SOIL EROSION ASSESSMENT IN GEJ WATERSHED, CHHATTISGARH

Dissertation submitted to School of Social Sciences, Jawaharlal Nehru University in partial fulfillment of the requirement of the award of the degree of

MASTER OF PHILOSOPHY

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DECLARATION

I, Poushali Roy, declare that the dissertation entitled "**Soil Erosion in Assessment in Gej Watershed, Chhattisgarh**" submitted by me for the award of the degree of Master of Philosophy of Jawaharlal Nehru University is my bonafide work. The dissertation has not been submitted for any other degree of this university or any other university.

Poushali Roy

POUSHALI ROY

CERTIFICATE

We recommend that this dissertation be placed before the examiners for evaluation.

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Dedicated
to

Miss D'Crouz
and
Jana Sir

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CHAPTER 1

INTRODUCTION

Perhaps our most precious and vital resource.........is that most common matter underfoot, which we scarcely even notice and sometimes call "dirt", but which is, in fact, the mother-lode of all terrestrial life and the purifying medium wherein wastes are decomposed and recycled, and productivity is generated.

------ *Daniel Hillel*

The most important natural elements that sustain life on earth are air, water and land. But land without proper soil cover is ecologically and economically not viable. In fact the major civilizations had evolved in the areas of fertile soils.

Soil, however, is naturally removed by the erosive action of water and wind. Hence soil may be defined as an *evolving*, living, organic/inorganic layer at the Earth's surface in dynamic equilibrium with the atmosphere and biosphere above, and the lithosphere below. The average natural rate of soil erosion is approximately 0.5 t ha^{-1} yr^{-1} and this is almost equal to the average rate of soil formation (Smoot and Smith, 1999). But the natural rates are increased by human activities which results in the loss of arable land, siltation of rivers, etc. "The soil in managed forests erodes at an average rate of 0.5 t $acre^{-1}$ yr^{-1}. The erosion rates from agricultural lands, such as pastures and cultivated fields are 1.5 and 20 t $acre^{-1}$ yr^{-1}, respectively. Lands being disturbed by mining and construction activities experience soil erosion at even higher rates. Unprotected construction sites can experience annual soil loss rates of 150 to 200 t $acre^{-1}$" (Smoot and Smith, 1999).

1.1. Extent of soil erosion

Human population is increasing at an alarming rate and so is the demand for more land for food production. But, simultaneously, the extensive use of agricultural land for intensive cultivation is leading to greater soil loss. As stated by Pimentel, et.al. (1987), serious soil erosion is occurring in most of the world's major agricultural regions and the problem is growing as more marginal land is brought into production.

Judson was one of the first geologists to assess the world soil erosion in the mid 1960s (Singh and Phadke, 2006). He estimated that "the amount of river-borne soil carried into the oceans had increased from 9.9 billion tons per year before the introduction of agriculture, grazing and related activities, to 26.5 billion tons per year" in the 60s. Pimentel, as quoted by Singh and Phadke (2006), had stated that more than 50 percent of the world's pastureland and about 80 percent of agricultural land suffer from significant erosion. Rates of erosion, however, vary from place to place. Soil loss rates in Europe, the United States, and in Asia, Africa and South America, were 10-20 t ha^{-1} yr^{-1}, 16 t ha^{-1} yr^{-1} and 20-40 t ha^{-1} yr^{-1}respectively (Stewart, 1994).

Soil erosion accounts for 87% of the total degraded land in India (UNEP, 2001). According to a study by Narayana and Babu (1983), soil was being eroded at an annual average rate of 16.35 t ha^{-1} yr^{-1}, yielding a figure of 5.3 billion tons a year for the entire country. In a study conducted by Singh, et al (1992), the annual rate of erosion by water in India was found to be less than 5 Mg ha^{-1} yr^{-1} for dense forest, snowclad cold deserts, and the arid region of western Rajasthan and more than 80 Mg ha^{-1} yr^{-1} in the Shiwalik hills.

It is, however, to be noted that the estimated soil erosion rates in most of the, above mentioned, soil erosion studies actually refer to the observed sediment delivery ratio. This requires an eye of caution as soil erosion and sediment delivery differ in their meaning and therefore the two terms should be used separately. Similarly, soil degradation and soil loss are also considered synonyms of soil erosion in literature. But the terms differ in their very element. The following section intends to figure out the concepts to be dealt with in the study.

1.2. Concepts

1.2.1. Soil erosion, degradation and loss and sediment delivery

Soil degradation is defined as the decline in the physical, chemical and biological quality of the soil resource. Soil degradation is of three types: biological, chemical and physical; and ***soil erosion*** is a form of physical soil degradation. Soil erosion is a naturally occurring process on land which involves the detachment, displacement, and distribution of individual soil particles from the soil matrix. The complete removal of the eroded soil from its place of origin by running water and wind; such that it cannot be replenished or replaced, is ***soil loss.*** The eroded soil, when carried by running water, constitutes sediment load of running water, viz. stream or river. Sediment delivery is the amount of sediment load in a stream measured at a particular place, and ***sediment delivery ratio*** is the total amount of sediment load to the total discharge of water of the stream at that place.

The terms, therefore, differ in their content and they should not be used synonymously. But they are linked with each other and together serve as a part of the entire process of denudation. Soil erosion is the detachment and displacement of soil particles from the soil matrix, thereby degrading the physical quality of the soil. The detached soil particles may be carried as sediment to far off places by running water wind which will incur loss of soil in the place of origin.

1.2.2. Types of soil erosion

Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing serious loss of topsoil. The natural gradual removal of soil by the erosive action of water and wind at an approximate rate of 0.5 t ha^{-1} yr^{-1} is called ***geological soil erosion*** (Smoot and Smith, 1999). The geological rate of soil erosion is approximately equal to the average rate of soil formation. But the geological rates are increased by human activities leading to ***accelerated soil erosion*** which results in the loss of arable land, reduced crop production, lower surface water quality, siltation of rivers, etc.

The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year. Therefore, based on the agent of erosion, soil erosion may be of two types: ***water erosion*** and ***wind erosion***.

Soil erosion by water takes place through two main processes: (1) detachment of soil particles, aggregates, clods and large soil volumes from the soil mass by raindrop impact; and (2) movement of detached material (e.g., by gravity or by overland flow). In humid, sub-humid and semi-arid areas, detachment of soil particles is brought about the impact of raindrop which is termed as rainfall 'erosivity' (Torri and Borselli, 2000; Toy, 2002), and this process is known as ***splash erosion*** (Morgan, 2005). The displacement of the detached soil particles by running water is brought about by the following processes: ***sheet or interrill erosion***, which removes soil in thin layers and is caused by the combined effects of splash erosion and surface runoff; ***rill erosion***, which is the removal of soil particles by concentrations of flowing water; and ***gully erosion***, that occurs when the flow concentration becomes large and the incision deeper and wider than with rills (Morgan, 2005). Thus the two phases of soil erosion by water, viz. detachment of soil particles and displacement of the detached particles are determined by rainfall erosivity and runoff respectively (Wischmeier and Smith, 1978).

The impact of rainfall erosivity and runoff on soil erosion is, however, controlled by susceptibility of the soil to erosion, simply termed as soil erodibility; slope of the land; and the surface cover, whether the soil surface is covered with vegetation or left barren. Based on these controlling factors, ***soil erosion susceptibility*** and ***soil erosion hazard*** of an area can be estimated or measured (Iyer, 1974). Soil erosion susceptibility is a measure of soil erosion without the effects of surface cover. This value is important in areas which are going to be put into agriculture or which are recently under cultivation. Soil erosion hazard, on the other hand, takes into account all the factors influencing soil erosion. It is a measure of the chance that erosion will take place or that future erosion that can be expected in areas where erosion has already started.

The aforesaid factors – rainfall erosivity, runoff, soil erodibility, slope and surface cover – have been considered, in literature, as the most important factors determining the process of soil erosion. The influence of the factors on soil erosion has been analyzed empirically and mathematical expressions have been created and models have been developed in order to estimate soil erosion rates based on these factors. The following sub-section, therefore attempts to understand the characteristics and constitution of each factor and the nature of influence of the factors on soil erosion.

1.2.3. Factors influencing soil erosion

(a) Rainfall Erosivity

Rainfall and runoff have been considered as the most important factors for assessing erosion by water (Wischmeier and Smith, 1978; Renard et.al., 1996). However, it may be mentioned here that "the use of runoff characteristics is not consistent with the notation of rainfall erosion which is a measure of climatic influence on erosion" (Yu and Neil, 2000). Runoff depends on the topography and soil properties in addition to the rainfall regime. Runoff can occur whenever there is excess water on a slope that cannot be absorbed into the soil or trapped on the surface. The splashing of soil particles also increases surface run-off through the effect of puddle (Singh and Phadke, 2006). On the other hand, rainfall erosivity depends on the aspects of rainfall only, and a rainfall erosivity index is computed using rainfall alone. A large part of soil erosion from a plot of land subjected to an erosive rain takes place through the medium of splashes rather than through the medium of runoff (Stoltenberg, 1950; Bhatia and Chandra, 1991).

As had been summed up by Stoltenberg (1950), raindrops impinging upon soil cause:
(i) Splashing which results in large quantities of soil and water being transported from one place to another. Soil splashed into nearby rapidly flowing water becomes highly susceptible to being carried away.

(ii) Loosening of the soil particles at the surface, giving the runoff waters an opportunity to act upon them.

(iii) Shattering or breaking down of the soil aggregates into more easily erodible material.

(iv) Rearranging of the particles at the ground surface which serves to reduce the infiltration rate.

(v) Puddling which tends to alter the soil structure near the surface, resulting in a thin compacted layer which further reduces the infiltration rate and thereby increases the run-off rate and rate of soil erosion.

Soil movement by raindrop splash is usually greatest and most noticeable during short-duration, high-intensity thunderstorms. Records from experimental plots showed that the rainstorms greater than 3 inches or 12.5 mm produce significant amount of soil erosion. Hence rainstorms with $\geq$12.5 mm of rainfall are considered as erosive storms and are used in the computation of rainfall erosivity (Wischmeier and Smith, 1978; Sudhishri and Patnaik, 2004).

According to Wischmeier and Smith (1978), when factors other than rainfall are held constant, rates of soil erosion are directly proportional to rainfall erosivity (EI): the total storm energy (e_m) times the rainfall intensity (i_m).

$$EI = e_m \cdot i_m$$

Since the energy of a given mass in motion is proportional to velocity-squared, rainfall energy is directly related to rain intensity. The relationship is expressed by the following equation (Wischmeier and Smith, 1978):

$$e_m = 0.119 + 0.0873 \log_{10}(i_m)$$

where, e_m = rainfall energy measured in units of megajoule per hectare per millimeter of rainfall (MJ ha^{-1} mm^{-1})

i_m = the rainfall intensity in mm hr^{-1}.

Traditionally the rainfall erosivity factor has mainly been used to compare the soil erosion potential at different locations, rather than for temporal analysis. However, rainfall derived from archived rainfall data has the potential to provide a measure of temporal variation of rainfall erosivity (Yu and Neil, 2000). Daily, monthly, seasonal and annual variations in rainfall energy and intensity will lead to increase or decrease in rainfall erosivity, thereby causing variations in soil erosion rates. An attempt has been made in the present study to analyze the impact of the variations in annual rainfall erosivity on the soil erosion rates of the study area.

(b) Soil erodibility

The soil erodibilty factor represents the susceptibility of soil to erosion. The soil properties that are considered for determining the factor are soil texture, soil structure, organic matter content, soil permeability, etc.

Generally, soils with faster infiltration rates, higher levels of organic matter and granular structure have a greater resistance to erosion. While lighter aggregates of silt, very fine sand and certain clay textured soils are easily broken by raindrops; sand, sandy loam and loam textured soils tend to be less erodible owing to their comparatively larger size. Tillage and cropping practices which lower soil organic matter levels cause poor soil structure which contributes to increases in soil erodibility.

(c) Slope Length and Gradient

The amount of soil loss from erosion by water is greater on steep slopes. Soil erosion by water also increases as the slope length increases because displacement of detached soil particle will be to a greater distance under the influence of gravity and also due to the greater accumulation of runoff. Hence, the degree and length of slope are considered together on order to estimate soil erosion (Wischmeier and Smith, 1978; Stocking, et al. 1988; Renard, et al, 1996). The effect of splash erosion is less on very gentle slopes. On flat surfaces, raindrops tend to be more buffered by water ponded on the soil surface than on steep slopes. Higher rainfall intensities that are correlated with higher R factors also tend to increase the depth of ponded surface water, which in turn protects the soil from rainfall impact.

(d) Cover Management

The cover management factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow and is usually given in terms of its average annual value for a particular combination of crop system, management and rainfall pattern (Wischmeier and Smith, 1978).

Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate.

The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil and intercept falling raindrops at and close to the surface are the most efficient in controlling soil erosion (e.g. forests, permanent grasses). Partially incorporated residues and residual roots are also important as these provide channels that allow surface water to move into the soil.

The effectiveness of any crop, management system or protective cover also depends on how much protection is available at various periods during the year, relative to the amount of erosive rain that falls during these periods.

Soil erosion potential is affected by tillage operations, depending on the depth, direction and timing of plowing, etc. No-till operations resulted in reduced erosion rates than conventional tillage (Brock, 1999).

(e) Support Practice

Support practice is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard, et al, 1996). For cultivated land, the support practices considered include contouring, stripcropping, terracing, and subsurface drainage.

The impact of all the factors on soil erosion has been assessed in different parts of the world with the use of soil erosion models that have been developed primarily for the estimation of soil erosion rates as well as sediment delivery ratios of different areas. The most widely used empirical model is the Universal Soil Loss Equation (USLE) which was introduced by Wischmeier and Smith in 1965. The USLE considers the above mentioned factors as the most significant, which determine the process of soil erosion. Coefficients of the factors are calculated with the help of respective formulae used in the USLE and then multiplied with each other for estimating the rate of soil erosion of an area. Estimation of soil erosion becomes a priority keeping in mind the adverse effects of, especially, accelerated soil erosion, viz. loss arable land, reduced crop productivity, etc. Variations in the rates of soil erosion also need to be assessed under different conditions of rainfall amount and intensity, soil erodibility, slope and surface cover, such that management measures can be undertaken to keep the rates to the limits of sustainability.

1.3. Statement of the problem

Knowledge of past soil erosion rates under undisturbed conditions provides a basis for understanding downstream and downslope processes and landforms. In areas where surface disturbance has occurred, information about present and possible future erosion rates furnishes a basis for reducing the adverse effects of accelerated soil erosion. Measurements of erosion resulting from agricultural disturbance provide the means for developing technologies to minimize loss of topsoil and therefore maximize crop productivity over extended periods. Thus, estimation of soil erosion is important for land and water management; primarily for estimating and controlling the on-site effects of soil erosion like deterioration of soil quality leading to reduced crop productivity (Schimdt, 2000); the "off-farm effects, viz. pollution of surface water and flooding" (Boardman and Favis-Mortlock, 1996) and also to "understand the suitability of current and potential suitability of land use alternatives" (Sharma and Singh, 1995).

