loss for a given site. Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages.

USLE only predicts the amount of soil loss that results from sheet or rill erosion on a single slope and does not account for additional soil losses that might occur from gully, wind or tillage erosion. This erosion model was created for use in selected cropping and management systems, but is also applicable to non-agricultural conditions such as construction sites

The mean annual erosion rate is expressed as a function of six parameters by Wischmeier and Smith which are considered as the main factors of erosion. Thus we can have the following equation:

$$A = R \times K \times L \times S \times C \times P \tag{2.1}$$

Where,

A = the computed spatial average soil loss and temporal soil loss per unit of area

R = rainfall-runoff erositivity factor or rainfall erosion index

K = soil erodibility factor

L = slope length factor

S = slope gradient factor

C = vegetation cover and crop management factor

P = erosion control practice factor or support practice factor

2.4.1 Rainfall Erosion Factor (R)

Rainfall erosivity Index (R) is generally calculated from an annual summation of rainfall data using rainfall energy over 30-minute duration (Bahr, 1999). The relative fall velocity of the single droplet and the overall rainfall intensity determines the erosive properties of rain droplets (Hrissanthou, 2003).

The rainfall erosion factor is main driving energy source of the USLE model. Rain energy e multiply by maximum hourly intensity I30 (mmhr-1) gives the rainfall erosion R for particular rain event. After summation of each individual R-value for all rainfall events of the year, taking the average value for longer period more then 20 years gives the annual average R-value.

$$R = \sum_{i \approx 1}^{j} (E\, I_{30})_j \Big/ N \tag{2.2}$$

Where

$(E\, I_{30})_J$ is E I_{30} for storms i.

J = number of storms in a N year period.

I_{30} is maximum 30 min rain intensity ($mmhr^{-1}$), and

E can be find out from brown and foster relationship

$$E = 0.29\ \{1 - 0.72\ \exp(-0.05 I_r)\} \quad (\mathrm{MJha^{-1}mm^{-1}}) \tag{2.3}$$

Rain intensity for particular storm can be written as

$$I_r = \Delta V_r / \Delta t_r \tag{2.4}$$

Where

ΔV_r = depth of rain fall (mm) for the period.

Δt_r = duration of constant rain fall in hours.

Total kinetic energy

$$KE = \sum_{r\approx 1}^{m} e_r V_r \tag{2.5}$$

Average annual rainfall and runoff erosivity factor R (MJ mm ha^{-1} year^{-1})

$$R = 1 / N \sum_{J\approx 1}^{n} \{\sum_{K\approx 1}^{m} (E)\ K\ (I30)\ k\}\ J \tag{2.6}$$

Where,

n is the number of years used for averaging, m is the number of rain events in each year.

2.4.2 Soil Erodibility Factor (K)

Soil erodibility Factor (K) is designed to account for the bonding or cohesion between the particles of a specific soil type regarding the soils' resistance to dislodgment or transportation by overland flow or runoff. When volume of overland flow is greater than the rate of soil detachment or if the detachment is greater than overland flow, soil loss will occur (Sanjay, 2001). This factor is also somewhat variable in that most soils retain water from the initial rain event, creating an erosion resistant layer, however, the threshold for maintaining this protective layer is easily over-exceeded through saturation and thus erosion will occur (Marsh, 1996; Nyabeze, 2003). Although soil erosion does not happen as readily in urban environments in comparison to rural regions, construction processes that are common occurring events within urban regions are one of the largest single contributors to sedimentation of fluvial systems (Marsh, 1996). Organic compounds are resistant to erosion and are therefore classified with a higher value whereas sand-based soils are more susceptible to erosion, and are quantified using a lower value (Brady, 1984).

$$K = [2.1 \times 10^{-4} (12 – OM) \times M^{1.14} + 3.25 (S-2) + 2.5 (P-3)] / 759 \qquad (2.7)$$

Where,

OM = % organic matter

M = product of the primary particle size fraction

= (% modified silt) (% silt + % sand)

S = classes for structure (s)

P = permeability

- % Percentage modified silt (0.002 – 0.1 mm)
- % Percentage modified sand (0.1 – 2 mm)

The K is the soil erodibility factor (tons ha hr / ha MJ mm).

2.4.3 Slope Length and Steepness Factor (LS)

(a) Slope length factor (L)

It is define as the horizontal distance from the origin of overland flow to the point either the slope gradient decreases enough that deposition begin or runoff concentrated in defined channel.

Empirical equation

$$L = (\lambda)^{m} / 22.1 \tag{2.8}$$

Where

λ = Slope length (m)

m = ranges from 0.2 to 0.5 depends upon the steepness of area.

Table 2.1 Adjustment of m value according to slopes.

SLOPE RANGE	M
>1 %	0.2
1- 3 %	0.3
3.1 – 4.9 %	0.4
> 5 %	0.5

McCool et al, (1989) have different value of slope length for standard experimental field (22m) and inclusion of slope gradient for the estimation of parameter (M).

Empirical equation

$$L = (l)^{m} / 22.1 \tag{2.9}$$

(b) Slope steepness factor (S)

Empirical relation for the S factor appears to be quadratic with the slope steepness of the target area

$$S = 0.065 + (0.045)\ s + (0.0065)\ s^2 \tag{2.10}$$

Where, S is the slope in percentage

2.4.4 Topographic Factor

Some researcher want to put Slope length factor (L) and Slope steepness factor (S) together so combination of L and S is a Topographical Factors (LS), where (L) is slope length and (S) is slope steepness, account for variation in the landscape regarding elevation and larger scale features and how these factors influence soil erosion. Slope steepness influences the velocity so that areas with greater slope gradients are capable of achieving higher overland flow velocity, generating more potential energy to further erode the surface (The Soil Erosion Site, 2004). In a similar manner, increasing the slope length provides more surface area that has the potential to be eroded by uphill sediments abrading the surface as they move downhill. In other words, as the slope length and gradient are increased, the potential for erosion is also increased (Marsh, 1996; Stone, 2000). The LS values are determined based on the characteristic of the slope for both length and slope steepness and then assigned a specific value.

$$LS = \{(\lambda)^m/22.1\}\{0.065 + (0.045)s + (0.0065)s^2\} \tag{2.11}$$

2.4.5 Crop Management and Vegetation Cover Factor

Cropping Factors (C) and types of vegetation cover can be analyzed together as both incorporate and compensate for variance between seasons, types of crop, crop yield, and crop rotation. This is significant because it influences the interception of rainfall onto the soil layer. Interception by ground cover not only lowers the potential of erosion by the splash effect, but it also reduces the overall volume of water reaching the surface, thus reducing the potential for overland flow to occur (Ritter, 1995). Land cover as developed by anthropogenic development also becomes significant as the impervious regions that generally make up urban environments allow little, if any, water to infiltrate into the ground surface through natural processes (Arnell, 2002).

2.4.6 Conservation Practice Factor (P)

Conservation Practice Factor (P) variable accounts for variations in agricultural management practices such as strip cropping and terracing. Strip cropping and contour plowing practices are designed to retain soil moisture and stop as much soil loss from the region as possible. Each of these methods relates to the total amount of cover over the agricultural area at one time as a means of protecting the soil from potential runoff (Marsh, 1996).

Agricultural practices generally require the usage of large-scale machines to maintain large-scale agricultural development and impact the soil both directly and non-directly. Plowing practices alters soil structure and the natural horizon layers within the soil and the use of large machines results in the compaction of the soil, thus reducing infiltration and increasing overland flow (Arnell, 2002).

Table 2.2 C and P factors and the classification of land use

Land cover	C-factor	P-factor
Forest	0.001	1.0
Agricultural Area	0.650	0.5
Paddy Field	0.100	0.5
Grass land / Shrub	0.150	0.5
Wetland	0.560	1.0
Mixture	0.400	0.5
Drainage/Water	1.000	1.0
Built up Area	1.000	1.0
Barren Area	0.280	1.0

2.5 LIMITATIONS OF USLE

Designed as a method to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. USLE is pretty much out-of-date, but still most widely used erosion prediction method. It is seriously inaccurate under many circumstances and is technologically obsolete. Erosion processes are not explicitly represented as physical processes in the USLE. It was scheduled for temporary replacement by the Revised USLE in 1991, which was supposed to replace by the WEPP models in 1995. However, RUSLE is gaining popularity and will replace most applications of the USLE soon.

EI - Does not accurately reflect rainfall characteristics.

K - The more we study it, the less we seem to know.

S - Too large on steep slopes. The relationship is more linear on steep slopes.

C - Canopy and soil roughness effects are not represented well.

P - For contouring should vary with ridge height and EI of 10-year storm

However, USLE is still widely used, as WEPP and RUSLE are too difficult to use for most users. USLE has been used throughout world because it seems to meet the need of research better than any other available tool (Risse et al., 1993). Despite the limitations of USLE, it proved to be the best prediction model for the project as it offered the most accurate results with the simplest application.

2.6 OTHER METHODS FOR ESTIMATING SOIL LOSS

Methods for estimating soil erosion were first developed for analysis of agricultural practices. Many different methods are now available to estimate sediment yield for basins with a variety of land uses. Some of the more popular methods are described below.

2.6.1 Modified Universal Soil Loss Equation (MUSLE)

Modified USLE (MUSLE) uses the same empirical principles as USLE. However, it includes numerous improvements, such as monthly factors, influence of profile convexity/concavity using segmentation of irregular slopes and improved empirical equations for the computation of LS factor (Foster & Wischmeier 1974, Renard et al. 1991).

The application of the USLE is limited to soil loss and develop another procedure for computing sediment yield from catchments. This method calculates the sediment yield based on the single storm event. They introduce a runoff factor instead of rainfall energy into the USLE to establish soil loss. This make the MUSLE more applicable to arid regions of the west, since the effect of short duration high intensity events can more adequately represented. This method modified the R in the USLE in order to predict erosion from a single storm event. The modified R represents the product of runoff volume and peak discharge for a single storm event.

The MUSLE can be expressed as follows:

$$Y_s = a\,(Q_v . q_p)^{ß}\ K\ L\ S\ C\ P \tag{2.12}$$

Where as Y_s is the sediment yield, Q_v runoff volume, q_p is the peak flow rate, a and β are coefficient and K, LS, C, P are soil erodibility factor, topographic factor, cropping and management factor and support practice factor respectively.

2.6.2 Revised Universal Soil Loss Equation (RUSLE)

In 1985 the USDA decided to revise the USLE in order to improve its performance. As a result a new equation called RUSLE (Revised Universal Soil Loss Equation) was developed. Although this new model maintains the basic structure of the USLE the algorithm for calculating the individual factors have changed significantly. These changes are mainly due to new computer technology to assist the calculation of complex factors. This method was developed to update and extend the USLE for non-agricultural applications and to incorporate additional data collected after development of the original USLE.

RUSLE has the same formula as USLE, but has several improvements in determining factors. These include some new and revised isoerodent maps; a time-varying approach for soil erodibility factor; a subfactor approach for evaluating the cover-management factor; a new equation to reflect slope length and steepness; and new conservation-practice values (Renard, et al., 1997).

The Revised Universal Soil Loss Equation (RUSLE) is a set of mathematical equations that estimate average annual soil loss and sediment yield resulting from inter-rill and rill erosion. It is derived from the theory of erosion processes, more than 10,000 plot-years of data from natural rainfall plots, and numerous rainfall-simulation plots. RUSLE is an exceptionally well-validated and documented equation. Strength of RUSLE is that it was developed by a group of internationally recognized scientists and soil conservationists who had considerable experience with erosional processes.

RUSLE reflects the evolutionary development of erosion-prediction technology. For nearly 100 years, erosion data have been collected, analyzed, presented, and discussed in the professional arenas of agricultural and civil engineers, agronomists, soil scientists, geologists, hydrologists, and geomorphologists. The breadth and depth of these scientific investigations allow confidence in the application of RUSLE for the estimation of soil loss from mined lands, construction sites, and reclaimed lands.

RUSLE resulted from a 1985 workshop of government agency and university soil-erosion scientists. The workshop participants concluded that the USLE should be updated to incorporate the considerable amount of erosion information that had accumulated since the publication of Agriculture Handbook 537 (1978) and to specifically address the application of the USLE to land uses other than agriculture. This effort resulted in the computerized technology of RUSLE as fully described in Agriculture Handbook 703 (1997).