As has been mentioned earlier, the process soil erosion is primarily determined by rainfall amount and intensity. But rainfall patterns are predicted to change in the near future, with subsequent increase in the amount and intensity of rainfall and the occurrence of extreme weather events are like floods, cyclones, etc. in some parts of the world (IPCC, 2001); and any increase in rainfall, will aggravate the problem of soil erosion, especially at times and in areas where land usage leave the soil surface unprotected (Schimdt, 2000; Sivakumar, 2007; Scholz, et al, 2008). This escorts the need to study the trend of the intensity of soil erosion over the years and predict future rates, such that medium and long-term planning and investment can be done in measures to control soil erosion. Soil erosion rates might be very low in some 'undisturbed' areas but estimation is necessary in these areas also because "in reality, it is the rare or unexpected storm events that may adversely affect soil stability and hydrologic function" (Spaeth, et al, 2003).

The influence of rainfall erosivity on the soil surface is controlled by other factors viz. slope of the land, land cover, soil type, etc. This necessitates an enquiry into the role of each individual factor in determining the rate of soil erosion. Spatial variation of these factors should be taken into account in order to understand the variations in the rates of soil erosion in different parts of the world.

Soil erosion in India has evolved as a matter of concern at the spark of 'higher than estimated' siltation rates of reservoirs and dams (UNEP, 2001), increasing frequency of floods and reduced crop production. Studies have been conducted for estimating soil erosion rates at the country level (Narayana and Ram Babu, 1983; Singh, et.al. 1992) as well as at the watershed level. Studies at the watershed level so far, have focused mainly on the estimation of soil erosion rates and sediment yield and introducing management measures;

on the suitability of erosion-prediction models in estimating soil erosion rates (Sharma and Singh, 1995); mathematical derivation of causal and controlling parameters of erosion (Panigrahi, et.al., 1996); and applicability of remote sensing data (Sharma and Singh, 1995) and geographic information system (GIS) in soil erosion estimation (Agrawal, et.al., 2003). Therefore it can be seen that emphasis has not been given on analyzing the role and significance of different factors affecting soil erosion in relation to each other. Work has also not been done to study the trend of soil erosion rates under changing rainfall conditions. Moreover, regional soil erosion analysis has been concentrated in a few pockets of the country. Sediment delivery ratio of the all the major rivers and the rate of siltation at the major reservoirs of the country have been measured but the soil erosion rates in their respective catchments have not been estimated extensively, which might help in understanding the contribution of soil erosion to the sediment load of the rivers so that measures can be taken to mitigate the problem. High annual rate of siltation (61.05 million cubic meters) at the Hirakud Reservoir of the Mahanadi River in Orissa, has resulted in the loss of water storage capacity of the Reservoir by 24.1 percent in 1999 (Mukherjee, et al, 2007). This necessitates the assessment of the magnitude of soil erosion in the Hirakud catchment because eroded soil is the prime source of the sediment load of rivers. The Gej River in Chhattisgarh is one of the major tributaries of the Mahanadi in its middle course before the latter debouches into the Reservoir. Therefore the Gej watershed has been selected for soil erosion analysis in the present study.

1.4. The study area

The present study concentrates on the analysis of soil erosion in the Gej watershed area of the Mahanadi River Basin in Chhattisgarh. It is to be mentioned here that the unavailability of topographical maps has restricted the area of analysis to a part of the Gej river basin.

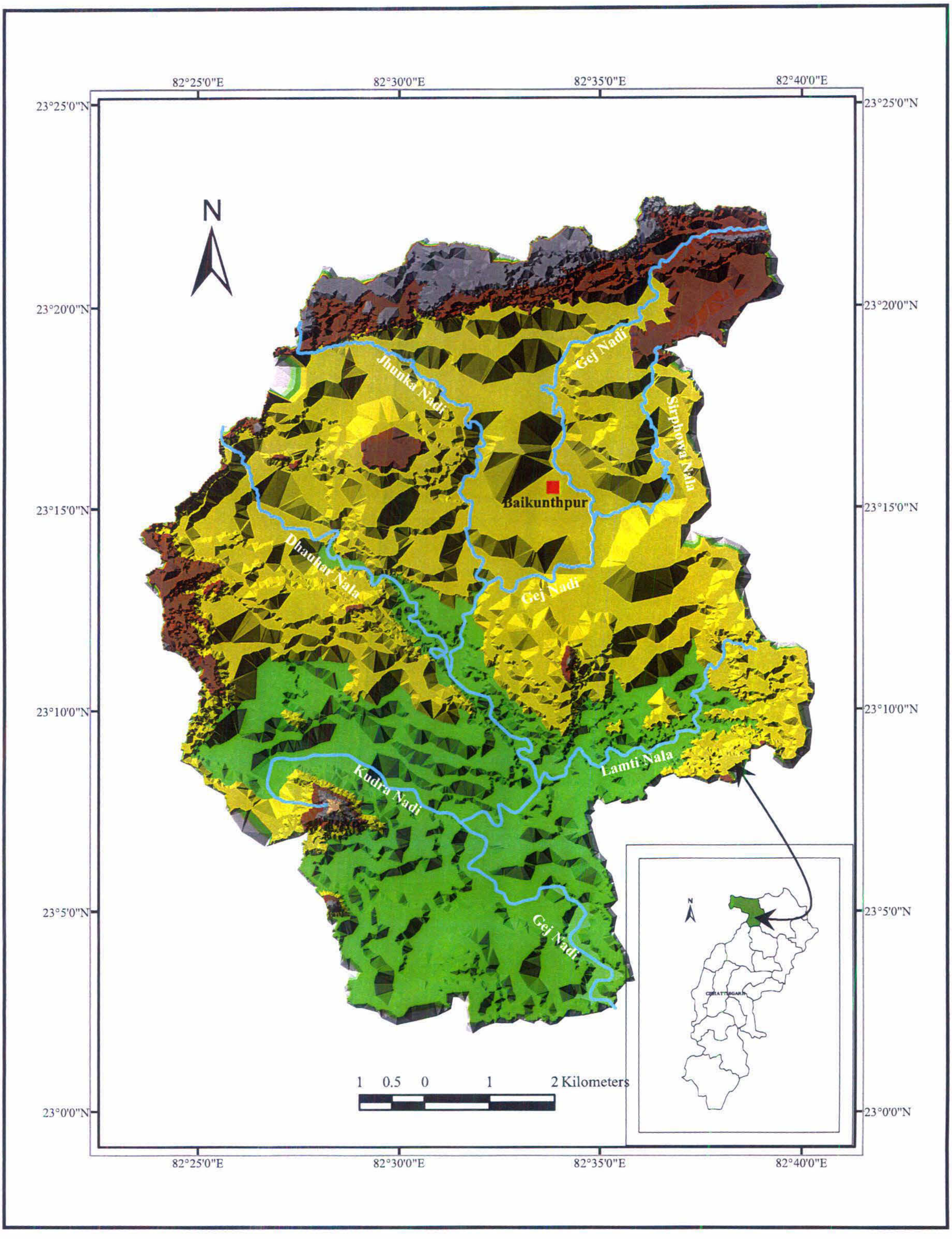


Fig. 1.1: Location Map of Gej Watershed

1.4.1. Location

The study area lies in the Koriya district of Chhattisgarh, extending from $23^0$03'N to $23^0$22'N latitude and $82^0$24'E to $82^0$36'E longitude. The Gej Nadi, a tributary of the River Mahanadi in its middle course, originates in the uplands of the Baikunthpur Tahsil of Koriya at an altitude of approximately 670m. The river, together with its numerous tributaries, drains an area of 700 sq. km.

1.4.2. Physiography

The study area lies in the Eastern Baghelkhand Plateau region. The relative relief of the area is 650m. Originating at an altitude of approximately 670m, the Gej Nadi flows through a longitudinal valley between ridges to the north and the south, before taking a southward bend by dissecting the southern ridgeline as a narrow channel, to debouch on to a gently (south) sloping terrain in the central part of the watershed. Here it is joined by its right bank tributaries - Jhunka Nadi and Dhauhar Nala, and left bank tributaries – Silphorwa Nala and Lamti Nala.

To the south of the Baikunthpur Town, the river takes 90^0 bend to the west and after joining with the Jhunka Nadi it flows south over a highly undulating terrain interspersed with isolated hillocks. The Kudra Nadi, a right bank tributary which rises from an escarpment in the western part of the watershed, joins the Gej Nadi before the latter joins the Jhink Nadi. The courses of the streams draining the watershed are determined by the slope of the area. Following the land capability classification scheme of the USDA, the study area can be divided into six classes on the basis of slope:

- gently sloping (less than 7^0 slope). 89.2 percent of the total watershed area falls in this category.
- moderately sloping (7^0 to 15^0 slope) covers about 7.2 percent of the total area.
- strongly sloping (15^0 to 20^0 slope). 1.6 percent of the area has slope varying between15^0 to 20^0.

- very strongly sloping (20^0 to 25^0 slope) covers only 0.85 percent of the total area.
- steep (25^0 to 30^0 slope). 0.46 percent of the study area is steep.
- very steep (more than 30^0 slope). 0.32 percent of the total area is very steeply sloping.

The watershed is, therefore, gently sloping but interspersed with moderate to steeply sloping areas in the north, west, south-west and southern regions (Fig. 1.2).

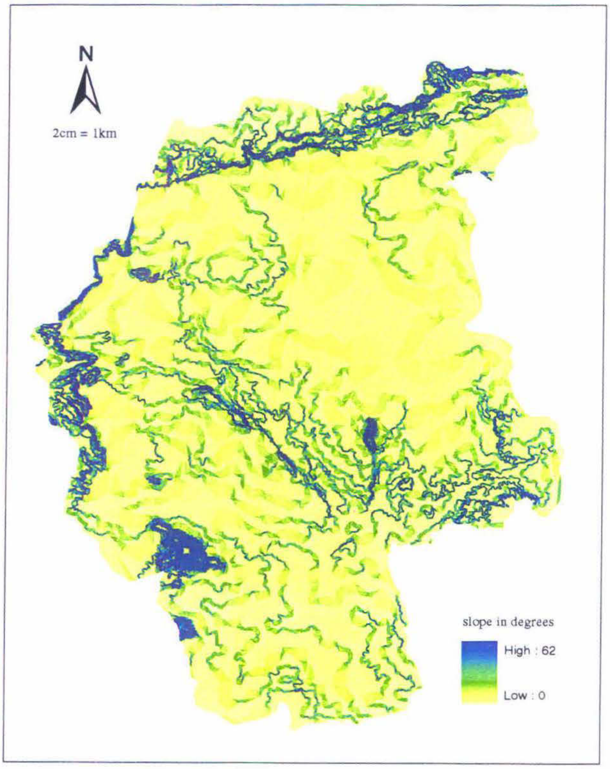
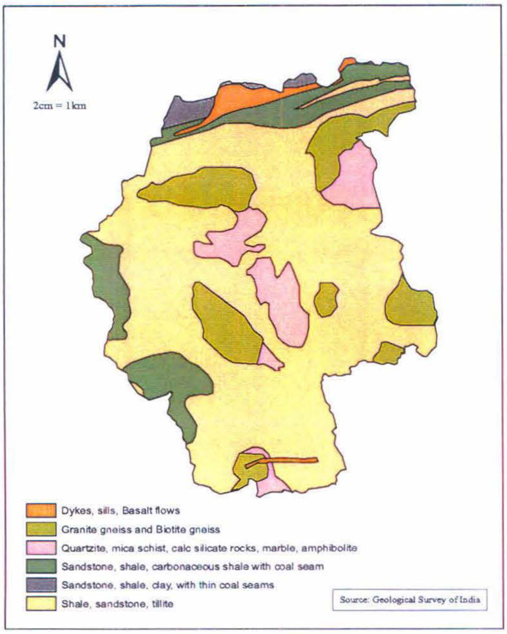


Fig. 1.2: Slope Map of Gej watershed

1.4.3. Geology



Source: Geological Survey of India

Fig. 1.3:Geological map of Gej watershed

The geology of the area dates back to the Archean to Proterozoic era, evidenced by the outcrops of gneisses of the Chhotanagpur Gneissic Complex. The Gneissic Complex comprises of quartzite, mica schist, calc silicate, marble, amphibolite, granite gneiss and biotite gneiss. Sandstone, red and green carbonaceous shale and tillite belonging to the Talchir Formation of the Lower Gondwana Group dating back to Carboniferous to Permian Period underlay most of the area.

1.4.4. Soil

Red and yellow soils primarily occupy the study area. Red gravelly soils are also found in the southern part. However, based on the landform, slope and soil texture different soil types can be identified (Raychaudhuri, et al, 1963; NBSS & LUP, 2003) in the study area: deep clayey soils or *Kanhar* in valleys and plain land; yellow sandy loam or *Matasi* on undulating terrain; *Marhan* on hills and ridges; and red gravelly soil or *Bhata* on steep slopes and escarpments. *Kanhar* is best suited for cultivation of paddy and wheat. Paddy is

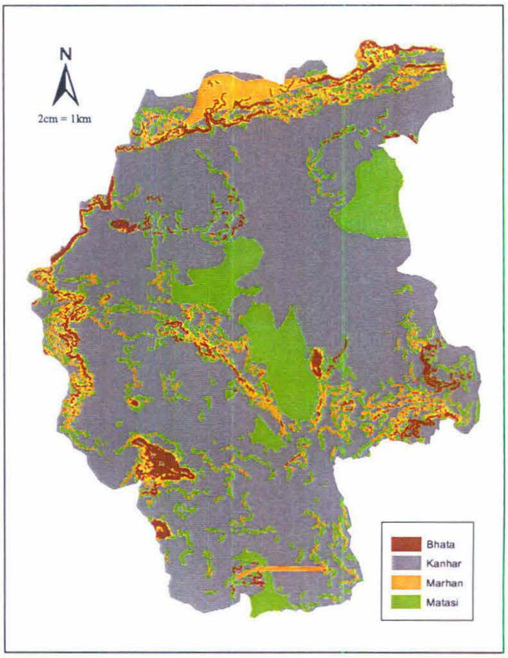


Fig. 1.4: Soil map of Gej watershed

also grown on *Matasi* but under irrigated conditions. *Marhan* and *Bhata* are poor soils and support only *tilli* and inferior millets. However, these are mainly kept under forest cover. *Marhan* and *Matasi* are found most extensively in the watershed area.

1.4.5. Climate

The study area lies in the humid tropics with hot wet summers and cool dry winters. The summer maximum temperature is 27.5^{0}C while in the winters temperature does not fall below 10^{0}C. The normal annual rainfall, as recorded at the Baikunthpur station within the watershed, is 1374.1 mm. 92 percent (1266.6 mm) of the total rarinfall is received during the monsoon months or *Kharif* season (June-October) in the form of heavy torrential rainfall with thunderstorm. 6 percent (84.7 mm) and 2 percent (22.8 mm) are received in the winter or *Rabi* season (November-March) and summer or *Zaid* season (April-May) respectively. Rainfall, in the area, is therefore, highly seasonal. Inter-annual variability in rainfall is also very high (23.8 percent). Very high annual rainfall of 1686 mm was recorded in the year 1994-95. On the other hand, in 1979-80 the area received very low annual rainfall (564 mm). It is also to be noted that total amount of annual rainfall has been increasing over the years, as depicted by the trend line in Fig. 1.5.