The development of RUSLE included several USLE modifications of importance to mined lands, construction sites, and reclaimed land applications. The climate data set in the CITY files was greatly expanded to include weather bureau stations at many more locations. The K (soil erodibility) factor was modified to account for the variability of soil erodibility during the year. Both the K and C (cover management) factors now take into account the multivariate influence of rock-fragment covers within soil profiles and fragments resting upon hill slope surfaces. The equations used to estimate the LS (hill slope length and steepness) factor were reconstituted to improve their accuracy and extended to include steeper hill slope gradients than the equations contained in the USLE. The method of determining C factor values was modified using a sub-factor approach that incorporates input values describing the main features of a cover-management system as it influences soil-loss rates. Consequently, RUSLE now can be applied to many more field conditions, and provides much more site-specific C values than does the USLE. New process-based equations were developed to estimate P (support practice) values, overcoming a major limitation of the USLE. These equations accommodate a wide range of site-specific practice conditions and can estimate sediment yield for concave hill slopes. Collectively, every factor included in the USLE and its supporting data was reexamined in the development of RUSLE. The new information compiled since 1978 was analyzed in the development of RUSLE. In every way, RUSLE is an improved erosion-estimation technology. Although perhaps convenient, the USLE no longer should be used for soil-loss estimation, as RUSLE estimates better reflect the actual field conditions. Both RUSLE and USLE can be expressed as follows:

$$A = R \times K \times LS \times C \times P \tag{2.13}$$

Where,

A = estimated average soil loss in tons per km^2 per year

R = rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = support practice factor

Another factor for soils is called "T value" which stands for "Tolerable Soil Loss." It is not directly used in RUSLE equation, but is often used along with RUSLE for conservation planning. Soil loss tolerance (T) is the maximum amount of soil loss in tons per acre per year that can be tolerated and still permit a high level of crop productivity to be sustained economically and indefinitely.

2.7 SOILS AND GROUND COVER

Each type of soil has its own inherent susceptibility to the forces of erosion, in large part because of chemical composition and organic matter content. Although large-grained materials are easily detached by raindrop splash or flowing water, they are not easily transported.

On the other hand, fine soils such as clays and fine silts that bond together tightly are not easily detached, but once free they are transported with little difficulty. For this reason, fine materials can be carried considerable distances; whereas larger particles are deposited somewhere along the flow path. Mulch and vegetative covers play an important role in hindering the erosion process. For example, mulch lying directly on the ground and completely covering the soil surface absorbs the force of a falling raindrop and thus eliminates splash erosion.

Canopy covers will also reduce drop erosion to a great extent. Close growing plants catch raindrops and keep them from hitting the soil directly. Much of the water runs down the plant stem, although some of it runs off the leaves. Falling on bare soil, these drops cause a small amount of detachment, but since they have not fallen far enough to reach an erosive velocity of any significance, detachment is less than with no canopy cover.

Trees provide less protection for bare soil because of the greater height from which the drops fall. However, forests usually contain protective ground cover in the form of leaf or needle mulch.

Not only do ground covers intercept raindrops and keep them from detaching soil particles, but these covers also prevent soil compaction, which restricts infiltration of water into the soil. With greater infiltration there is less runoff. However, some runoff with transport capacity will occur.

Even when no particles are detached by raindrop splash, the flow itself, forming larger and larger rivulets, can eventually loosen particles. By slowing down the velocity of flowing water, vegetation is helpful in reducing flow erosion. In a highly susceptible soil, some rill erosion may occur beneath the mulch cover, but the flow is impeded and the degree of erosion reduced.

Chapter III
THEORETICAL BACKGROUND

The sediment delivery system is a major research subject nowadays, in which a lot of questions are still left unanswered. Walling (1990) indicate that there are many uncertainties surrounding the modeling and prediction of sediment delivery, and quotes U.S. researcher “predicting how much of the eroded soil will be delivered eventually to the channel of a neighboring stream still remain difficult”. This latter conclusion was drawn even through the methods for estimating on-site erosion is quite extensive in the United States. Essentially, the problem is that there is rather limited knowledge about the sediment delivery system.

3.1 SEDIMENT YIELD

Sediment yield, usually expressed as tones per unit area of the basin per year, is the amount of sediment measured at some point in the basin divided by the basin area. It always less than the total erosion due to sediment storage during transport, and is highly variable because of measurement difficulty, the temporal variability of hydrological processes, and changes in land management practices in the basin from one year to the next. Sediment yield values are also highly variable in time, with smaller basins subject to greater variability than larger basins. Consequently, published values for sediment yield (tons/ha/yr) must be interpreted with great caution.

Another feature of accelerated erosion is the destructive power of rivers in flood. Changes in course, undermining of embankments, bridges or spillways, and the destruction of vegetation or of human habitations are commonplace throughout the semi-arid tropics. In the wake of the destructive flood wave, flows decrease, following the pattern of the recession limb of the hydrograph. Gradually decreasing velocities cause the river to drop its charge of sediment, rapidly filling up surface water reservoirs, diversion weirs, irrigation channels and any water control features. The effects of erosion and deposition, therefore, must be taken into account in any development of surface water resources. Clearly, there is little point in investing in surface water in a catchment, which is suffering from accelerated erosion until a management plan for soil and water conservation is implemented over the whole catchment.

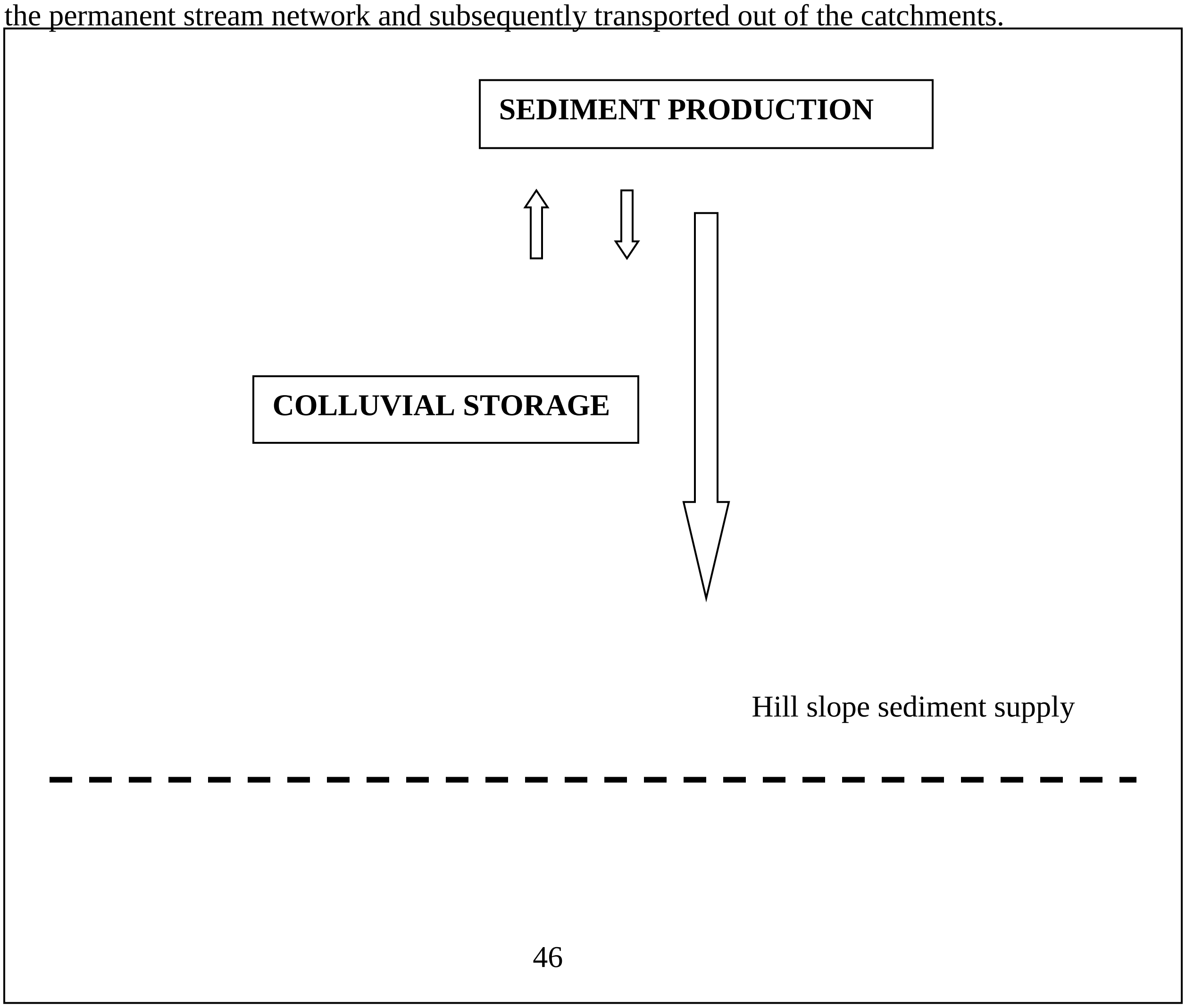
The measurement of sedimentation (embodying the processes of erosion, entrainment, transportation and deposition) is a complex subject. The financial cost of damage produced by sedimentation is enormous.

3.2 SEDIMENT SUPPLY FROM HILL SLOPES

The river sediment is supply by down slope movement of loose soil material on valley side slope with or without the assistance of overland water flow within the basin. Example of sediment producing hill slope processes is soil erosion by overland flow and rain splash, landslide, earth flow and the dispersed clay traveling toward stream in subsurface flow. Another part of the suspended sediment load of the river derives from channel processes like bed and bank erosion. The sediment supply to rivers varies in space and time for the same reason as the water supply, but the variability for sediment is larger due to fluid and / or gravity force threshold for down slope movement and due to the discrete character of mass movement events. A part of the supplied sediment travels at the speed of the fluid and only settles in places where turbulences intensity in low (e.g. lakes, reservoir, flood plains etc).

Once the soil partials are detached due to the rain drop impact and overland flow, then these are carried by the flow depending on its transport capacity and load carried by the flow, if the total detached load is less than the remaining transport capacity of the flow then the material is carried away (erosion) otherwise material is dropped by the flow (deposition).

Not all sediment that is produced on hill slope by soil erosion reaches a branch of the permanent stream network and subsequently transported out of the catchments.



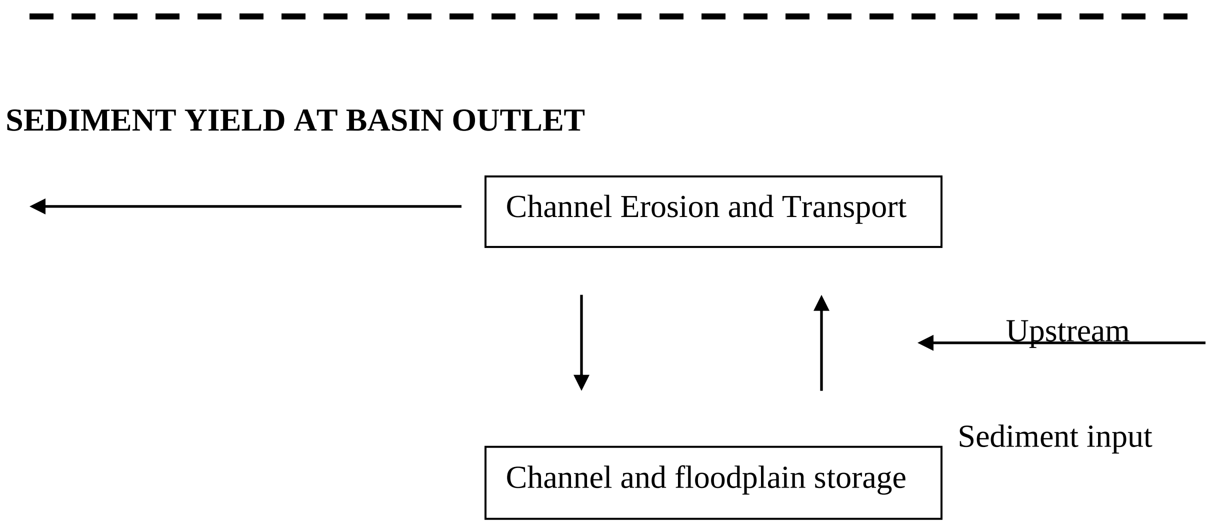


Fig. 3.1 Flowchart of hill slope sediment supply and the fate of delivered sediment in channels.