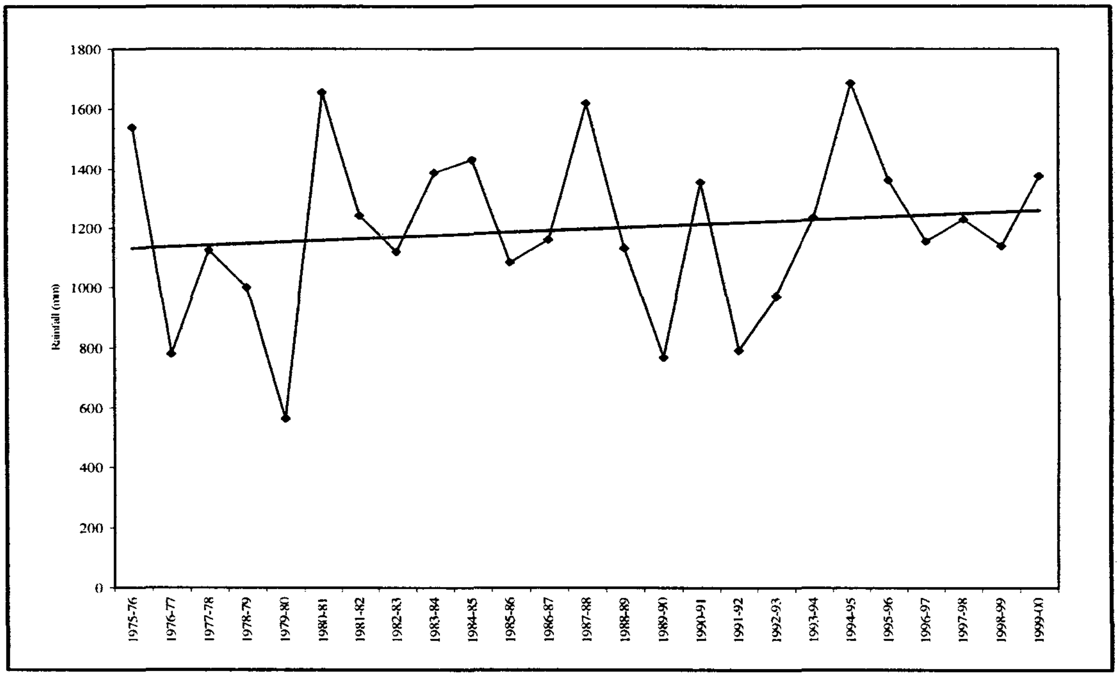


Fig. 1.5: Annual rainfall, Baikunthpur, 1975-76 to 1999-200

1.4.6. Land use/land cover

The land use/land cover (LULC) of the watershed is primarily guided the slope conditions. An overlay of the LULC map (Fig. 1.7) and the slope map (Fig. 1.2) shows that the gently sloping areas are mostly brought under cultivation whereas the steeply sloping areas are kept under forest cover (Table 1).

Table . 1: LULC in different slope conditions

LULC	Slope (^{0})
Cropped land	0 - 41
Dense Forest	0 - 55
Open Forest	0 - 62
Built-up area	0 - 17
Barren Land	0 - 30

Moist tropical deciduous forests are found under a wide range of slopes but their maximum extent is to be found in the steeply sloping areas in the watershed. The abundant flora comprises of Sal, Mahua, Tendu, Palas, Char, Bija, Harra, Bahera, Sheesam, Kusum, Salya, Khair, Arun, Gamhar and Bamboo. The highlands are covered by dense forests (which have been maintained as Reserved and Protected Forests) and open mixed jungles.

The low, gently sloping areas have been brought under cultivation. However agricultural practices have been extended to steeply sloping areas too. Paddy is exclusively grown as monoculture in the study area. It is principal crop of the area, cultivated mainly in the *Kharif* season when abundant rainwater is available. The growing season is of 150-180 days. Seeds are sown in the third or fourth week of June, transplanted in the third or fourth week of July and crops are harvested in the third or fourth week of November. However the crop suffers because of inadequate rainfall and lack of irrigation. Therefore the alternative crops of this area are small millets and pulses.

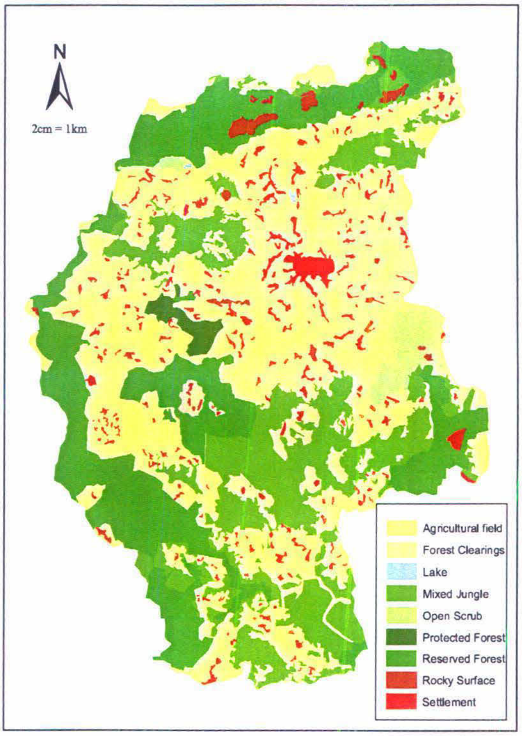


Fig. 1.7: LULC map of Gej watershed, 1970

Against the backdrop of the conceptual framework build on the basis of early studies on soil erosion, the characteristics of all the physical aspects of the study area have been considered in order to attain the main aim of the study, i.e. to analyze the process of soil erosion in the Gej watershed. The objectives, literature review and the methodology have been discussed in the subsequent sections which help to give a layout view of the entire study.

1.5. Objectives

- To estimate the average annual rate of soil erosion in the Gej watershed.
- To understand the extent of influence of different factors, viz. rainfall erosivity, slope, soil type and land use/cover, on the rate of soil erosion.
- To study the variations in soil erosion rates in the study area under varying conditions land use/land cover and rainfall erosivity.

1.6. Literature Review

The objectives of the study will be met with the application of the Universal Soil Loss Equation (USLE). Therefore the approach to existing literature on soil erosion has been kept very specific; it deals with the estimation and application of the different parameters of the USLE that had been used in early studies. The review of literature actually serves as an adminicle to the development of the methodology for the study. A theme wise review of literature has been given in the present section.

1.6.1. Development of USLE

"Quantification of soil erosion helps us to know the actual amount of depreciation of our natural capital, soil" (Fu, et al, 2006). Over the years there has been considerable research on the development of appropriate models for the prediction of soil loss. The existing erosion models can be divided into empirical models and physically-based models (Morgan, 1995). Empirical models have a statistical basis of soil erosion analysis, whereas physically-based models intend to describe the processes causing soil erosion on a storm event basis (Vrieling, 2007). The models intend to represent the important factors controlling erosion including the complex interactions between them and their spatial and temporal variability. The applicability of a model basically lies in its ability to predict soil loss as accurately as possible, and also on the ease of availability of data on its input factors (Schmidt, 2000). The Universal

Soil Loss Equation (USLE) is one of the most commonly used empirical erosion estimating procedures (Sudhishri and Patnaik, 2004).

Early erosion research focused on finding simple solutions to erosion problems, rather than investigating the causes of the problems (Meyer and Mouldenhauer, 1988). Research began with the work of Wollny in Germany in the later half of the 19th century, who studied of the physical properties of soil that affect runoff and erosion (Meyer and Moldenhauer, 1988). In 1936, Cook listed three major factors that affect soil erosion by water: susceptibility of soil to erosion, potential erosivity of rainfall and runoff, and soil protection afforded by plant cover. Zingg published an equation in 1940 relating soil loss rate to length and percentage of slope. In 1941, Smith added crop and conservation practice factors and the concept of a specific soil loss limit.

All the equations discussed so far, gave emphasis on any single factor influencing soil erosion. A holistic approach to the problem was absent until in 1946, a national committee of the U.S.A., chaired by Musgrave, introduced a new equation that took into consideration all the factors that influence the soil erosion. The equation was introduced in 1955 by the Soil Conservation Society (SCS) as follows:

$$A = C\,M\,S\,L\,P\,K\,E$$

where, A was estimated soil loss, C was crop rotation factor, M was a management factor, S was degree or percent of slope factor, L was the length of slope factor, P was a conservation practice factor, K was the soil erodibility factor and E was a erosion factor. As discussed in literature this equation is not accepted universally due to its inherent problems.

Based on the Musgrave equation, Wischmeier and Smith introduced Universal Soil Loss Equation (USLE) at a series of regional soil loss prediction workshops from 1959 through 1962. Its field use began in the Midwest in the 1960s. The Agriculture Handbook 282 was published by the USDA in 1965, which served as the main reference manual for USLE until it was revised in 1978 as Agriculture Handbook 537. This empirical equation was developed from over 10,000 plot years of data both from natural rainfall and rainfall simulator plots. It computes sheet and rill erosion as annual average soil loss (t ha^{-1} yr^{-1}) from a unit plot which is defined as a 72.6 feet length of uniform 9 percent slope continuously in clean-tilled fallow, using the values representing the four major factors affecting erosion: climate, soil, topography, land cover and management. The equation is as follows:

$$A = R\,K\,L\,S\,C\,P$$

where, A = computed soil loss per unit area (t ha^{-1} yr^{-1})

R = rainfall erosivity (MJ mm hr^{-1} ha^{-1} yr^{-1})

K = soil erodibility factor which is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot (t ha hr MJ^{-1} mm^{-1})

L = slope length factor, is the ratio of soil loss from the field slope length to that from a 72.6 feet length

S = slope steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9% slope

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

P = support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight row farming up and down the slope.

(LS, C and P are dimensionless units.)

Over the years the USLE became the standard tool for predicting soil erosion by water not only in the US, but throughout the world. According to Chandra (1986), it enables land management planners to estimate average annual erosion rates for a range of rainfall, soil, slope, cover and management conditions and to select alternative land use and practice combinations that will limit erosion rates to acceptable limits.

The model, however, is plagued with several limitations, such as too much generalization of reality and over-estimation of erosion rates. Hence modifications were made to the model leading to the introduction of the Revised Universal Soil Loss Equation (RUSLE 1) in the late 1980s. The RUSLE 1 model was introduced in great detail in the Agricultural Handbook 703 in 1996 by Renard and others. RUSLE 1.06c was introduced in 2003 followed by RUSLE 2 in the same year by USDA-ARS-NSL. "While it maintains the basic structure of the USLE, the algorithms used in RUSLE to calculate the individual factors are changed significantly" (Croke & Nethery, 2006).

Several studies (Spaeth, et.al, 2003; Shi, et.al., 2004; Croke and Nethery, 2006) revealed that both USLE and RUSLE tend to over-estimate soil erosion rates in areas of high values of observed erosion rates and under-estimate soil erosion rates in areas of small values of observed erosion rates. Moreover, USLE does not involve a spatial resolution (Fistikoglu, et al, 2002), i.e., it does not enable one to analyze the spatial variations in erosion rates.

The latest modeling approaches such as the Water Erosion Prediction Project or WEPP (Renschler, 1999) aim to overcome the aforesaid limitations of the empirical USLE. But these models require huge amounts of input data which are commonly not available. This allows the USLE to be used widely which are based on modest data requirements (Millward and Mersey, 1999; Shi, et.al 2004; Croke and Nethery, 2006).

1.6.2. Estimation of input factors in USLE

The usage of the original equation, however, is in many studies restrained by the lack of adequate data. Hence modifications have been made to the equation by researchers in order to estimate soil erosion in different areas of the world. Thus the present sub-section reviews literature on the changes made to the USLE.

(a) Rainfall Erosivity – R factor

The numerical value used for R in USLE quantifies the effect of raindrop impact and is considered as the best indicator of erosivity potential of the storm (Sudhishri and Patnaik, 2004). Therefore, R is considered as the annual average of the sum of erosion indices at maximum 30 minutes rainfall intensity of moderate-sized storm events as well as occasional severe storms during a rainfall record of at least 22 years (Wischmeier and Smith, 1978).

$R = \sum (EI_{30})_i / N$

where $(E1_{30})_i = EI_{30}$ for storm i, j = number of storms in an N year period.

As the intensity of individual storms varies considerably with various time durations, controversy still remains on the selection of time interval for correlating EI values with erosion losses (Sudhishri and Patnaik, 2004). EI_{30} is generally acknowledged to be significant in describing erosive power where soil is bare (Wischmeier and Smith, 1978), but studies in Zimbabwe showed that while EI_{15} was a better predictor of storm rainfall under moderate vegetation covers, EI_5 under good vegetation cover (Stocking, et.al., 1988) as well as for the Mediterranean areas (Uson and Ramos, 2001).

The computation of the rainfall erosivity index requires a continuous record of rainfall intensity for single rainfall events (Loureiro and Coutinho, 2001). But continuous record of rainfall intensity for single rainfall events is not available as a standard output of most meteorological surveys around the world. In most cases only daily rainfall amounts are available. As mentioned by Panigrahi, et al (1996) Richardson et al developed a model in 1983 for estimating the erosivity index for rainfall events from daily rainfall amounts for American conditions. Daily rainfall values were considered as the individual storm events. Erosivity index was estimated using the following equation:

$EImin = P^2 (0.00364 \log_{10}P - 0.000062)$

where P is the daily rainfall amount.

Panigrahi et al. (1996) developed a regression model for estimating the minimum value of erosion index (EImin) for rainfall events from daily rainfall amount for the period 1957–1987 at Bhubaneshwar. They reported that seasonal pattern of the computed EImin closely follows the seasonal pattern of observed EImin. As the average deviation between the observed and calculated EImin was found to be 12.22 %, they concluded that the model developed for computation of EImin worked well by using the daily rainfall data.

Yu (1995) highlighted that although, traditionally, the R-factor has mainly been used to compare the soil erosion potential at different locations; it has the potential to provide a measure of temporal variation of rainfall erosivity.

(b) Soil Erodibilty – K factor

K values for soils with more than 70 percent silt + very fine sand can be estimated using the soil erodibility nomograph (Wischmeier and Smith, 1978). The nomograph is based on data obtained from soil samples and field observations. In case of soils with less than 70% silt + very fine sand, the following equation as proposed by Wischmeier, et al (1971) can be used to measure the K-factor:

$$K = [2.1*10^{-4}(12\text{-}OM)\, M^{1.14} + 3.25\,(s-2) + 2.5\,(p\text{-}3)]/100$$

where, K = soil erodibility factor (t.ha.hr.ha^{-1}.MJ^{-1}mm^{-1})

M = percentage of silt (0.002-0.05μm) and very fine sand (0.05-0.10 μm)

OM = percentage of organic matter content

s = structure of the soil

p = permeability of the soil

The higher the value of K, the more susceptible the soil is to erosion. The formula has been accepted in almost all the research papers for prediction of soil erosion rates (Millward & Mersey, 1999; Shi et.al., 2004; Fu et.al., 2006, Singh and Phadke, 2006).