High levels of sedimentation in rivers lead to physical disruption of the hydraulic characteristics of the channel. This can have serious impacts on navigation through reduction in depth of the channel, and can lead to increased flooding because of reductions in capacity of the river channel to efficiently route water through the drainage basin. For example, calculations of erosion and sediment transport in the San Francisco River Basin, a large drainage system in eastern Brazil, demonstrate that the central portion of the river basin is now dominated by sediment deposition. This has resulted in serious disruption of river transportation, and clogs hydraulic facilities that have been built to provide irrigation water from the main river channel. The sediment largely originates from rapidly eroding sub-basins due to poor agricultural practices.

Sand, silt and clay and other insoluble materials transported by flowing water of streams, either as suspended matter or as bed load present problems of vital importance in many projects for flood control, soil conservation, irrigation, water power development, etc; sometimes complete loss of important engineering works may be experienced due to filling of reservoirs by sediment. Whenever there is a coordinated development of the Water potential of a country, the sedimentation of reservoirs, the entry of suspended matter along with water into canals, and other sediment phenomena are important problems to river basin planners. The design and sizing of many hydraulics structures require a Pre-determined knowledge of the quality and quantity of suspended. Particles carried by water. This necessitates a comprehensive study of sediment carrying capacity of streams, the quantity of total sediment deposited in reservoirs, the particle size of the sediment, and the quantitative relation of sediment to the flow of water.

3.3 GEOGRAPHIC INFORMATION SYSTEM

A Geographic Information Systems (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geographic data. GIS is not new. Since the late 1960,s, computers have been used to store and process geographic data.

For many years, through, GIS has been considered to be too difficult, expensive, and proprietary. The advent of the graphical user interface (GUI), powerful and affordable hardware and software and public digital data has broadened the range of GIS applications and brought GIS to mainstream use.

3.4 APPLICATION OF GIS

Application for GIS technology developed around the world. Many of the early application in Europe built land registration system and environmental database. However, Britain's largest GIS expenditure in the 1980s was for developing utility system and creating a comprehensive topographic database for the country.

Application in China and Japan emphasized monitoring and modeling possible environmental changes. In the United States, the U.S. Bureau of census and the U.S. Geological Survey used GIS technology for their Topographically Integrated Geographic Encoding and Referencing (TIGER) project. They produced a computerized description of the U.S. transportation network to facilitate taking and reporting the 1990 census.

Since the beginning, GIS has been important in natural resource management, such as land use planning, timber management, wildlife habitat analysis, riparian zone monitoring, and natural hazard assessment. In more recent year GIS has been used in emergency planning, market analysis, facilities management, transportation planning, and military applications.

GIS support the daily activity of automated mapping and facilities management with applications for electricity, water, sewer, gas, telecommunications, survey, transportation and traffic engineering using capabilities such as load management, voltage drop, base map generation maintenance, line system analysis, siting, network pressure and flow analysis, leak detection, and inventory. Demographers use GIS for target map analysis, facility siting, address matching and geocoding, as well as product profiles, forecasting, and planning.

Integration of GIS with other technologies such as Global Positioning System (GPS) and the Internet has introduced new application such as precision farming, interactive mapping on the Internet and location – based services. A new application that has been promoted by GIS companies is called location-based services (LBS). This application allows users to deliver and receive information that is related to a particular location through wireless communication. In summary, GIS has become one type of information system, specializing in information that has geographic or spatial component.

The users become part of the GIS whenever complicate analyses, such as spatial analyses and modeling, have to be carried out. These usually require skill in selecting and using tools from the GIS toolbox and intimate knowledge of the data being used. At present and for years to come general purpose GIS will rely on users to know what they are doing.

3.5 GIS AS A DECISION MAKING TOOL

GIS is an ideal tool to use to analyze and solve multiple criteria problems

- GIS databases combine spatial and non-spatial information.

- A GIS generally has ideal data viewing capabilities - it allows for efficient and effective visual examinations of solutions.
- A GIS generally allows users to interactively modify solutions to perform sensitivity analysis.
- A GIS, by definition, should also contain spatial query and analytical capabilities such as measurement of area, distance measurement, overlay capability, corridor analysis.
- GIS has the potential to become a very powerful tool to assist in multiple criteria spatial decision making and conflict resolution.
- Some GIS have already integrated multiple criteria methods with reasonable success.

3.6 COMPONENTS OF GIS

The ability of GIS to handle and process geographically referenced data distinguishes GIS from other information systems. Geographically referenced data describe both the location and characteristics of spatial features on the earth's surface. Roads and land use types are spatial features as are precipitation and elevation. GIS therefore involves two geographic data components i.e. spatial data related to the geometry of spatial features and Attribute data gives the information about the spatial features.

GIS is not simply a computer system for making maps, although it can create maps at different scales, in different projections, and with different colors. A GIS is an analytical tool. The major advantage of a GIS is that it allows user to identify the spatial relationships between map features.

GIS does not store a map in any conventional sense nor dose it store a particular image or view of a geographic area. Instead, a GIS stores the data from which user can draw a desired view to suit a particular purpose.

GIS links spatial data with geographic information, about a particular feature on a map. The information is stored as attributes of the graphically represented feature. For example, the centerline that represents a road on a map doesn't tell user about the road except its location. To find out the road's width or pavement type, user must query the database. Using the information stored in the database, user could create a display symbolizing the roads according to the type of information that needs to be shown.

A GIS also uses the stored feature attributes to computer new information about map features: for example, to calculate the length of a particular road segment or to determine the total area of a particular soil type.

3.7 GEOGRAPHIC DATABASE

In short, a GIS does not hold maps or pictures rather it holds a database. The database concept is central to a GIS and is the main difference between a GIS and drafting or computer mapping systems, which can only produce good graphic output. All contemporary geographic information systems incorporate a database management system.

If user wants to go beyond just making pictures, user need to know three things about every feature stored in the computer: what it is, where it is, and how it relates to other features (e.g., which roads link to form network). Database systems provide the meanings of storing a wide range of such information and update it without the need to rewrite programs. Essentially, GIS gives user the ability to associate information with a feature on a map and to create a new relationship that can determine the suitability of various sites for development, evaluate environmental impacts, calculate harvest volumes, identify the best location for a new facility, and so on.

3.8 GIS OPERATIONS

GIS activities can be grouped into spatial data input, attribute data management, data display, data exploration, data analysis, and GIS modeling.

3.8.1 Spatial Data Input

The most expensive part of a GIS project is database construction. Two basic options for database construction are (a) use existing data and (b) create new data. Digital data clearinghouse have become commonplace on the Internet in recent years. The strategy for a GIS user nowadays is to look at what exists in public domain before deciding either to create new data or to buy data from private companies.

New GIS data can be created from satellite images, GPS data, or paper maps. A variety of maps such as land use, land cover and hydrograph can be extracted from processing satellite images. Using satellite in space as a reference points, a GPS receiver can determine its precise position on the Earth's surface, which can be used to determine the location and shape of spatial features.

3.8.2 Attribute Data Management

To complete database construction for a GIS project, attribute data must be entered, verified and managed. Similar to spatial data, attribute data entry and verification also involve digitization and editing. Attribute data are usually managed in a relational database in GIS, whether attribute data are separated from spatial data or not.

3.8.3 Data Display

Data display through maps, tables, and charts is a common part of a GIS project. As a visual tool, maps are most effective in communicating spatial data, whether the emphasis is on the location or the distribution pattern of spatial data. Either individually or grouped together, maps are important for visualization and query. Map are also plotted to show results of GIS analysis.

3.8.4 Data Exploration

Data exploration is data centered query and analysis. Data exploration can be a GIS operation by itself or a precursor to formal data analysis. Data query allows the user to explore the general trends in the data, to take a close look at data subsets, and to focus on possible relationships between data sets. The purpose of data exploration is to better understand the data and to help formulate research questions and hypotheses.

3.8.5 Data Analysis

Data analysis is GIS is closely related to the data model. The basic data models are vector and raster, each having its own set of analytical functions. Common vector functions include buffering, map overlay, distance measurement, and map manipulation. Raster data analysis can be conducted at the level of individual cells, or group of cells, or cell within an entire grid. Base on the level of computation, raster data operations are commonly grouped into local, neighborhood, zonal, and global operations. Although some GIS concepts, such as map overlay and buffering, are the same for vector and raster data, the operational procedures differ.

The difference between vector and raster data is not an issue for terrain mapping and analysis because both types of data can be used. Raster data are ideal for the representation of surfaces, and the raster data structure is well suited to intense computation often required for terrain analysis. But vector data, such as elevation points, contour lines, and streams and roads that represent changes of the terrain, are important inputs for terrain mapping and analysis. Moreover, the TIN is a basic data model in terrain analysis.

3.8.6 GIS Modeling

A model is a simplified representation of a phenomenon or a system GIS modeling refers to the use of GIS in building analytical models with spatial data. A useful GIS operation for modeling is map overlay, which combines spatial and attribute data of different variables into a composite map.

GIS can assist the modeling process in several ways, it can integrate different data source including maps, DEM, images and tables etc. These data sources cam displayed together and dynamically linked. Model built by GIS can be vector based or raster based. GIS modeling may take place in GIS or required the linking of a GIS to other computer programs.

USLE is a well-known example of process model. Process models are typically raster based. The role of GIS in building a process model depends on the complexity of model. A simple model may be prepared and run entirely within a GIS. But more often a GIS is delegated to the role of performing modeling related tasks such as data visualization, database management, and exploratory data analysis. The GIS is then linked to other computer programs for complex and dynamic analysis.

3.9 INTRODUCTION TO ARC/VIEW

ARC/View allows you to easily create maps, and add your own data to them. Using ARC/View's visualization tools, you can access records from existing databases and display them on maps. ARC/VIEW used to:

- Integrate and share data across any organization.

- Work with data geographically—seeing undetected patterns, revealing hidden trends and distributions, and gaining new insights.
- Map customer and competitor site locations.
- Understand relationships between the forces that drive business, and make better decisions to solve business problems faster and smarter.
- Publish intelligent maps and create interactive map presentations by linking charts, tables, drawings, photographs, and other files.
- Develop custom tools, interfaces, and complete applications

ARC/INFO and ARC/VIEW GIS, developed by the Environmental Systems Research Institute (ESRI, http://www.esri.com/), are the most commonly used GIS software packages.

3.10 WATERSHED ANALYSIS WITH GIS

The use of GIS and geo-based information for water resources and watershed analysis is rather new. GIS is a system of computer hardware and software tools that processes raw spatial data and stores the information in a grid system of cells for use in other computer programs. It is used for mapping and analyzing such factors as land use, population, demographics, soil types, and precipitation. GIS integrates common database operations with the visualization and geographic analysis offered by maps. The first step in developing GIS data for use with the hydrologic and hydraulic models is to establish a base map, such as scanned quadrangle (quad) maps, digital ortho-photos, and digital elevation models (DEMs—i.e., digital three-dimensional terrain data). The base map must contain a geographic reference, such as latitude and longitude or a national grid coordinate such as the Universal Transverse Mercator. All of the other GIS data used in the analysis must be in the same coordinate system as the base map.

There are generally five data structures used in GIS:

1. Points having x and y (generally northerly and southerly) coordinates, such as stream gauges and rainfall gauges;
2. Directed lines with x and y coordinates, such as streams;
3. Polygons in the x-y plane that represent homogenous or relatively homogenous areas, such as watersheds, land-use zones, and soil types;
4. Grids that are geographic layers partitioned into square cells in the x-y plane where each cell stores numeric value with geographic information, such as elevation, water depth, velocity, and sediment concentration (e.g., DEMs are grid data);
5. Triangulated irregular networks (TINs) that represent surfaces using contiguous no overlapping triangles.

Information about watersheds and their associated streams can be compiled in GIS using these data types and the model inputs can be prepared.

Geo-based information, in the context of watershed analyses, refers to the digital information processed by a GIS that is representative of a small area, or cells, of the watershed.

That area is located geospatially - meaning that it is assigned coordinate points that represent its position in the watershed. For the same small area of a watershed, there may be many different bits of information. For instance, a cell may contain two data types, such as the average surface slope and a number that is associated with a type of ground cover (e.g., 1 = pasture, 2 = woodland). Such information is determined for each cell of the watershed by overlaying maps containing the information and by digitizing it.

Sometimes the information can be directly entered into a GIS system by more advanced techniques, such as remote-sensing interfaces. Each type of information is called a layer since the same type of data (but possibly different values of the data) applies to all the cells covering the watershed. Using the GIS tools, one can define relations between layers to create another layer. For instance, you may wish to relate the ground cover (layer one) and soil type (layer two) for each cell to create a new layer that is representative of rainfall runoff potential.

Chapter IV
METHODOLOGY

4.1 GENERAL

In recent years, advances in the Geographic Information Systems (GIS) have opened many opportunities for enhancing hydrologic modeling of watershed system. The ability to perform spatial analysis for the development of lumped hydrologic parameters can not only save time and effort but also improve accuracy over traditional methods. In additional, hydrologic modeling has evolved to consider radar rainfall and advanced techniques for modeling the watershed on a grid level. Rainfall and infiltration are computed cell-by-cell providing greater detail than traditional lumped methods.

4.2 DATA REQUIRED AND DATA SOURCES

Land use management and landscape process modeling supported by Geographic information system (GIS) technology require representation of landscape and its features in a digital form as point, vector or raster data. Digital landscape characterization data are usually obtained from direct field measurements, remote sensing imagery or digitized maps.

The soil and topographic data will be collected from Survey of Pakistan topo sheet.

- Soil attribute data, Land attribute climatic data etc.
- Land set -7 Satellite image having best resolution of 60m x 60m to 15m x 15m will be used.
- Digital Elevation Model (DEM), the digital representation of topography, will be used to refer specifically to a raster or regular gird of spot heights.
- Other relevant Satellite image data will also be collected through internet

4.3 DATA DESCRIPTION

Topographic data (Elevation), Soil data, Land use data, Land cover data, Rainfall data, Slope maps etc.

Elevation data is required as a raster DEM, with vertical precision in cm. If a raster DEM is not available, contours or points can be interpolated to create the DEM.

Elevation data are used to compute slope, direction of flow, and upslope area.

Land cover data is required in the form of a vegetation, land cover or land use map, preferably as a raster file. If raster data is not available, polygon areas can be transformed to raster at desired resolution. Land cover data are used to estimate the C (Crop management factor) and as a basis for creating new land use alternatives.

Soils data is required as polygons and have to be transformed to raster. If soil samples are available, spatial interpolation is used to compute the raster representation. Soil data are used to derive the K-factor, which is usually included within the related database.

Rainfall data are required in the form of isoline maps for R-factor or from databases used for RUSLE. For field and small watershed scales; for regional modeling the rainfall factor should be given as raster map.

4.4 DATA PROCESSING

DEM, soil data, land use data and precipitation data was processed to generate attribute tables and raster maps, which were mutually integrated to acquire soil erosion maps

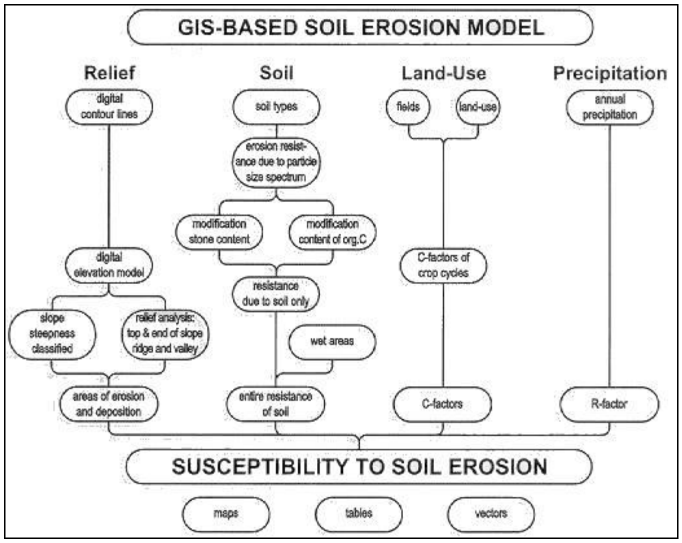


Fig. 4. 1 Flow Chart of Methodology.

4.5 LAND USE ANALYSIS

Land set ortho Satellite images having best resolution was used for analysis of land use parameters including vegetation cover etc, and following classification were obtained as shown in Fig 4.2

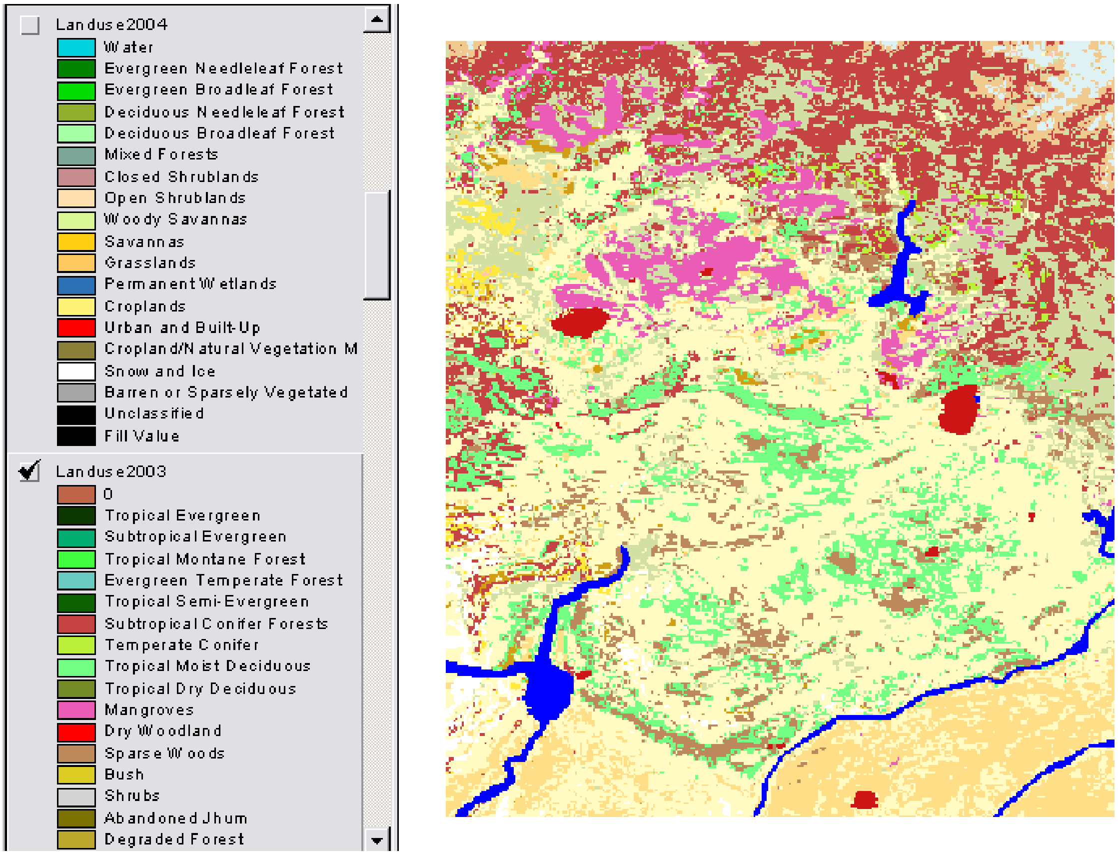


Fig. 4. 2 Land Use Analysis of Soan Catchment.

4.6 IMPORTING DEM

DEM of Indus basin was imported in ILWIS for delineation of soan catchment.

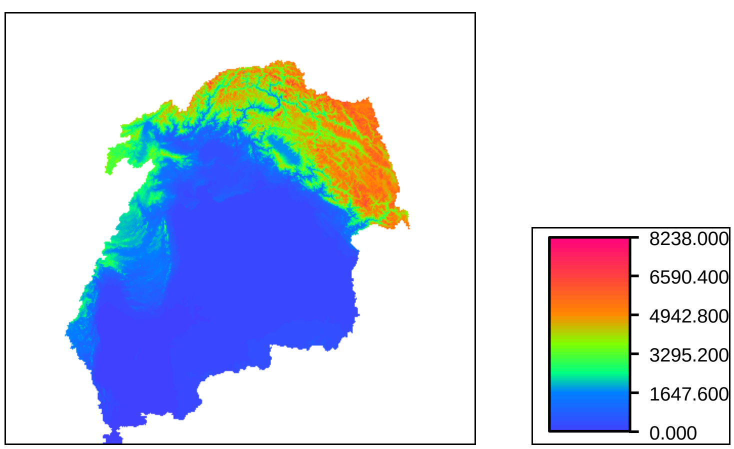


Fig. 4. 3 DEM Indus Basin

4.7 DIGITIZATION

This step involve the digitization of the catchments area of Soan River, the DEM and Boundary layers are interlaced in ILWIS map view and by using the create command from file menu and creating segment map than converting it to polygon, the resultant digitized map is shown in Fig 4.4

Fig. 4.4 Digitized map of Soan catchment.

4.8 FILL SINKS AND CATCHMENT EXTRACTION

This step fill sinks the unfilled values of DEM. The Fill sinks operation will 'remove' the following from a Digital Elevation Model (DEM):

- Depressions that consist of a single pixel, i.e. any pixel with a smaller height value than all of its 8 neighboring pixels,
- Depressions that consist of multiple pixels, i.e. any group of adjacent pixels where the pixels that have smaller height values than all pixels that surround such a depression.

Resultant map is shown in Fig 4.5

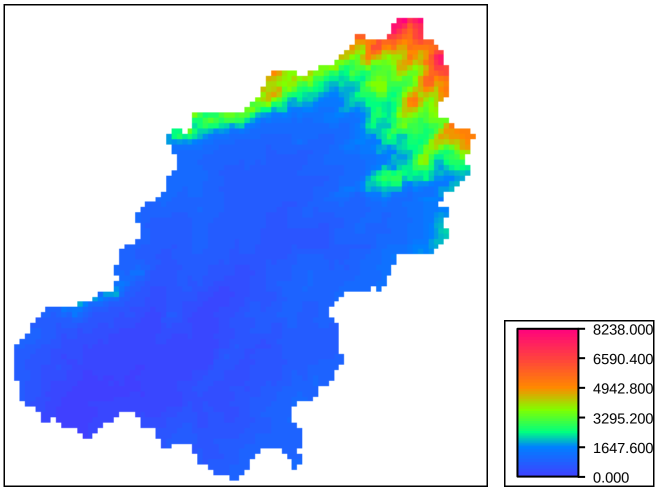


Fig. 4. 5 Fill Sink Soan DEM

4.9 FLOW DIRECTION

Flow direction is calculated for every central pixel of input blocks of 3 by 3 pixels, each time comparing the value of the central pixel with the value of its 8 neighbors. The output map contains flow directions as N (to the North), NE (to the North East), etc.

The flow direction for the central pixels was calculated;

- By steepest slope: find the steepest downhill slope of a central pixel to one of its 8 neighbor pixels, or
- By lowest height: simply find the neighbors pixel that has the smallest value of all 8 neighbors, while this value should also be smaller than the value of the central pixel.

When the position of the steepest-slope-neighbor pixel or the lowest-height-neighbor pixel is determined, the flow direction for the central pixel is known. Resultant map is shown in Fig 4.6

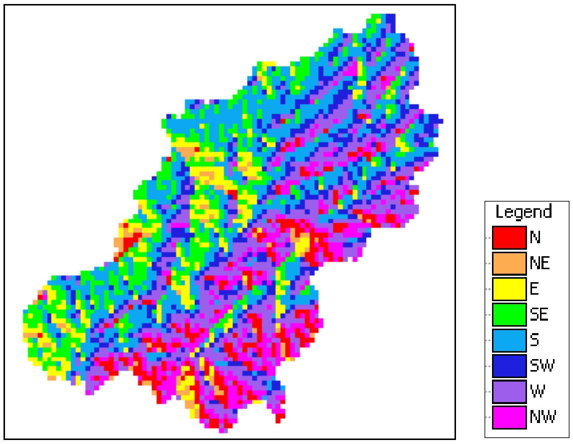


Fig. 4. 6 Flow Direction Soan catchment area

4.10 FLOW ACCUMULATION

The Flow accumulation operation performs a cumulative count of the number of pixels that naturally drain into outlets. The operation can be used to find the drainage pattern of a terrain.