(c) Hillslope Length and Gradient – LS Factor

The effect of topography on erosion is accounted for by the LS factor in USLE. It combines the effects of a hillslope length factor, L, and a hillslope gradient factor, S. As hillslope length and/or hillslope gradient increases, soil loss increases. Wischmeier and Smith (1978) proposed the following equation for calculating the LS factor:

$$LS = (L/22.1)^m (0.065 + 0.045S + 0.0065S^2)$$

where, L = slope length in meters

S = gradient in percent

m = 0.5 if slope is 5% or more, 0.4 on slopes of 3.5 - 4.5 %, 0.3 on slopes of 1- 3% and 0.2 on uniform gradients of less than 1%.

It may be noted that in the above equation the value of m remains 0.5 for very steep slopes. This may give lesser values for higher slopes. Modification was, therefore, made in the calculation of m in RUSLE. Renard, et al (1996) used the formula proposed by Foster in 1977 as follows:

$$m = \beta / (1 + \beta)$$

where, $\beta = (\sin\theta/0.0896) / [3.0(\sin\theta)^{0.8} + 0.56]$

θ = slope angle.

The above equation has been modified to make the model more readily applicable in different regions. Shi et.al. (2004) stated that soil loss was linearly related to the sine of the slope angle according to the following relationship:

$$S = 21.91 \sin \theta - 0.96$$

where, S = slope steepness factor normalized to 9% slope

θ = slope angle in degrees

Application of the above equation was basically an attempt to measure soil loss from steep to very steep slopes.

Integration of soil erosion model with GIS is at vogue in recent years. Thus, Millward and Mersey (1999) used the following equation to substitute the L-factor value with each of the grid cells within the digital elevation model (DEM) considered as a slope segment having uniform slope:

$$L_{i,j} = (A_{i,j\text{-out}}{}^{m+1} + A_{i,j\text{-in}}{}^{m+1}) \,/\, [(A_{i,j\text{-out}} - A_{i,j\text{-in}})\,(22.13)^{m}]$$

where, $L_{i,j}$ = slope length factor for cells with co-ordinates (i,j)

$A_{i,j\text{-out}}$ = contributing area at the outlet of the grid cell with co-ordinates (i,j) (m^2)

$A_{i,j\text{-in}}$ = contributing area at the inlet of the grid cell with co-ordinates (i,j) ($m^2 m^{-1}$)

m = slope length exponent of the RUSLE S-factor

Slope steepness was calculated in this paper with the help of the following equation:

$$S = -1.5 + [17 \,/\, (1 + e^{2.3 - 6.1 \sin(\theta)})]$$

where, θ = slope angle in degrees of the cell for which the LS-factor is to be determined.

The complexity of the above equations for LS factor can be overcome by the application of the following equation used by Ma (2001). In this equation the LS factor has been estimated from the slope geometry (given as DEM) and the accumulated water flow as follows:

$$LS = (\text{flow accumulation} * \text{cell size}/22.13)^{0.6} * (\sin\theta * 0.01745/0.09)^{1.3} * 1.6$$

where, flow accumulation is a grid theme of flow accumulation expressed as the number of grid cells and cell size is the length of grid.

(d) Cover Management – C Factor

The C factor represents the effects of plants, soil cover, soil biomass and soil disturbing activities on soil loss (Renard, et al, 1996). Values for C factor can be derived from the USLE tables. Table values for C have also been provided by Singh and Phadke (2006). RULSE uses sub-factors, viz. prior land use, canopy cover, surface roughness and soil moisture to compute soil loss ratio (SLR), which is the ratio of soil loss at any given time in the cover management sequence to soil loss from the standard condition. The factor C is expressed as:

$$C = PLU \, . \, CC \, . \, SC \, . \, SR \, . \, SM$$

where, PLU is the prior-land- use sub-factor, CC is the canopy-cover sub-factor, SC is the surface-cover sub-factor, SR is the surface-roughness sub-factor and SM is the soil-moisture sub factor.

Benkobi, et al (1994) introduced a refined surface cover sub-factor (RSC) and concluded that refined values predicted soil loss considerably better than those obtained with the original model.

In the era of satellite remote sensing, vegetation indices such as normalized vegetation difference index (NDVI) have also been explored for mapping C factor from satellite images (Asis, 2007). C is determined using the following formula:

$$C = e^{[-2 * \{NDVI / (1 - NDVI)\}]}$$

(d) Support Practice – P factor

Factor P is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture. The USLE provides tables the values of P as derived from different experiments (Wischmeier and Smith, 1978; Renard, et.al., 1996).

1.6.3. Remote sensing and GIS in soil erosion assessment

Estimation of soil erosion requires the assimilation of the above input parameters. This necessitates the compilation of a huge amount of data which can be readily done with the use of GIS. Integration of USLE with GIS also provides a means to isolate and describe areas that are vulnerable to soil erosion, thus enabling immediate application of conservation planning in that area (Millward and Mersey, 1999).

Agrawal, et.al. (2003) suggested that since all the parameters that determine soil erosion have a spatial distribution, satellite remote sensing and GIS do have a wide application in impact assessment on soil erosion. Other studies that used empirical models in a GIS environment for soil erosion assessment were those of Shi, et.al. (2004) and Fu, et.al. (2006).

Prior to the use of satellite remote sensing, aerial photograph were widely used for detecting erosion features and obtaining model input. The scale of the aerial photograph was a deciding factor on the accuracy of the study. Iyer (1974) concluded that large scale (1:12500 or more) aerial photographs are preferable than medium scale ones (1:25000) for accurate estimation of slope lengths and gradients and for the preparation of detailed landuse map to evaluate C and P values.

Starting in 1972 with the launch of Landsat I, satellite imagery has become increasingly available to the scientific community (Vrieling, 2007). Spectral differences in an image allowed identification of soil degradation and erosion areas in arid and semi-arid environments of the USA (Frank, 1984; Robinove et al., 1981).

Soil classification by visual interpretation of optical satellite imagery has been used to assess differences in soil erodibility (Sharma et al, 1989). Sharma and Singh (1995) concluded that visual interpretation is more effective for hydrological studies than supervised computer classification techniques.

Metternicht and Zinck (1998) performed a maximum likelihood classification on Landsat TM and on the combination of Landsat TM with JERS-1 SAR data, in order to detect and map soil erosion features in the Sacaba Valley in Bolivia. They achieved highest classification accuracy using the combination of both images.

However, successful application of satellite remote sensing to detect eroded areas is generally limited to arid and semi arid areas or extensive areas suffering gully erosion. In more humid regions, vegetation cover often obscures the visibility of the soil, whereas agricultural activities may furthermore greatly influence vegetation cover, soil properties, and surface roughness (Vrieling, 2007).

Despite the vast amount of existing studies on the remote sensing of variables that are of importance for erosion studies, little work has been done on developing methodologies for mapping soil erosion based specifically on these remotely sensed variables.

1.6.4. Soil erosion and change in rainfall pattern

Rainfall erosivity has been regarded as the most important climatic factor affecting soil erosion. Yet concern regarding the possible deviations of rainfall aspects from the normal, and its impact on soil erosion is revealed in few research papers.

Boardman and Favis-Mortlock (1993) explained that an increase of 15% in winter rainfall and/or increase in the frequency or severity of summer rainstorm in Britain will increase the potential for erosion.

Walling and Webb (1996) recorded a five-fold increase in sediment load of the Dnester River in Ukraine since the 1950s which was due partly, to major land use changes such as forest clearances, but more importantly to the observed changes in the rainfall pattern.

Nearing (2001) investigated the impact of climate change on rainfall erosivity, using Global Climate Models and RUSLE. The results showed critical changes in rainfall erosivity of up to 58% at some locations will considerably affect future soil erosion rates.

Erosion index analysis based on daily rainfall data of 1970-2001 was done by Sudhishri and Patnaik (2004) for the Eastern Ghat Highland Zone in Orissa. The study established a strongly positive monthly, seasonal and annual relationship between erosion index and total rainfall for the study area with r^2 value 0.906, 0.901 and 0.946 respectively.

Scholz, Quinton and Strauss (2007) predicted a decline in annual average soil loss by 10.6 to 24.1% due to an overall 4.7% reduction in precipitation in the Central European region of Upper-Austria.

It can, therefore, be seen that so far efforts have been made to develop adequate methods to estimate soil erosion rates. Estimation of soil erosion has, in fact, been considered as a prerequisite for the implementation of watershed management scheme in an area. The USLE has been most widely used for soil erosion assessment. However, modifications were made to the original equation in order to make it more readily applicable to different parts of the world. The significance of different factors affecting soil erosion has been noted in some cases, but rainfall erosivity has been found to be the most influential, in most studies.

1.7. Methodology

In the present study, soil erosion rate in the Gej watershed has been estimated with reference to the climate scenario 1975-99. The USLE has been employed for the purpose of estimation. This is because the study aims at the estimation of soil erosion at an average annual basis and not on the analysis of soil erosion during a single storm event. Moreover the availability of minimum input data permits the use of this empirical model but with some modifications in the equations for estimating the input parameters – R, K, LS, C and P.

Various thematic maps (soil, slope, land use/land cover, etc) have been prepared on the basis of interpretation of Survey of India topographical sheets and remote sensing data. Digital classification of Landsat TM (1990) and Landsat ETM^+ (1999) has been carried out to identify different land use/land cover classes in the area. Subsequently the superimposition and integration of the thematic maps using the USLE has been executed in a GIS environment for the generation of erosion map. The methodology has been discussed in detail in the respective chapters of the dissertation.

1.8. Sources of data

The following sources of data have been referred to:

- Survey of India topographical maps 64 I/7, I /8, I /11 and I /12 on 1:50,000 scale
- District Resource Map of Koriya, Chhattisgarh published by the Geological Survey of India

- Daily rainfall data for the period 1975 to 1999 for the Baikunthpur raingauge station from Indian Daily Weather Report published by the Indian Meteorological Department
- Soil data regarding texture, structure, etc. from All India Soil and Land Use Survey, New Delhi and National Bureau of Soil Survey and Land Use Planning, Pune
- Sediment load data at Bamnidhi, 1993-94 to 1999-2000 from Central Water Commission, New Delhi (www.cwc.nic.in)
- Landsat TM/ETM$^+$ satellite imageries will be used. (source: www.glcf.umiacs.umd.edu/data/landsat/)

Path/Row	Satellite ID	Sensor	Product Date
142/44	Landsat	a. TM b. ETM$^+$	a.1990-11-10 b.1999-11-11

CHAPTER 2

ESTIMATION OF PARAMETERS FOR EROSION ASSESSMENT

The Universal Soil Loss Equation (USLE) has been used for estimating the average annual rate of soil erosion in the Gej watershed area. However, due to data limitation, the USLE per se, as given by Wischmeier and Smith (1978), has not been used. Modifications have been made to the equation for measuring the input factors. The input factors or model parameters are rainfall erosivity, soil erodibility, slope-length, surface cover and support practices. Coefficients required for each parameter have been calculated using different equations given by different authors. The selection of the equations is guided by the availability of secondary data. The coëfficients were derived in a spatial domain using the raster model. The estimation of the coefficients of the different model parameters has been discussed in the following sections of this chapter.

2.1. Rainfall erosivity – R factor

Rainfall erosivity has been calculated from the daily rainfall data for the Baikunthpur meteorological station for 25 years (1975-76 to 1999-2000). Such a specific range for precipitation data meets the necessary requirement of the USLE model which states that the minimum record length of climate data to be used for R factor is 22 years (Wischmeier and Smith, 1978).

Erosivity is expressed as the product of kinetic energy of rainfall and maximum 30-min rainfall intensity (Wischmeier and Smith, 1978). This, however, needs continuous (hourly) precipitation data. But the available daily rainfall data does not provide rainfall intensity of 30 minutes. Hence, the original equation had to be modified. In this study, it has been assumed following Sudhishri and Patnaik (2004) and Panigrahi (1996) that erosivity can result from a total rainfall (P) of ≥ 12.5 mm* that would occur with uniform intensity for the whole day, i.e. 24 hours, i.e. the rainfall is distributed throughout the day with uniform intensity. Erosivity was then derived for all erosive rainfall events using the following equations, as applied by Panigrahi, et al (1996):

$$e = 0.119 + 0.0873 \log_{10} * i \qquad (1)$$

where, e = kinetic energy in MJ ha^{-1} mm^{-1} of rainfall in a day

i = rainfall intensity in mm hr^{-1}, i.e. $i = P/24$ (2)

$$EI_{min} = e * i \qquad (3)$$

where, EI_{min} = rainfall erosivity index of day receiving ≥ 12.5 mm of rainfall

Now, substituting equation (3) by equations (1) and (2), we get:

$$EI_{min} = P\,[0.119 + 0.0873 \log_{10} (P/24)] * (P/24) \qquad (4)$$

Monthly EI_{min} is the summation of the daily EI_{min} and a total of the EI_{min} of twelve months gives the annual EI_{min}. Average annual rainfall erosivity (R) measured in units of MJ. mm. ha^{-1} hr^{-1} yr^{-1} was calculated as follows:

$$R = \sum EI_{min} / t \qquad (5)$$

where, t = number of years, in the present study - 25 years

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* Records from experimental plots showed that the rainstorms greater than 12.5 mm produce significant amount of soil erosion (Wischmeier and Smith, 1978). Therefore, a rainy day with ≥ 12.5 mm of rainfall has been considered as an erosive event (Sudhishri and Patnaik, 2004) in this study.

The average annual erosivity, R, for the study area was calculated to be 316.32 MJ. mm. ha^{-1} hr^{-1} yr^{-1}. Since daily rainfall data for only one station was available for the Gej watershed, a raster layer with pixels of same R value (316.32 MJ. mm. ha^{-1} hr^{-1} yr^{-1}) was created to be used as R factor map of the watershed. Daily rainfall data of more than one station would have improved the accuracy of the results.

A linear regression analysis reveals a strong positive correlation between annual rainfall and erosivity ($r = 0.72$) which is significant at 1 percent level. This is close to the result derived by Panigrahi, et al (1996) in which a correlation coefficient of 0.71 was obtained. The annual values of rainfall amount and erosivity indices for the period 1975-1999 are given in Table 2.1. EI_{min} was maximum (933 MJ. mm. ha^{-1} hr^{-1} yr^{-1}) from an annual rainfall amount of 1539 mm in 1975-76 and was lowest (116 MJ. mm. ha^{-1} hr^{-1} yr^{-1}) off 564 mm in 1979-80. Thus it may be stated that rainfall erosivity decreases with decrease in rainfall amount (Fig.2.1).