As input the operation uses the output map of the Flow direction operation. The output map contains cumulative hydrologic flow values that represent the number of input pixels which contribute any water to any outlets (or sinks if these have not been removed); the outlets of the largest streams, rivers etc. will have the largest values. Resultant map is shown in Fig 4.7.

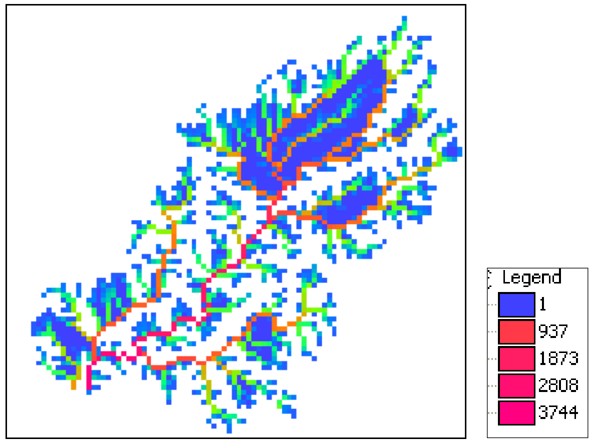


Fig. 4. 7 Flow Accumulation Soan catchment.

4.11 GENERATION OF SLOPE MAPS

Slope maps (Height differences maps) shown in Fig 4.9 were created by using following commands shown in Fig 4.8.

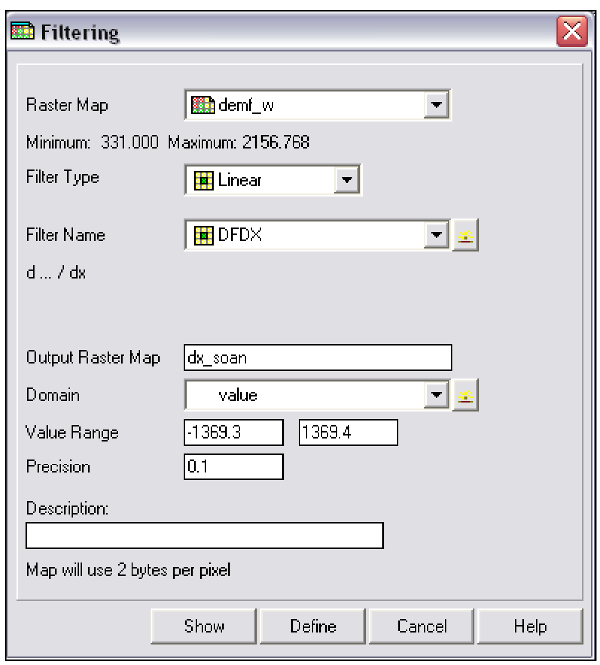


Fig. 4.8 Slope map command

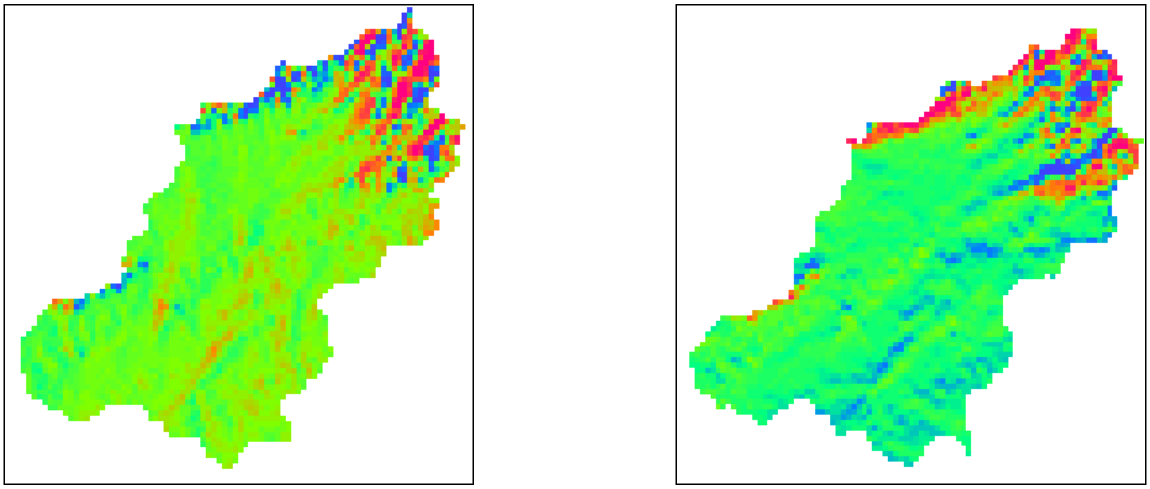


Fig. 4. 9 Slope Maps of Soan catchment.

Percentage Slope (Slope_p) and degree slope (Slope_d) maps were created by using following formulas.

Slope_p = ((hyp (dx, dy))/30)*100), Slope_d = raddeg (atan (slope_p/100))

Percentage slope maps resulting form the above equation are shown in Fig 4.10.

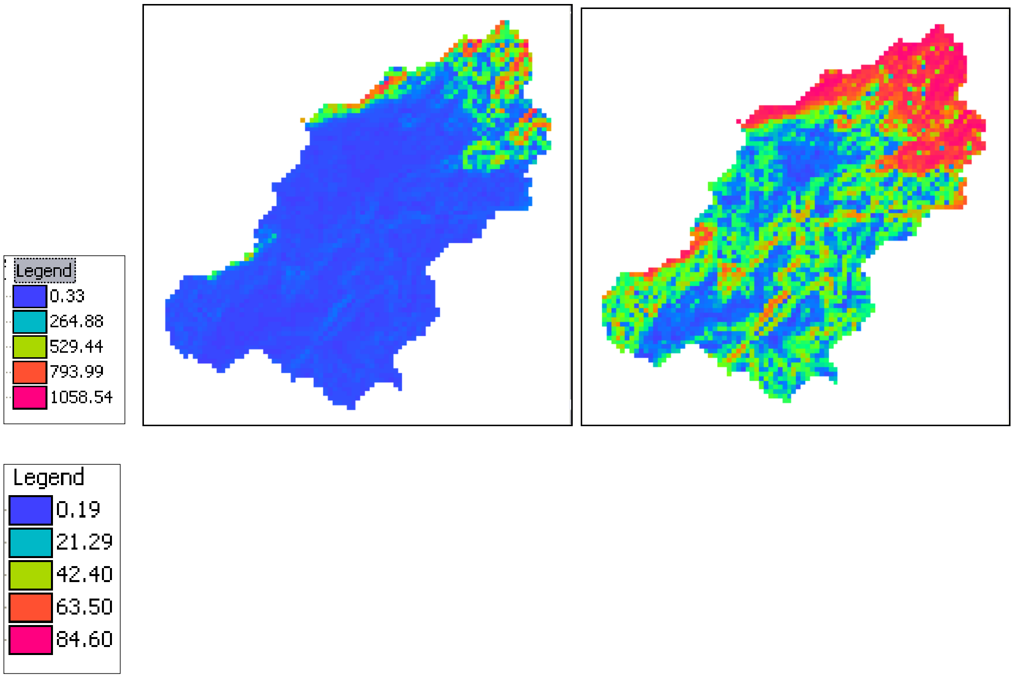


Fig. 4. 10 Percentage Slope Maps Soan catchment.

4.12 GENERATION OF RAINFALL AND ENERGY MAPS

Rain map (Soan catchment) shown in Fig 4.12 was created using formula “Rain = 1384.2 + 0.329 * Elevation” where Elevation is the contour height i.e. “dy”, Raster map definition command is shown in Fig 4.11.

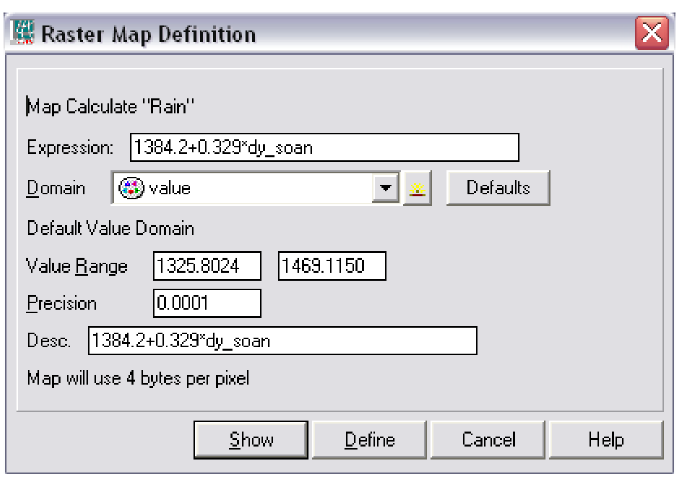


Fig. 4.11 Raster map definition.

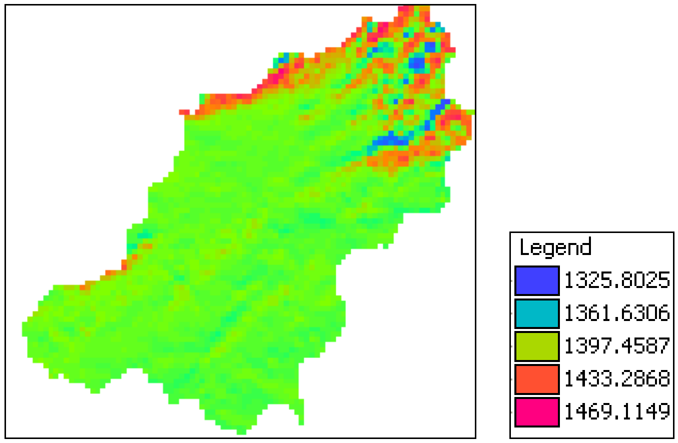
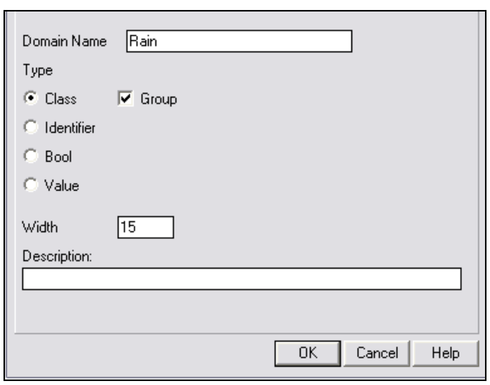


Fig. 4. 12 Rain map (Soan catchment).

Domain group Rain shown in Fig 4.14 was created from file menu (create command shown in Fig 4.13) for classification of different rainfall (entering different values for different classes).



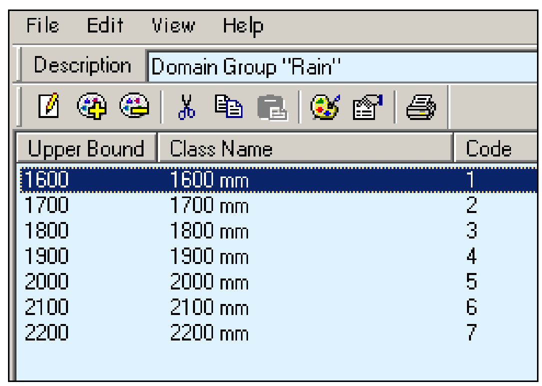


Fig. 4.13 Create Domain Command.

Fig. 4.14 Domain group “rain”

Classifying the rain map using command Rainclas = clfy (Rain, Rain) and “Rainclas” map is created to represent the classes of rain, as red color is one class shown in Fig 4.15.

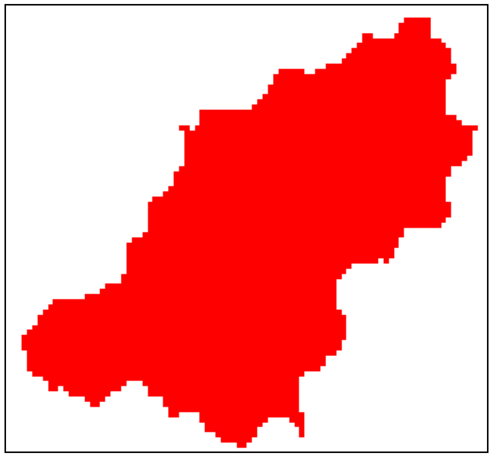


Fig. 4. 15 Rain class map of Soan catchment.

Creating the attribute table Rainfall and entered the rain data shown in Fig 4.16

	Rainfall
1600 mm	1600
1700 mm	1700
1800 mm	1800
1900 mm	1900
2000 mm	2000
2100 mm	2100
2200 mm	2200
Min	1600
Max	2200
Avg	1900
StD	216
Sum	13300

Fig. 4.16 Table “rainclass”

Rainfall map shown in Fig 4.17, with value domain was created using command

Rainfall = rainclas. rainfall, rainfall. Now the map shows values instead of classes

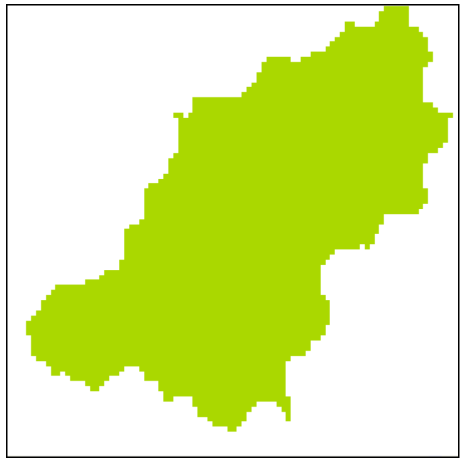


Fig. 4. 17 Rainfall map Soan catchment.

Generating annual rainy days map shown in Fig 4.18 as a function of elevation as follows, Based on the climatic data it seems that the number of average rainy days in a year appear to be 75 days in the lower elevations while the average rainy days are 95 in high elevated areas

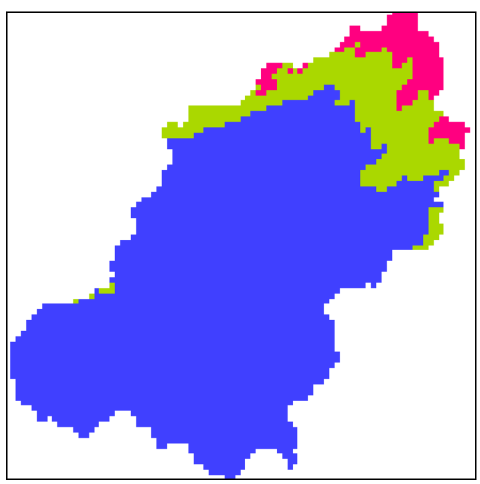


Fig. 4. 18 Annual Rainfall Map Soan catchment.

Rainfall energy map shown in Fig 4.19 was created entering formula in command line

$E = R * (11.9 + 8.7 * \log(10\ I))$

E= energy map, R= Rainfall map, and I= 25 mm/hr

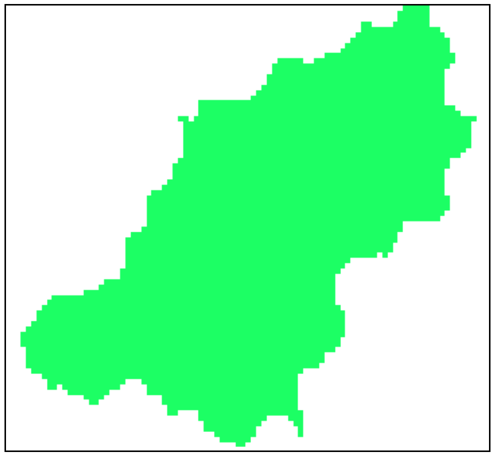


Fig. 4. 19 Rainfall Energy map Soan catchment.

Rate of soil detachment shown in Fig 4.22 was estimated using formula

$F = K * (E * e^{(-0.058A)}) * 1.0 * 10^{-3}$

F= Rate of soil detachment in kg/m^2, K= soil detachment index, A = interception

Generating attribute maps of soil detachability index shown in Fig 4.20 using soil table and percentage rainfall map shown in Fig 4.21 using land use table.

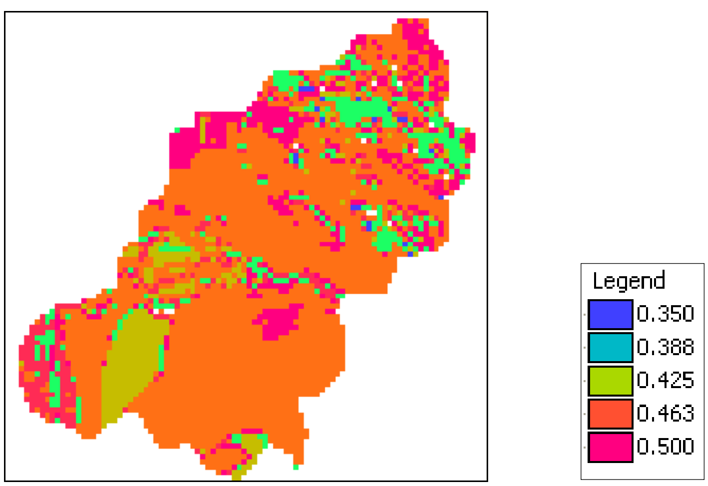


Fig. 4. 20 Soil Detachability factor K.

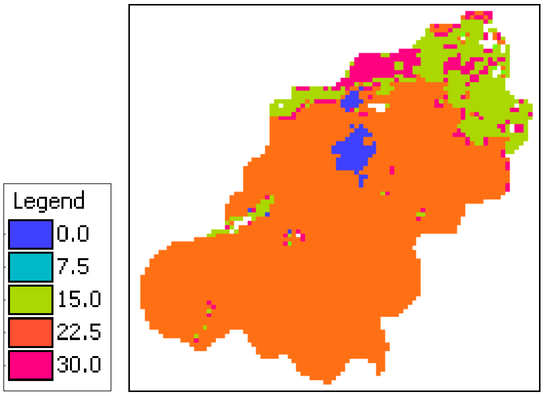


Fig. 4. 21 Percentage Rainfall Area.

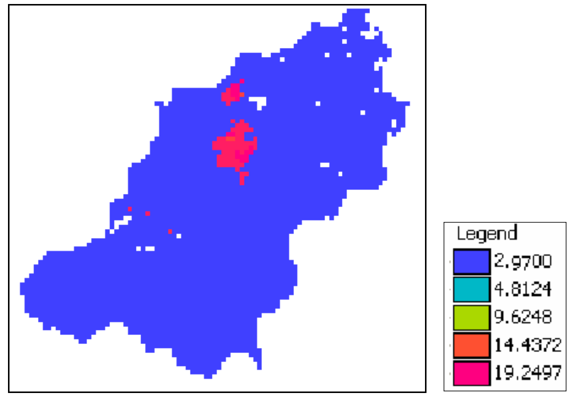


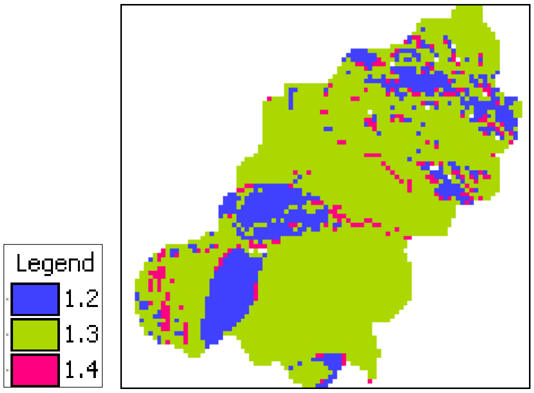
Fig. 4. 22 Rate of Soil Detachment.

4.13 GENERATION OF OVERLAND FLOW MAP

Overland flow (Q) is dependent on moisture storage capacity (MS) of surface soil which can be derived from field capacity. It is also dependent on the soil bulk density (BD). Moreover it is dependent on rooting depth (RD) of various cover types, the ratio of actual to potential evapotranspiration (Et/Eo), the amount of annual rain (R) and the number of rainy days (Rn). It can be explained by following equations:

Q= R* exp (-Rc/Ro), where R is annual rain. Rc= 1000*MS*BD*RD*(Et/Eo)*0.5.

Ro= R/Rn, Rn = rainy days and Generating attribute maps MS, BD, RD and Et/Eo shown in Fig 4.23 to Fig 4.26 respectively.



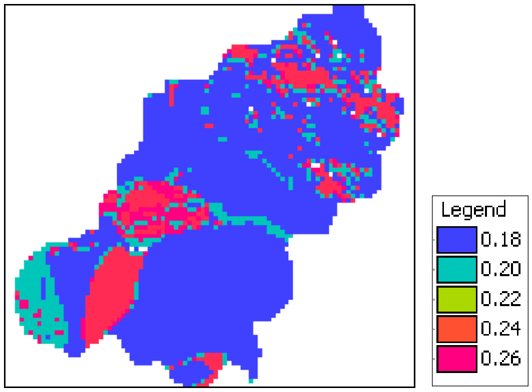
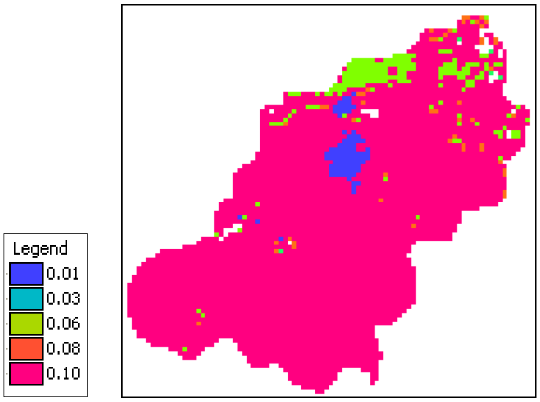


Fig. 4. 23 Bulk Density of Soan catchment soil

Fig. 4. 24 Moisture Storage Capacity of Soan catchment soil



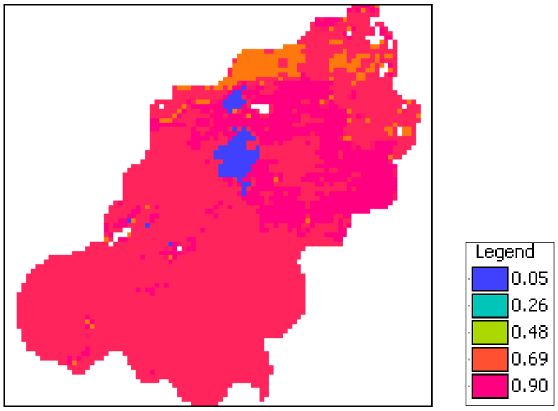


Fig. 4. 25 Rooting Depth of catchment

Fig. 4. 26 Et/Eo of Soan catchment soil

Using equation Rc= 1000*MS*BD*RD*(Et/Eo)*0.5 to generate map Rc as shown in Fig 4.27. Resultant overland flow volume map is shown in Fig 4.28.