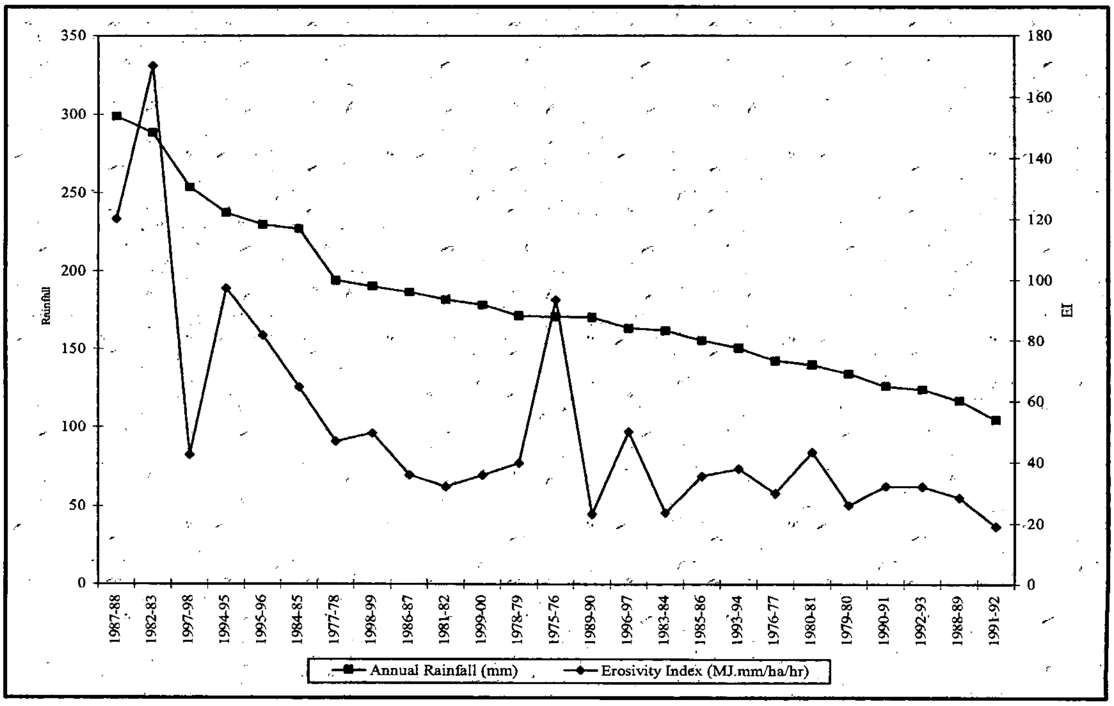

Fig 2.1: Annual Rainfall and Erosivity, Baikunthpur, 1975-76 to 1999-2000. Rainfall data has been arranged in descending order.

Table 2.1: Annual Rainfall and Erosivity, Baikunthpur, 1975-76 to 1999-00

Years	**Annual Rainfall (mm)**	**Annual Erosive Rainfall (mm)**	**Annual Rainfall Erosivity (MJ.mm/ha.hr)**
1975-76	1539	1334	933
1976-77	781	631	133
1977-78	1126	1049	279
1978-79	1000	946	216
1979-80	564	500	116
1980-81	1655	1445	449
1981-82	1243	1099	262
1982-83	1120	864	405
1983-84	1388	954	156
1984-85	1429	1149	385
1985-86	1104	821	234
1986-87	1205	944	225
1987-88	1620	1343	633
1988-89	1131	863	238
1989-90	787	557	108
1990-91	1356	1134	329
1991-92	787	643	126
1992-93	964	821	236
1993-94	1244	1067	315
1994-95	1686	1457	621
1995-96	1399	1180	518
1996-97	1154	918	274
1997-98	1296	1084	203
1998-99	1140	1001	307
1999-2000	1377	1099	214
Average annual	**1204**	**996**	**316**

It is to be noted, however, that rainfall erosivity does not decrease linearly with rainfall amount. In fact there are some years with markedly high annual erosivity index, even though these years show little or no evidence of high annual rainfall (Fig. 2.1). For example, EI_{min} was 156 MJ. mm. ha^{-1} hr^{-1} yr^{-1}off 1388 mm rainfall in 1983-84 and but in 1982-83 it was 405 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off only 1120 mm of rainfall. Strikingly, an annual total of 1620 mm of rainfall in 1987-88 resulted in 633 MJ. mm. ha^{-1} hr^{-1} yr^{-1} of erosivity as against 449 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off 1655 mm in 1980-81. Therefore an attempt has been made to see whether the high annual erosivity indices were explained by the total amount of annual erosive rainfall (≥12.5 mm).

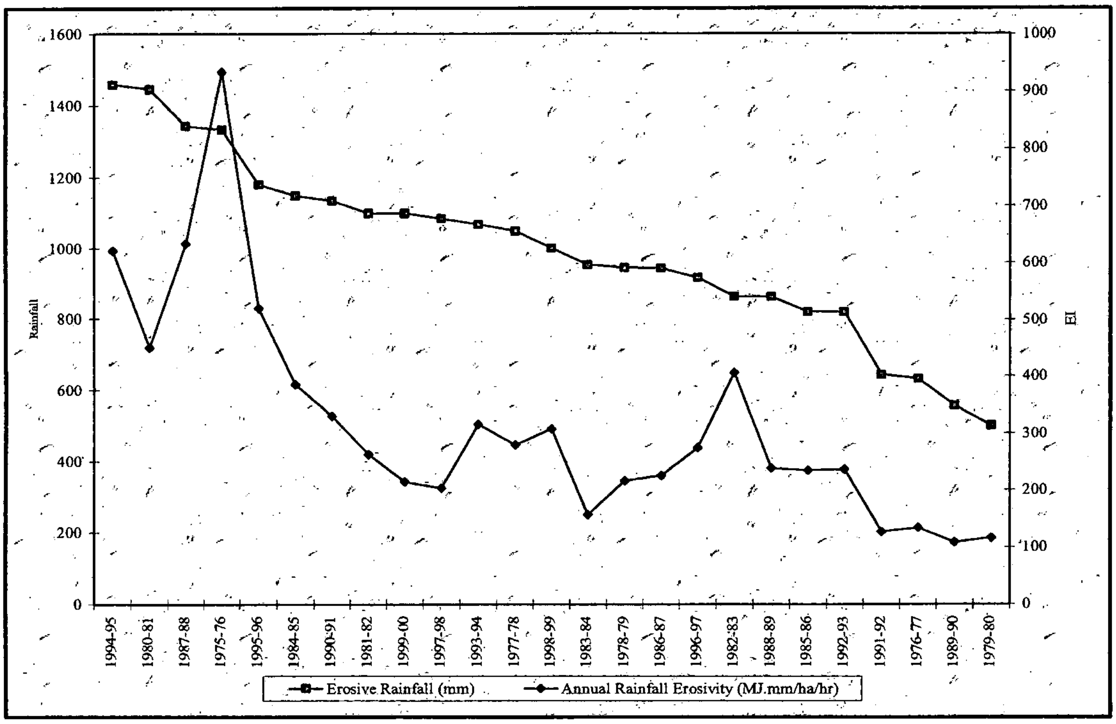

Fig 2.2: Annual Erosive Rainfall and Erosivity, Baikunthpur, 1975-99. Rainfall data has been arranged in descending order.

Annual rainfall erosivity decreases with decrease in the amount of annual erosive rainfall (Fig. 2.2). For example, erosivity was 116 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off 500 mm of erosive rainfall in 1979-80. On the other hand, it was 214 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off 1099 mm of erosive rainfall in 1999-2000. Thus a strong positive relation exists between annual erosive rainfall and annual erosivity (r = 0.77). However, it is to be noted that in the case of erosive rainfall, too, erosivity does not decrease linearly (Fig. 2.2). For example, in Table 2.1 it can be seen that EI_{min} was 156 MJ. mm. ha^{-1} hr^{-1} yr^{-1}off 954 mm of erosive rainfall in 1983-84 and but in 1982-83 it was 405 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off only 864 mm of erosive rainfall. Moreover, an annual total of 1445 mm of rainfall in 1980-81 resulted in 449 MJ. mm. ha^{-1} hr^{-1} yr^{-1} of erosivity as against 633 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off 1343 mm in 1987-88.

There are, therefore, instances of high rainfall erosivity off low annual rainfall as well low annual erosive rainfall. This feature reflects an increased frequency of high magnitude storm events, the occurrence of which is not reflected in the values of annual rainfall. A similar conclusion has been arrived by Walling and Webb (1996) in their study of rainfall erosivity in the Yellow River Basin in China. Thus, inter-annual variations in rainfall erosivity may be explained by the occurrence of heavy rainfall event or *extreme rainfall event* in any year. In this study, following Goswami, et al (2006), a day with a total rainfall amount of 100 mm or more is considered as an *extreme rainfall event.* Analysis of the available data shows that more the number of extreme rainfall events in a year, higher is the rainfall erosivity ($r = 0.8$). Table 2.2 shows the number of extreme events that had occurred during the period 1975-76 to 1999-2000.

Table 2.2: Years of Extreme Events during the period 1975-76 to 1999-2000, Baikunthpur

Year	**Rainfall (mm)**		**Months**	**Number of Extreme Events**	**Annual Erosivity Index**
1975	208	212	August *(21,22)*	2	933
1980	103		August *(28)*	1	449
1982	128 *(4)*	137 *(19)*	June *(4, 19)*	2	405
1984	102	118	August *(7, 18)*	2	385
1985	107		August *(15)*	1	234
1987	130		August *(18)*	3	633
	103	109	September *(12, 16)*		
1992	108		August *(8)*	1	236
1993	104		September *(18)*	1	315
1994	105		June *(18)*	3	621
	108		August *(8)*		
	140		September *(18)*		
1995	161	108	July *(14, 17)*	2	518
1996	106		July *(28)*	1	274
1998	110		August *(19)*	1	307

N.B: *Values in ( ) are the days in the month that recorded extreme event*

Regression analysis of the rainfall data helped to determine a mathematical relationship between annual rainfall and number of extreme events as independent variables and annual EI_{min} as the dependent variable. A constant value of -83.768 was derived. The coefficients for extreme event and rainfall were 111.366 and 0.259 respectively. Based on the derived coefficients, the following equation has been developed that can be used for calculating annual EI:

$$EI = -83.768 + 111.366\ E_x + 0.259\ Rf \qquad (6)$$

where, E_x = number of extreme events

Rf = rainfall in mm

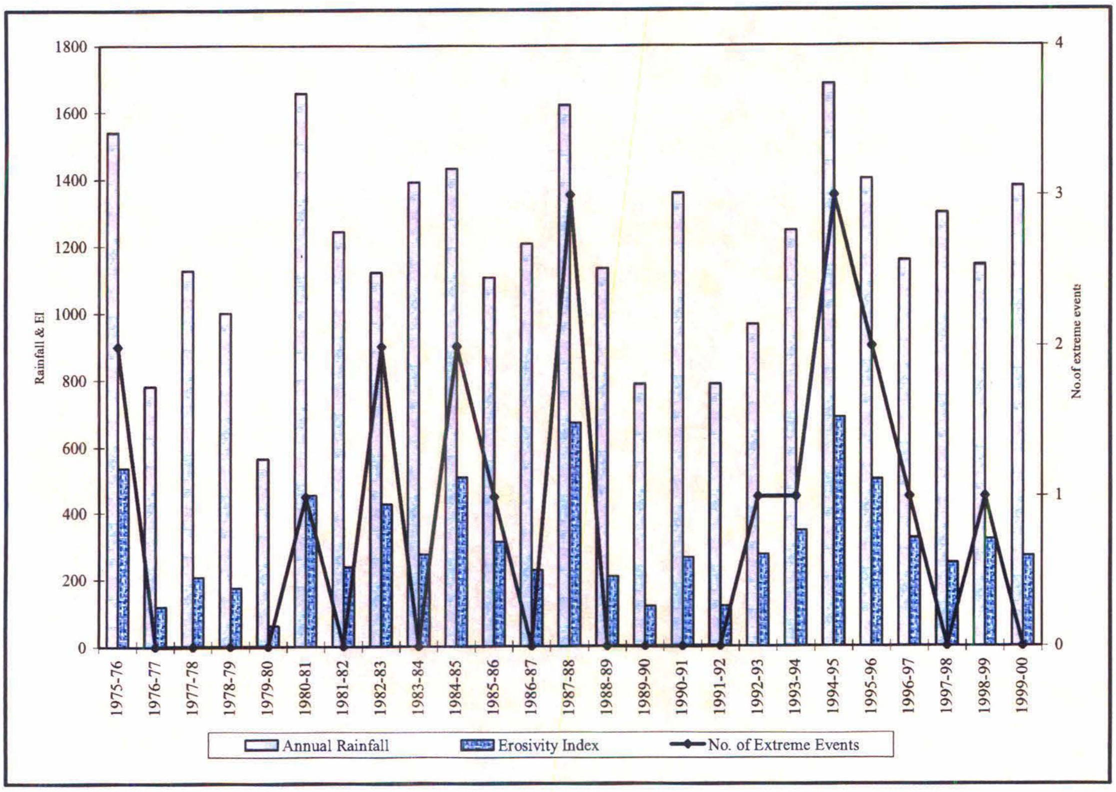

Fig. 2.3: Annual rainfall erosivity indices (1975-76 to 1999-2000) determined by the combined impact of annual rainfall total and number of extreme events.

It can be seen (Fig. 2.3) that EI_{min} is high in years which recorded high annual rainfall with some days receiving $\geq$100 mm rainfall. On the other hand, EI_{min} is low in years which did not record any extreme rainfall event, even if the annual rainfall total is high. For example, EI was 156 MJ. mm. ha^{-1} hr^{-1} yr^{-1}off 1388 mm rainfall in 1983-84 and but in 1982-83 it was

405 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off only 1120 mm of rainfall. This is because 2 extreme events occurred in 1982-83 whereas not a single extreme event was recorded in 1983-84. Moreover, an annual total of 1655 mm of rainfall in 1980-81 resulted in 449 MJ. mm. ha^{-1} hr^{-1} yr^{-1} of erosivity but EI_{min} was 633 MJ. mm. ha^{-1} hr^{-1} yr^{-1} off 1620 mm in 1987-88. This is because, 3 extreme events were recorded in 1987-88 as against 1 extreme event during 1980-81. Therefore, low annual rainfall can result in high annual EI_{min} if extreme rainfall event(s) are recorded during the year; because, heavy rainfall ($\geq$100 mm) will have higher erosivity and hence the sum of the erosivity of the days with erosive rainfall ($\geq$12.5 mm) will be higher. In fact, a very strong positive relationship ($r = 0.86$) is established between rainfall amount and number of extreme events on one hand and EI on the other. The correlation is significant at 1% level.