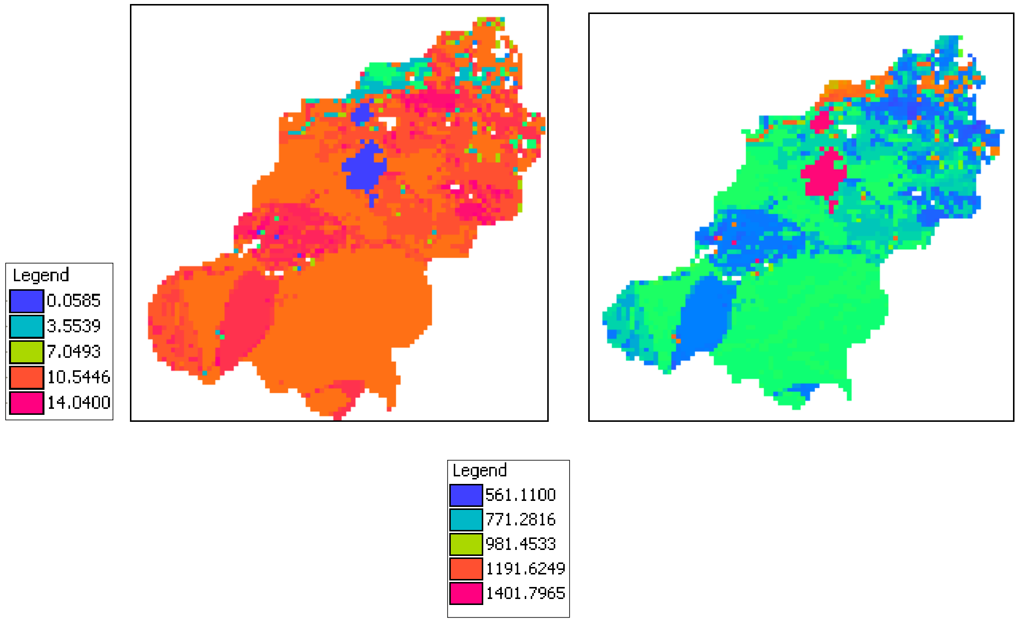


Fig. 4. 27 RC calculated for Soan catchment Fig. 4. 28 Over Land Flow Q Soan Catchment

4.14 CALCULATIONS USING MAP CROSSING

Soil Land map was generated from raster operations, Selecting cross command shown in Fig 4.29 and entering the soil and land use maps for crossing.

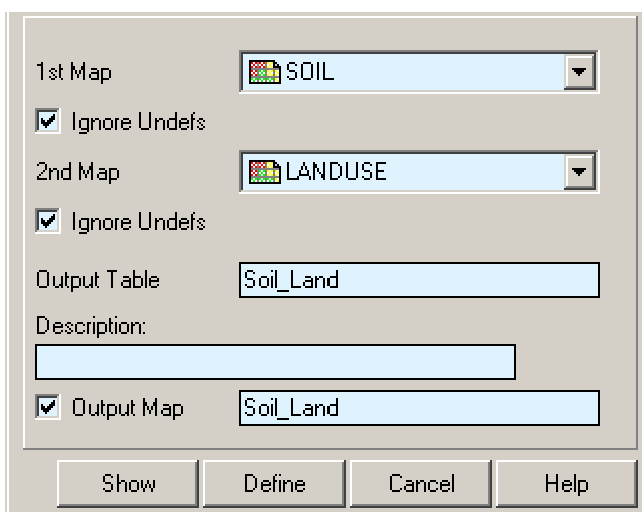


Fig. 4.29 Map Cross Command

Resultant Soil Land map is shown in Fig 4.30.

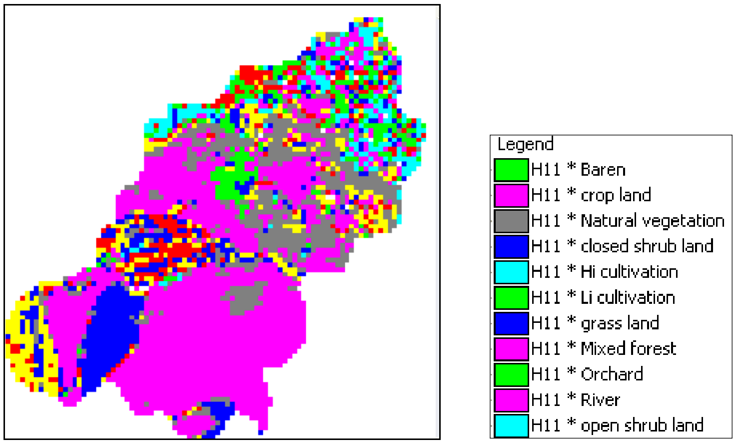


Fig. 4. 30 Soil Land crossed map Soan catchment

Joining columns MS, BD, RD, Et_Eo to Soil_Land table from soil and landuse tables and computing product of MS,BD,RD and square root of Et_Eo and storing the result in column Rc shown in Fig 4.31.

File Edit Columns Records View Help

RC=(MS*BD*RD*(Et_Eo)^0.5)*1000

	MS	BD	RD	Et_Eo
H11 * Baren	0.18	1.3	0.01	0.05
H11 * Deg sa	0.18	1.3	0.10	0.80
H11 * Den mi	0.18	1.3	0.10	0.90
H11 * Den sa	0.18	1.3	0.10	0.90
H11 * Hi cult	0.18	1.3	0.07	0.85
H11 * Li cult	0.18	1.3	0.05	0.60
H11 * Open m	0.18	1.3	0.10	0.80
H11 * Open s	0.18	1.3	0.10	0.80
H11 * Orchard	0.18	1.3	0.10	0.90
H11 * river	0.18	1.3	?	?
H11 * open sl	0.18	1.3	0.04	0.60
H11 * ?	0.18	1.3	?	?
CrossNr 34	0.18	1.3	?	?
CrossNr 29	0.18	1.3	?	?
CrossNr 20	0.18	1.3	?	?
CrossNr 60	0.18	1.3	?	?
H12 * Baren	0.18	1.3	0.01	0.05
H12 * Deg sa	0.18	1.3	0.10	0.80
H12 * Den mi	0.18	1.3	0.10	0.90
H12 * Den sa	0.18	1.3	0.10	0.90
H12 * Hi cult	0.18	1.3	0.07	0.85
H12 * Li cult	0.18	1.3	0.05	0.60
H12 * Open m	0.18	1.3	0.10	0.80
Min	0.18	1.2	0.01	0.05
Max	0.26	1.4	0.10	0.90
Avg	0.21	1.3	0.08	0.74
StD	0.03	0.1	0.03	0.23
Sum	16.52	101.5	5.09	46.75

Fig. 4.31 Dependent Table “soil-land”.

Using attribute command shown in Fig 4.32, Adding column by using

RC= (MS*BD*RD*(Et_Eo)^0.5)*1000 and creating attribute map for RC2

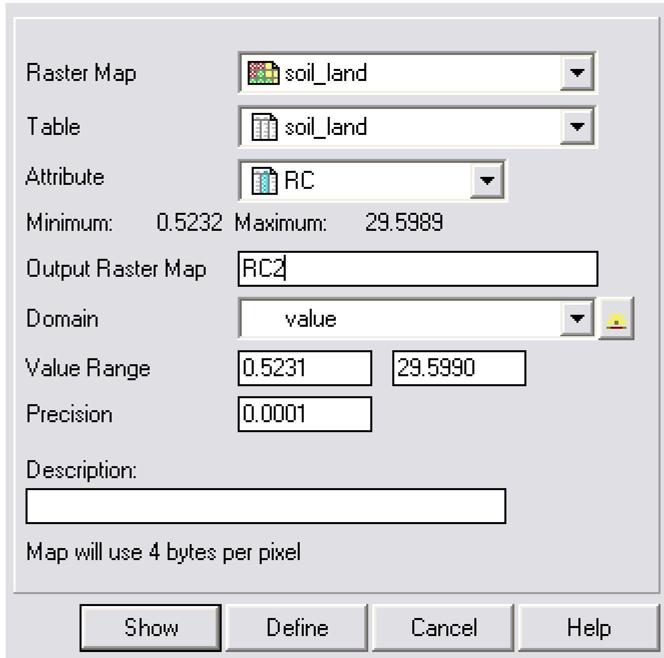


Fig. 4.32 Attribute map command.

Resultant RC2 crossed map and Overland flow volume map by cross calculation are shown in Fig 4.33

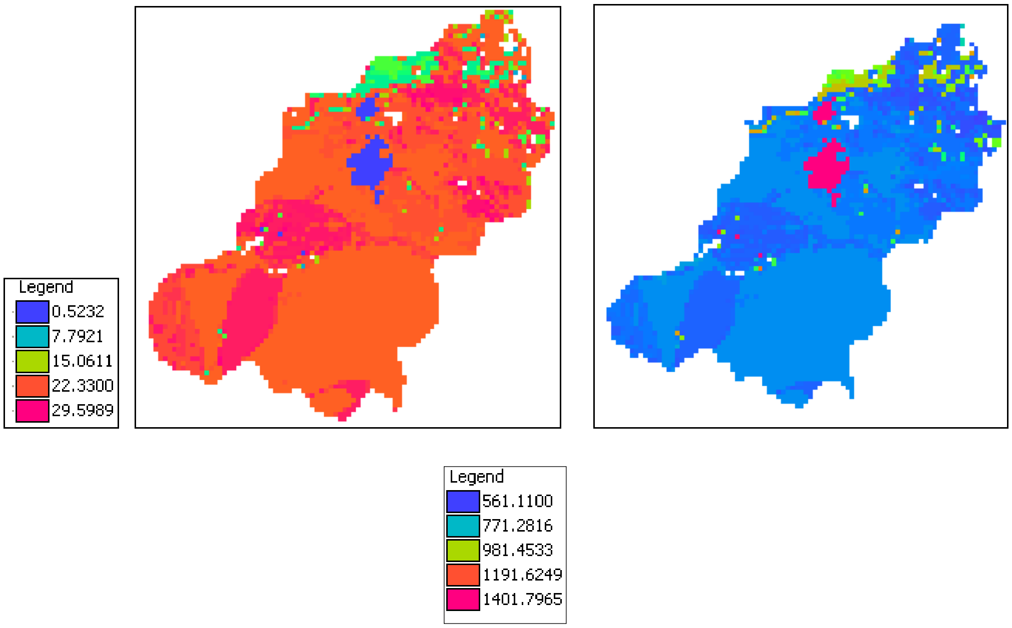


Fig. 4. 33 RC2 map cross calculation.

Fig. 4.34 Overland Flow Volumes map cross calculation.

4.15 GENERATION OF TRANSPORT CAPACITY OF OVERLAND FLOW

Transport capacity of overland flow (G) is dependent on the volume of overland flow (Q), crop cover management factor (C) and the topographic slope factor (S). It was calculated by using following equations:

$$G = C*sq(Q)*sin(degrad(S))*0.001$$

Generating crop cover management map C shown in Fig 4.35 from land use table.

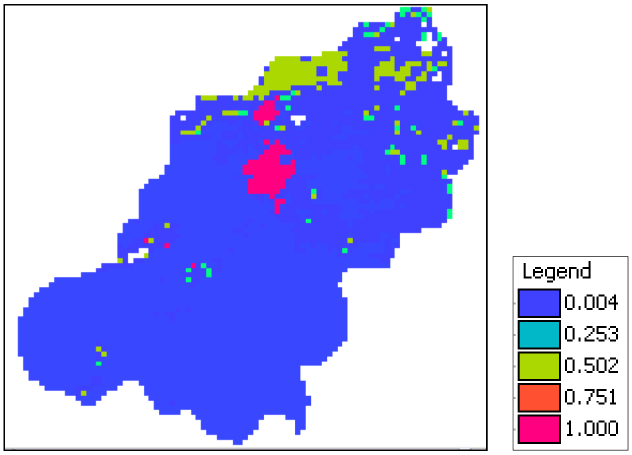


Fig. 4. 35 Crop Cover Management Factor Soan catchment.

Generating map G (Transport capacity of overland flow) shown in Fig 4.36 using equation below

G = C*sq(Q)*sin(degrade (Slope_d))*0.001 G2 = C*sq(Q)*sin (Slope_d)*0.001

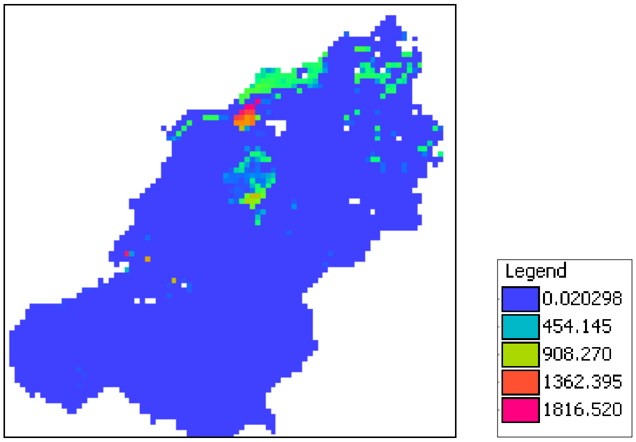


Fig. 4. 36 Transport Capacity of Overland flow Map.