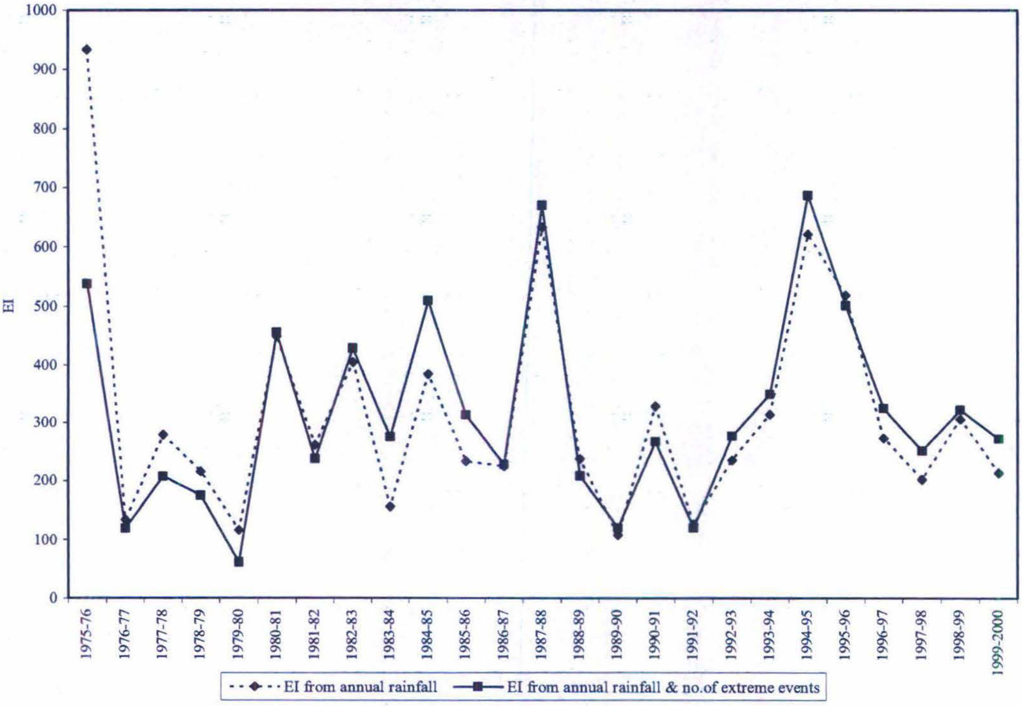

Fig 2.4: Annual rainfall erosivity indices from 1975-76 to 1999-2000 calculated using annual rainfall (dashed lines) and as a function of annual rainfall and number of extreme events (continuous lines)

The mean deviation between the annual EI_{min} (which was a summation of the EI_{min} calculated using equation 4) and the EI calculated using equation (6) was found to be only 10% (Fig. 2.4). Hence it may be concluded that equation (6) developed for the computation of annual EI works well by using a combination of daily rainfall amount and number of extreme events. Table 2.3 shows the annual erosivity index values that have been derived using equation 6.

Table 2.3: Annual rainfall Erosivity Indices, Baikunthpur, 1975-76 to 1999-2000

Years	**Annual Rainfall (mm)**	**Number of Extreme Events**	**Annual Erosivity Index**
1975-76	1539	2	538
1976-77	781	0	119
1977-78	1126	0	208
1978-79	1000	0	175
1979-80	564	0	62
1980-81	1655	1	456
1981-82	1243	0	238
1982-83	1120	2	429
1983-84	1388	0	276
1984-85	1429	2	509
1985-86	1104	1	314
1986-87	1205	0	228
1987-88	1620	3	670
1988-89	1131	0	209
1989-90	787	0	120
1990-91	1356	0	267
1991-92	787	0	120
1992-93	964	1	277
1993-94	1244	1	350
1994-95	1686	3	687
1995-96	1399	2	501
1996-97	1154	1	326
1997-98	1296	0	252
1998-99	1140	1	323
1999-2000	1377	0	273
Average Annual			**317**

2.2. Topography

The role of topography is incorporated into the erosion modeling by considering the slope length and steepness. The slope length and steepness values for the LS factor were determined from a digital elevation model (DEM). The following steps were applied to calculate the LS factor for the Gej watershed:

- The contours were digitized from the topographical maps, using GIS software.
- A Triangulated Irregular Network (TIN) model was created from the contour layer.
- The TIN model was converted to a raster layer of cell size 30m and z-factor as 1, thus creating a DEM 1 of the study area. (A cell size of 30m has been selected so that it is compatible with Landsat data)
- A slope map, with output measurements in degrees, was created from DEM 1.
- Flow accumulation map in grid data structure was created from the flow direction raster layer. The latter was developed from a new DEM 2 without topographical depressions and sinks. This was done by applying the Fill Tool to DEM 1.

The slope-length factor (LS) was then calculated by applying the formula used by Ma (2001):

$$LS = (f * \text{cell size} / 22.13)^{0.6} * (\sin \theta / 0.0896)^{1.3} * 1.6 \qquad (7)$$

where, f = flow accumulation expressed as the number of grid cells;

cell size = the length of grid or pixel size (30 m) ;

θ = gradient in degrees

The above formula was run in the raster model, where the flow accumulation layer (Fig. 2.8) was used as the value for f and the slope layer (Fig. 2.7) for θ. The result was saved as the LS factor map (Fig. 2.9). Equation (7) helps in a grid-wise analysis of the slope of the area, thus enhancing the adaptability of the model to the GIS environment.

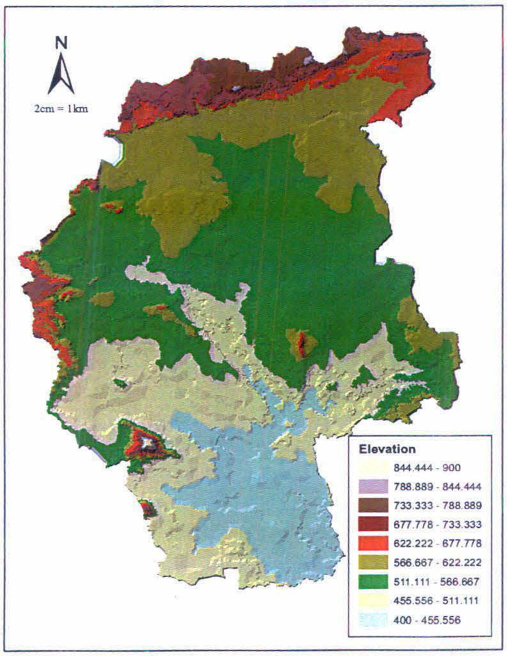

Fig. 2.5 TIN image of Gej watershed

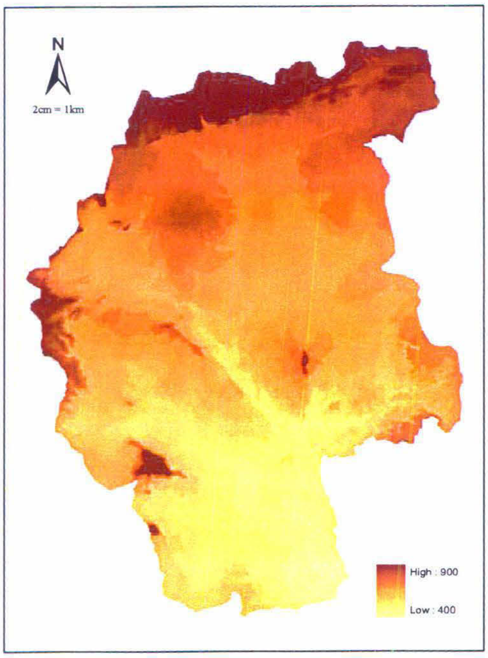

Fig. 2.6: DEM of Gej watershed

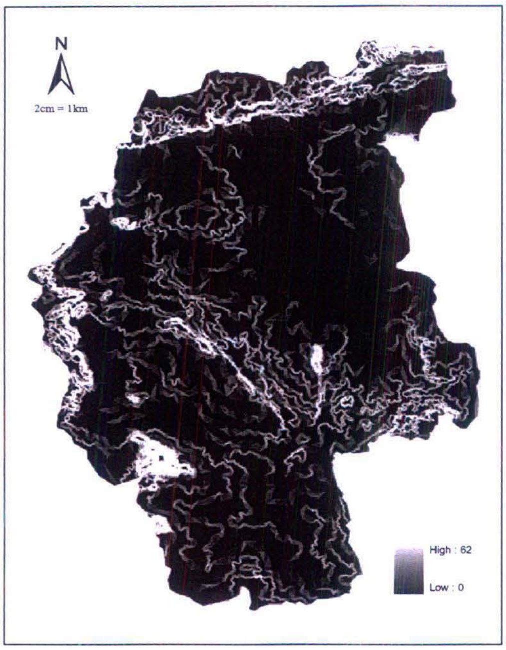

Fig.2.7: Slope map of Gej watershed

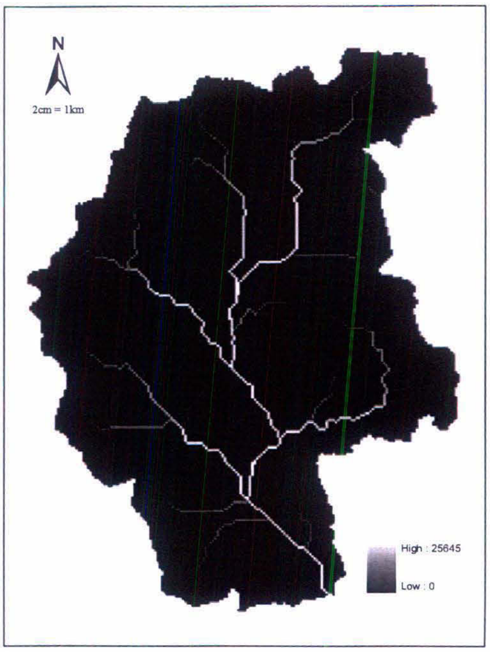

Fig. 2.8: Flow accumulation map

The value of LS factor varies between 0 in low lying areas of long and gentle slopes, and 2928 in highland areas with short and steep slopes. Splash erosion is less on gentle slopes (Renard, et al, 1996) and more on steep slopes. The northern and western hill regions, hills with escarpment, isolated hillocks and the southern undulating terrain of the watershed are the areas with high LS values and hence soil erosion in these areas will be high. On the other hand, soils of the central gently sloping terrain are relatively less erodible and those of the valley areas are least erodible. This is because; soil particles detached by raindrops are likely to be displaced for a longer distance downslope along steeper slopes, under the impact of gravity as well as runoff. The displacement will be lesser along gentle slopes.

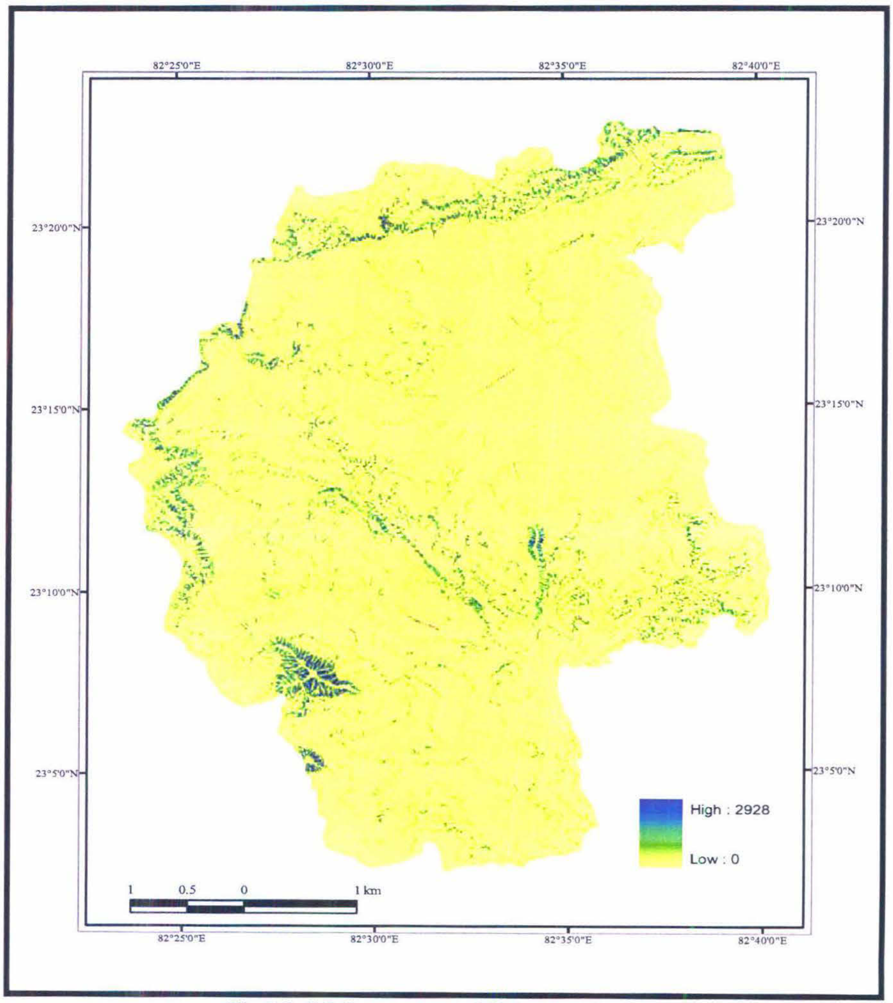

Fig 2.9: LS factor map of Gej watershed

2.3. Soil erodibility

Soil map (Fig. 1.4) was generated from an overlay of the slope map (Fig. 2.7) and the geological map (Fig. 1.3) of the study area. The slope map which was in grid format was converted to a vector layer. A spread sheet file was created which contained the percentage values of each slope unit. The file was joined to the attribute table of the vector slope map. The geological map of the study area was extracted from the District Resource Map of Koriya District, Chhattisgarh published by the Geological Survey of India. The geological map was intersected with the slope map. In order to reduce data redundancy, the overlay was dissolved. Based on the slope percent and the geological attributes of the area, and on the basis of the NBSS & LUP (2003) tables, were four soil types were identified in the watershed: Kanhar, Matasi, Marhan and Bhata.

Kanhar occupies 71.4% of the total area of the watershed, followed by Matasi (18.5%), Marhan (6.3%) and Bhata (3.2%). Kanhar develops on very gentle slopes of 1-3% in the areas of sedimentary rocks as well as granite gniess, whereas Matasi develops on slightly steeper slopes of 3-8%. Marhan is to be found on moderate slopes of 8-15% in areas of sedimentary rocks and over gentler slopes (3-8%) in areas underlain with basalt. Bhata occupies the moderate to very steep slopes irrespective of the parent material or underlying lithology.

The soil erodibility of different soil types was calculated using the following formula:

$$K = [2.1*10^{-4}(12 - OM)\, M^{1.14} + 3.25\,(s - 2) + 2.5\,(p - 3)]/100 \qquad (8)$$

where, M = percentage of silt * (100 – percent clay)

OM = percentage of organic matter content

s = structure of the soil

p = permeability of the soil

Silt is most readily detached by raindrop splash erosion (Wischmeier and Smith, 1978). Coarser particles are not shifted much because of their greater volume and weight, whereas finer particles, such as clay, are not readily detached because of the strong forces of cohesion that keep them aggregated (Donahue, et al, 1977). Hence, silt being most susceptible to erosion has been considered in equation (8). Thus equation (8) is also a modification of the original equation where the percentages of silt and very fine sand were considered for calculating the silt fraction.

Table 2.4: K factor values of different soil types in Gej watershed area

Order	Suborder	Local name	Rock Type	Slope (%)	Silt (%)	Clay (%)	Particle size	OM [1]	Structure[2]	Permeability[3]	K factor
Vertisol	Typic Haplusterts	Kanhar	Sedimentary	1-3	21	52	2654.27	2.26	4	slow (5)	0.169
Alfisol	Typic Haplustalfs	Matasi	Sedimentary	3-8	23..16	42..16	3670.64	4.86	4	moderate (3)	0.12
Entisol	Typic Ustorthents	Marhan	Sedimentary	8-15	25.25	49.25	3489.6	1.02	4	rapid (1)	0.095
Entisol	Lithic Ustorthents	Bhata	Sedimentary	15-30	14.6	24.4	2943.59	1.71	4	rapid (1)	0.079
Entisol	Lithic Ustorthents	Bhata	Sedimentary	30-50	6.5	19.8	1251.64	0.84	4	rapid (1)	0.044
Vertisol	Typic Haplusterts	Kanhar	Granite Gneiss	1-3	30.55	59.02	3398.17	3.98	4	slow (5)	0.172
Alfisol	Typic Haplustalfs	Matasi	Granite Gneiss	3-8	19.36	31.66	3619.11	1.42	4	rapid (1)	0.095
Entisol	Lithic Ustorthents	Bhata	Granite Gneiss	8-15	8.9	23.2	1704.58	2.3	4	rapid (1)	0.05
Entisol	Lithic Ustorthents	Bhata	Granite Gneiss	15-30	9.05	21.45	1782.57	4.5	4	rapid (1)	0.043
Alfisol	Typic Ustorthents	Marhan	Basalt	3-8	18.2	28.5	3551.32	1.47	4	rapid (1)	0.094
Alfisol	Lithic Ustorthents	Bhata	Basalt	8-15	23.3	39.3	3905	3.96	4	rapid (1)	0.081
Inceptisol	Typic Haplustepts	Matasi	Quartzite	3-8	14.35	32.35	2542.82	1.57	4	moderate (3)	0.121

[1] OM - Organic Matter (%)

[2] soil structure - 4 is assigned to blocky structure (Wischmeier and Smith, 1978); soil structure in the study area is sub-angular blocky

[3] numbers in ( ) are values assigned to different rates of permeability (Wischmeier and Smith, 1978)

The overall soil erodibility in the study area is found to be low (< 0.2). "Usually a soil type becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction" (Wischmeier and Smith, 1978). Kanhar, with very high silt content (30.55%and 21%), is the most erodible soil type (K = 0.172 and 0.169), followed by Matasi (K = 0.12 and 0.095). On the other hand, Bhata with the least silt content (6.5%, 8.9% and 9%) is the least erodible (K =

0.44, 0.5 and 0.43 respectively). High concentration of organic matter content in the soil reduces soil erodibility. For example, Matasi with 23.16% silt has lower erodibility (K = 0.12) than Kanhar with 21% silt (K=0.169) because of the higher organic matter content (4.86%) in the former than in Kanhar (2.26%). As can be deduced from the soil map (Fig. 1.4), most of the watershed area (71.4%) is under Kanhar and is highly susceptible to splash erosion.

A spread sheet file was created in which the values of the K factor were assigned to the respective soil types. The file was then joined to the attribute table of the soil map (Fig. 1.5) and a grid data structure of K factor was generated (Fig. 2.10).

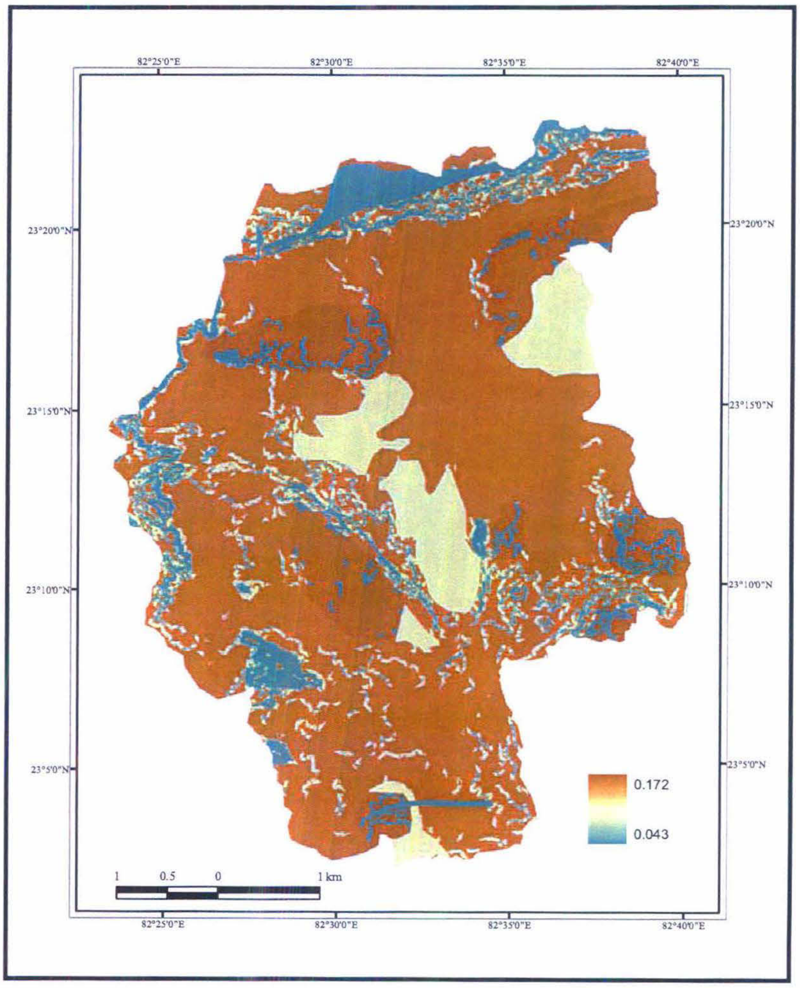

Fig 2.10: K factor map of Gej watershed

2.4. Cover management

Nine land use/land cover (LULC) classes for 1970 were identified and a geodatabase was created from the Survey of India topographical maps of the study area. The LULC map (Fig. 2.11) depicts the cover management practices in 1970. On the other hand, LULC maps of 1990 and 1999 were generated from the Landsat TM and ETM$^+$ satellite images.

All the TM bands, except the thermal band (Band 6), of the satellite image Landsat TM 1990 were collected, stacked together and rectified with respect to the geo-referenced topographic maps.

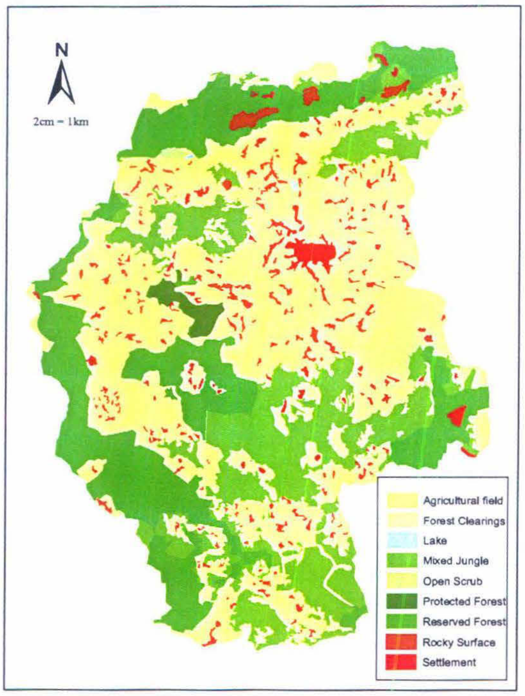

Fig. 2.11: LULC map of Gej watershed, 1970

The watershed was then extracted from the rectified image. The study area was extracted from the Landsat ETM$^+$ image of 1999 by the same way. Unsupervised classification algorithm was applied to the stacked Landsat data to identify the different types of LULC. Meaningful classes were derived by conjunctive use of topographic maps and other published maps (Fig. 2.12). The classified output of the images is given in Table 2.5.

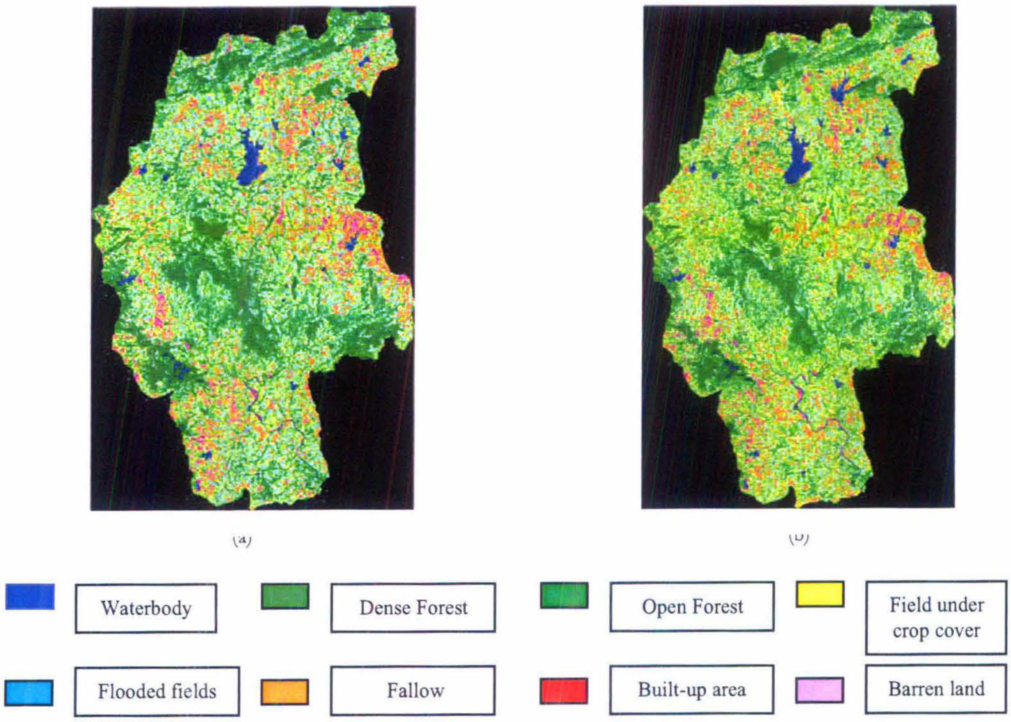

Fig. 2.12: LULC map of Gej watershed of 1990 (a) and 1999 (b). There has been decrease in the dense forest area, fallow and barren land; and increase in the open forest area and waterbodies, from 1990 to 1999.

Table 2.5: LULC of Gej watershed in different periods

LU/LC types	1970		1990		1999	
	Area (sq.km)	%	Area (sq.km)	%	Area (sq.km)	%
Waterbodies	**0.21**	**0.03**	**10.21**	**1.46**	**12.49**	**1.78**
Forest	**325.87**	**46.56**	**302.93**	**43.28**	**296.19**	**42.32**
Dense Forest	182.4	26.06	174.96	25	134.27	19.18
Open Forest	143.47	20.5	127.97	18.28	148.6	21.23
Agricultural land	**330.44**	**47.21**	**347.9**	**49.7**	**346.49**	**49.5**
Field under crop cover			104.59	14.94	149.91	21.42
Flooded field			136.11	19.45	115.09	16.44
Fallow			107.2	15.32	81.5	11.64
Built-up area	**22**	**3.14**	**25.43**	**3.63**	**31.81**	**4.54**
Barren land	**23.41**	**3.34**	**13.47**	**1.92**	**12.95**	**1.85**

The LULC classes of the three different periods – 1970, 1990 and 1999 – were grouped into 6 new categories in order to maintain consistency in data analysis. The Reserved and Protected forest classes of 1970 were merged into one class – Dense Forest, whereas mixed jungle and open scrub were grouped as Open forest. Rocky surface and forest clearing summed up to Barren Land. The LULC classes for 1990 and 1999 were also changed. Waterbody and flooded fields were considered as one group, while fallow land was brought under the category of barren land.

Cover factor of the different LULC types were identified for 1970 (Table 2.6) with reference to the C-factor tables used by Ma (2001) and Singh and Phadke (2006). The value of C varies between 0 and 1, with maximum cover attained in areas under water (0) and minimum in fallow and barren land areas (1).

Table 2.6: C factor of different LU/LC types, 1970

LULC	**C factor**
Waterbody/flooded areas	0
Dense Forest	0.007
Open Forest	0.009
Built-up area	0.03
Cropped land	0.58
Fallow/Barren land	1

Source: Ma (2001) and Singh and Phadke (2006)

The C factor values were incorporated in the attribute table of the LULC map of 1970. A raster layer was then generated using the attribute field of C factor. This has been used as the C factor map of 1970 in the study.

The C factor maps for 1990 and 1999 were generated using the normalized vegetation difference index (NDVI) values. NDVI shows the temporal and spatial change of the vegetation cover. NDVI values for 1990 and 1999 were derived from the Landsat TM and ETM$^+$ respectively using the following formula:

$$\text{NDVI} = (\text{band } 4 - \text{band } 3) / (\text{band } 4 + \text{band } 3) \qquad (9)$$

The C factor values for 1990 and 1999 LULC were then calculated using equation 10 which is a modification of the one (equation 11) used by Asis (2007).

$$C = \alpha / (1 + \alpha) \qquad (10)$$

where, $\alpha = \text{Exp}\,[-2 * \{\text{NDVI} / (1 - \text{NDVI})\}]$ (11)

The resultant raster layers for 1990 and 1999 have been used as the C factor maps for 1990 and 1999 respectively.

2.5. Support practices

The value for P factor has been taken as 1, i.e. no measures are being taken in the watershed area to prevent or reduce soil erosion. The value for P has been derived from the support practice factor map of Chhattisgarh created by the NBSS & LUP (2003). A grid data structure for P factor was also generated.

CHAPTER 3

EROSION ASSESSMENT IN GEJ WATERSHED

As discussed in literature, estimation of soil erosion rates is a pre-requisite for the implementation of watershed management scheme in an area. Therefore, the present chapter aims at estimating the average annual rate of soil erosion in the Gej watershed, using the Universal Soil Loss Equation (USLE) in a GIS environment.

The independent raster layers of the different parameters of the USLE – rainfall erosivity (R), slope-length (LS), soil erodibility (K), cover management (C) and support practices (P) – were created (discussed in chapter 2 of the dissertation). The layers were multiplied with each other successively to obtain the soil erosion map of the watershed. In order to estimate the rate of soil erosion under conditions of 'no cover', the raster layers of only R, LS and K were multiplied with each other. This led to the generation of the soil susceptibility map. Then the raster layers of C and P were multiplied with R, LS and K layers to derive the actual rates of soil erosion and hence generate the soil erosion hazard map of the Gej watershed.

The rates of soil erosion in the watershed are found to vary from less than 1 t ha^{-1} in some areas to more than 80 t ha^{-1} in other areas. Therefore four classes of soil erosion rates have been made for the purpose of analysis of the spatial variations in the rates of erosion. Since the soil loss tolerance limit for the Chhattisgarh region is 12 t ha^{-1} (NBSS & LUP, 2003), therefore, soil erosion rates of less than 12 t ha^{-1} have been categorized as 'very low rate of soil erosion'. The average annual rate of soil erosion in the Gej watershed has been estimated as 31.5 t ha^{-1}. Hence values between 12 t ha^{-1} and 31 t ha^{-1} are grouped as 'low rate of soil erosion', whereas 'moderate rate of soil erosion' is characterized by erosion rates varying between 31 t ha^{-1} and 50 t ha^{-1}. Erosion rates ranging from 50-69 t ha^{-1}, 69-81 t ha^{-1} and more than 81 t ha^{-1} have been grouped as 'severe', 'very severe' and 'extremely severe' soil erosion rates.