4.16 ESTIMATION OF SOIL EROSION

Soil loss estimation was calculated from the transport capacity of overland flow (G) and the estimated rate of soil detachment (F). If the transport capacity is higher than the rate of soil detachment, the soil detachment value can be taken as the soil loss. Similarly, if the rate of soil detachment is higher than the transport capacity of overland flow, the value of the transport capacity will be considered for the soil loss. Resultant Soil Loss map (Soan catchment) is shown in Fig 4.37.

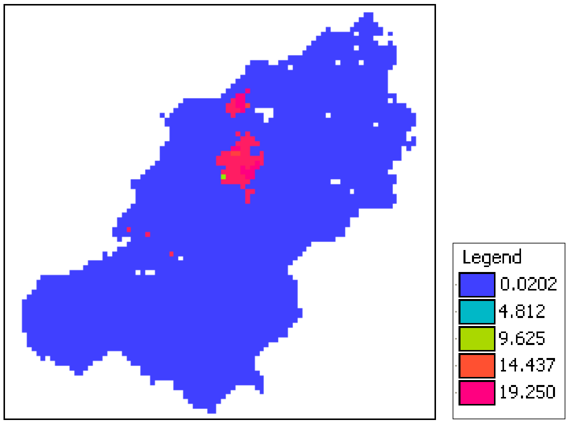


Fig. 4. 37 Soil Loss map (Soan catchment).

Erosion map (Soan catchment) shown in Fig 4.38 was created by dividing soil loss maps by 11.02, for converting kg/m2 to tons/ha.

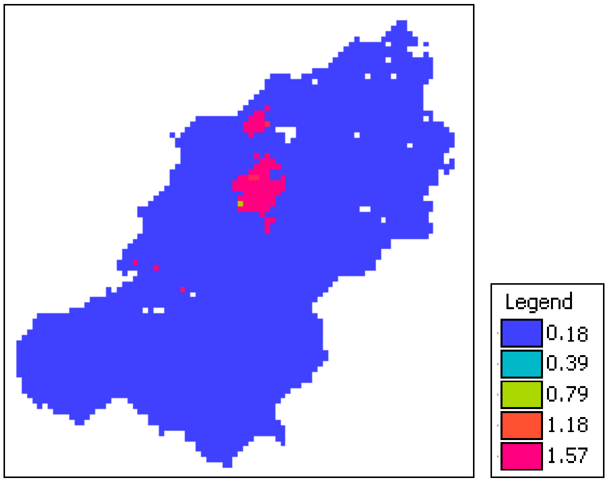


Fig. 4. 38   Erosion map (Soan catchment).

Chapter V
RESULT AND DISCUSSION

By analyzing the over land flow map and crossing it with land use and soil classes, it is computed that, the Barren unit of land use has the highest possible volume of overland flow (1555.96 ft^3/sec) due to low infiltration and high overland velocity of water (shown in table 5.1) and the soil unit gravely sand has lowest volume of overland flow due to high infiltration and low overland velocity of rainwater.

Table 5. 1 Overland flow/Land use classification of Soan catchment.

Classes	**Area (ha)**	**Q2 (over land flow ft^3/sec)**
Barren	79.83	1555.96
Crop Land	50.95	536.03
Natural vegetation	101.9	495.1739
Closed Shrub land	1018.79	490.9616
Hi Cultivation	1239.09	722.61
Li Cultivation	1480.46	987.37
Grass Land	638	528.3596
Mixed Forest	300.83	534.2196
Orchid	5.59	484.7603
Open Shrub land	2.5	1081.37

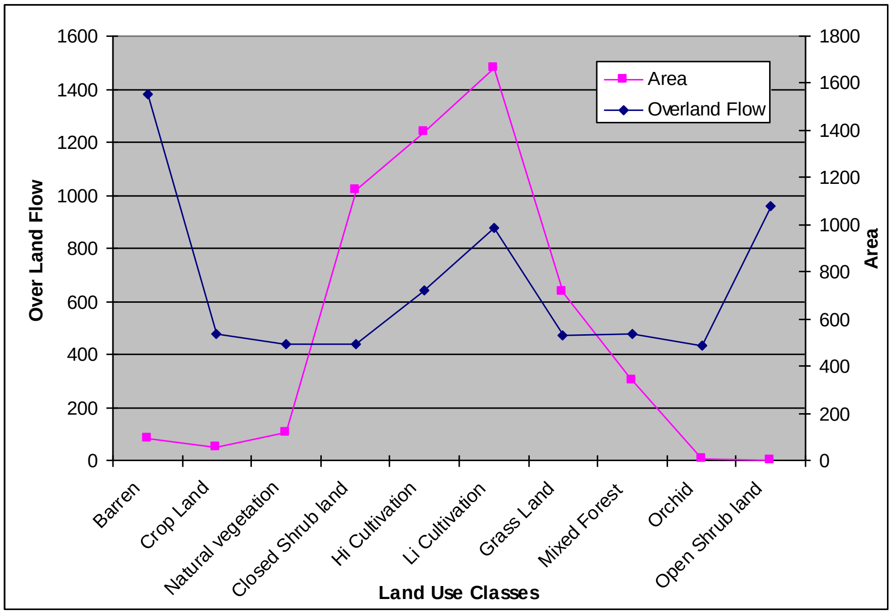


Figure 5.1 Overland Flow over Land Use Classes

Table 5.2 Overland Flow Soil type Classification of Soan catchment.

Classes	Area(sq.m)	Soil Texture	Q (overland flow ft^3/sec)
H11	2449561	Gravely Loam	1555.43
H12	2829484	Loam	1555.96
H13	246370	Gravely loam	1546.78
H21	2977356	Loam	875.79
M1	1070312	Gravely sandy	831.08
M2	5713150	Gravely sandy	863.42
M3	535729	Gravely sandy	856.52
P11	2198135	Gravely loam	897.71
P12	6610258	Loam	678.97
P21	4503889	Gravely sandy	567.87
P22	6125919	sandy loam	734.56
V2	9911202	Loam	876.89

Table 5.3 Soil Loss over Land use classification of Soan catchment.

Classes	Area (ha)	Soil Loss (tons/ha/year)
Barren	79.83	63.41
Crop Land	50.95	18.76
Natural vegetation	101.9	20.53
Closed Shrub land	1018.79	33.76
Hi Cultivation	1239.09	25.89
Li Cultivation	1480.46	36.91
Grass Land	638	43.21
Mixed Forest	300.83	19.26
Orchid	5.59	19.72
Open Shrub land	2.5	53.41
River	613.51	55.22

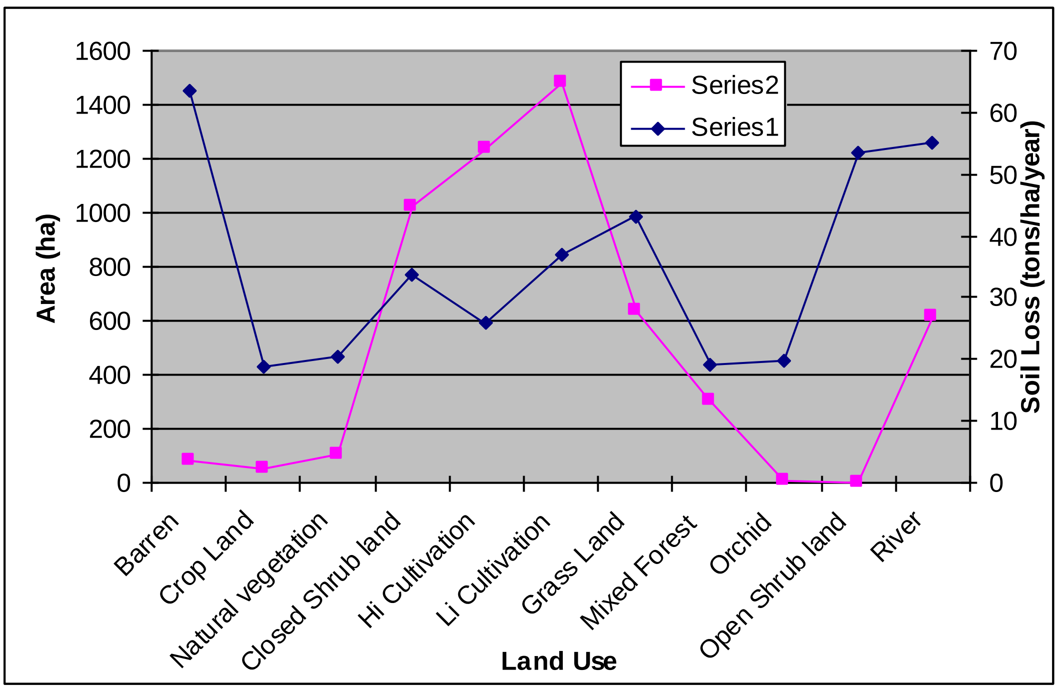


Figure 5.2 Soil Loss over Land Use Classes

The result shows that soil loss estimation in low intensity agriculture i.e. in Li cultivated area comprising 1480.46 ha the estimated soil loss 36.91 tons/ha/year, in open shrub land having area 2.5 ha estimated soil loss 53.41 tons/ha/year is higher as compared to high intensity agriculture i.e. Hi cultivation covering area of 1239.09 ha estimated soil loss 25.89 tons/ha/year due to high detachability factor of soil having low agriculture intensity.

Table 5.4 Soil Loss over different soil classification of Soan Catchment.

Classes	**Area(sq.m)**	**Soil Texture**	**Soil Loss (tons/ha/year)**
H11	2449561	Gravely Loam	88.6
H12	2829484	Loam	71.5
H13	246370	Gravely loam	73.1
H21	2977356	Loam	79.01
M1	1070312	Gravely sandy	78.4
M2	5713150	Gravely sandy	42.2
M3	535729	Gravely sandy	41.1
P11	2198135	Gravely loam	43.4
P12	6610258	Loam	47.6
P21	4503889	Gravely sandy	39.1
P22	6125919	sandy loam	40.8
V2	9911202	Loam	12.9

Annual average soil loss for the Soan river basin is 35.41 tones/ha/year, Barren land has the highest value of soil loss i.e. 63.41 and crop land has the lowest value of soil loss i.e. 18.76 tons/ha also barren lands are contributing much for this soil loss (52.11 tones/ha/y), because in the barren lands detachability factor is pretty high.

Chapter VI
CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. Areas of 79.83 ha and 613.51 ha are falling under very high and high priority classes respectively for whole Soan river basin. These areas should be prioritized for immediate conservation measures.
2. Areas of 2.13, 2.07 and 2.31 km^2 of sub watersheds are falling under very high priority class and should be considered for conservation measures urgently.
3. It is clear from the results of this study that this model is use full for the qualitative as well as quantitative assessment of soil erosion intensity for the conservation management.
4. 90 m resolution data is good enough for analysis of soil erosion and sediment yield estimation.
5. Land Sat Ortho data provides good information for land use analysis. Multi-temporal, multi-sensor and multi-spectral remote sensing data have provided valuable and very important factors like C and P for this study. Since, the crop cover is a powerful weapon to reduce the direct impact of rainfall on soil particles.
6. GIS has given a very useful environment to undertake the task of data compilation and analysis within a short period at very high resolution.

6.2 RECOMMENDATIONS

1. It is recommended that all barren lands in Soan river basin be converted to agricultural land or forest plantations through proper land reclamation measures
2. Image data should be used as a primary source of natural resources information in thematic mapping which in turn can utilize in various hydrological studies.
3. The remote sensing data provides synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum at regular intervals.
4. The space borne multi spectral data enable generating timely, reliable and cost effective information on various natural resources, namely surface water, ground water, land use/cover, soil, forest cover and environmental hazards, namely water logging, salinity and alkalinity, soil erosion by water etc.
5. Soil and water conservation structures as following should be considered: Cultivation on slopes steeper>10% causes much erosion. If it is not possible to convert the land use, it is better to use strip cropping.
6. And finally, before planning any soil and water control program socio-economic conditions should be studied.
7. It can be recommended that all barren lands in Soan river basin be converted to agricultural land or forest plantations through proper land reclamation measures.

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