The following sections deal with the estimation of soil erosion rates in the study area and attempts to analyze the impact of slope and land use/land cover factors on the spatial variations in the erosion rates within the watershed.

3.1 Soil erosion susceptibility

Without any cover management, the watershed would have been subjected to an average annual soil erosion of 136 t ha^{-1} yr^{-1}.

With R being considered as constant spatially in this study, such a high rate of potential erosion is determined by the LS factor. LS factor is the major deciding factor of soil erosion susceptibility of the different parts of the study area. It explains 35 percent of the variations in erosion rate. Soil erosion increases with increase in slope and length ($r = 0.6$, correlation significant at 1 percent level). As can be seen in Fig. 3.1, soil erosion rates vary from less than 12 t ha^{-1} in the low lying areas to more than 81 t ha^{-1} in the very steeply sloping areas.

The positive effect of slope on soil erosion rate also obscures the impact of soil erodibility (K). The soil erosion susceptibility map Fig. 3.1 implies that the areas under *Kanhar* are least erodible whereas those under *Bhata* are susceptible to high erosion rates, although *Kanhar* was considered to be the most erodible soil ($K = 0.179$) and *Bhata*, the least erodible ($K = 0.43$). This is simply because *Kanhar* develops on very gentle slopes (1-3 percent) whereas *Bhata* on very steep slopes (>30 percent); and steeper the slope, greater is the rate of soil erosion. It is also to be noted that areas of *Kanhar* soil have varying rates of soil erosion which also due to variations in topography.

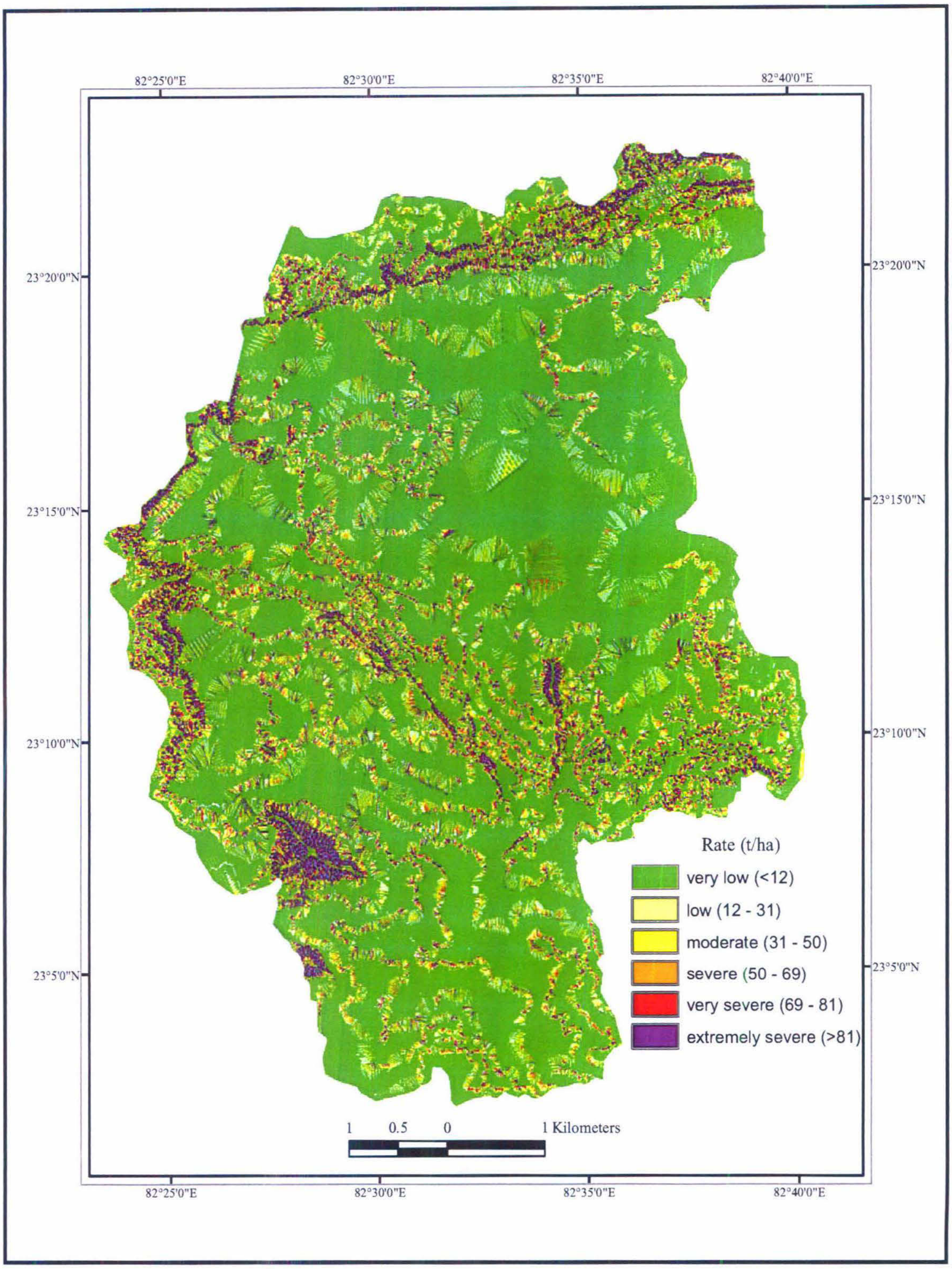

Fig. 3.1: Soil erosion susceptibility map of Gej watershed

3.2. Soil erosion hazard

Cover management (C) factor, however, weakens the effect of slope on soil erosion ($r = 0.33$ significant at 1 percent level). In fact if the surface cover of the area is considered, LS explains only 11 percent of the variations in erosion rates.

The overall rate of erosion of the area is much less than the susceptible levels under conditions of surface cover. The watershed experiences an average annual soil erosion rate of 31 t ha^{-1} yr^{-1} that results in erosion of about 2.5 million metric tonnes of soil on an average. Fig. 3.2 shows the spatial distribution the actual rates of soil erosion within the watershed.

The average annual rate of soil erosion in the study area is, however, higher than the national average, 16.35 t ha^{-1} (Narayana and Ram Babu, 1983). Moreover, the result does not comply with that of Singh, et al (1992). Singh, et al (1992) prepared an iso-erodent map of India which shows that the average rate of soil erosion rate the Baghelkhand Plateau region ranges between 10 t ha^{-1} yr^{-1} and 15 t ha^{-1} yr^{-1}. But the study area which lies within the Baghelkhand Plateau region has a much higher rate of soil erosion than the regional average. Thus based on the results of the present study it can be mentioned that regional average values obscure the local variations in soil erosion rates and hence can be misleading. Moreover, as has been stated by Wang, et al (2002), the input factors of soil erosion vary in space and time. Therefore the sensitivity of soil erosion to the variability of the causal factors will also vary both spatially and temporally. Hence, neglecting the variability may lead to improper decision making.

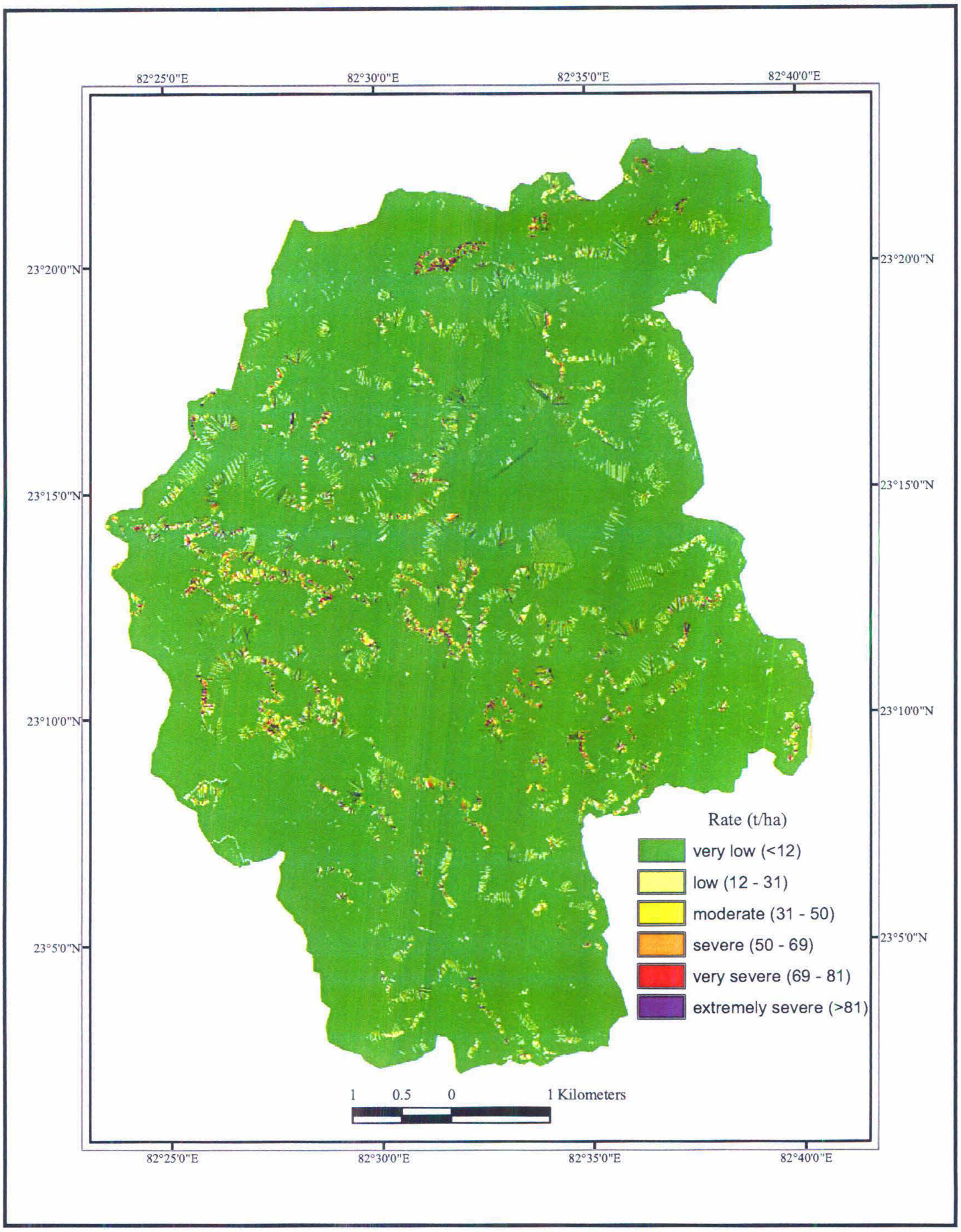

Fig. 3.2: Soil Erosion Hazard map of Gej watershed

The independent raster layers of soil erosion susceptibility and soil erosion hazard were intersected separately with the land use/land cover (LULC) map of the watershed. The attribute fields of the overlays, viz. type of LULC, area, rates of erosion were exported as spreadsheets. The percentage area under different rates of erosion under different types of LULC was then calculated.

The effect of surface cover has brought a large part (83 percent) of the watershed area within the soil loss tolerance limit[*] of the area (12 t ha^{-1}). 17 percent of the area would have been subjected to a soil erosion rate of 12-81 t ha^{-1}. But this has been reduced to 15 percent due to the cover effect. About 10 percent of the total watershed area was susceptible to more than 81 t ha^{-1}. But under surface cover conditions this has reduced to less 2 percent. Fig. 3.3 shows the percentage area under different rates of erosion.

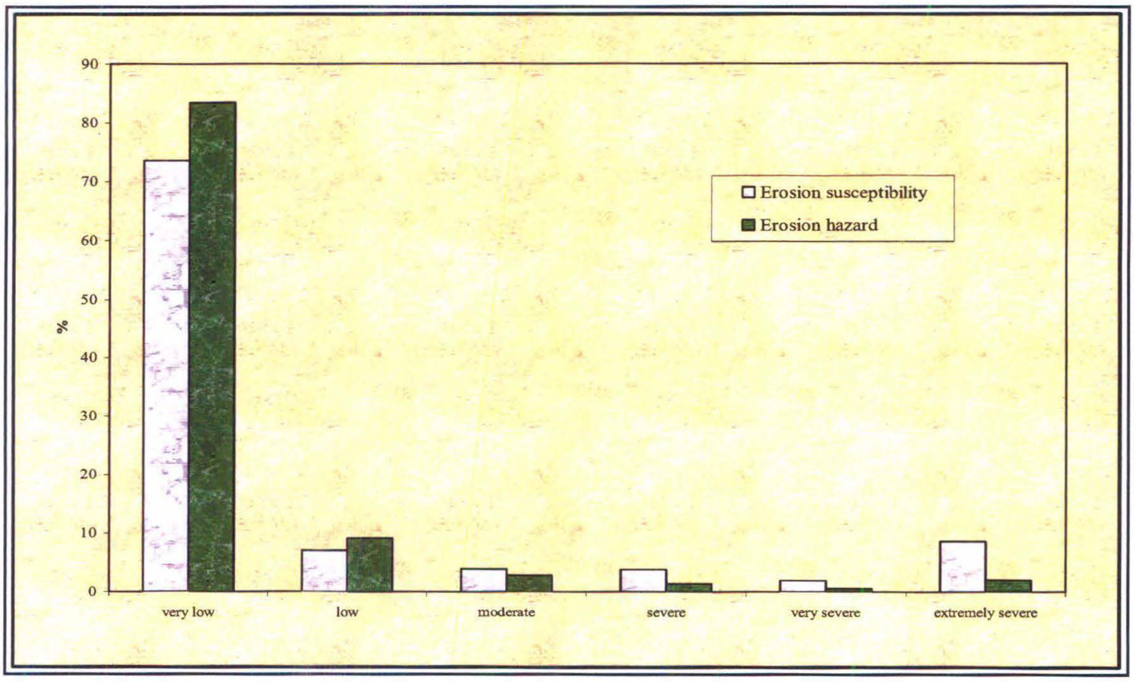

Fig.3.3: Percentage area of Gej watershed experiencing different rates of soil erosion

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[*] Soil loss tolerance limit is the maximum level of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith, 1978).

Under conditions of 'no cover' and considering rainfall erosivity as spatially constant, soil erosion rates are primarily controlled by the LS factor; higher the value of LS, greater will be the rate of soil erosion. Hence soil erosion susceptibility from the low lying areas of the watershed is less; it accounts for only 7.2 percent of the total rate of erosion in the area. But if the LULC is taken into consideration, then it is to be noted that the low lying are brought under cultivation and therefore the erosion rates in these areas are increased by 29 percent (Fig 3.4). Soil erosion rate in the low lying areas that have been left barren land is increased by 20 percent. On the other hand, erosion susceptibility from the steeply sloping areas accounts for 91 percent of the total erosion. But these areas are under forest cover; and soil erosion from these steeply sloping, forest covered areas is only 38.2 percent of the total erosion; thus recording a 63 percent decrease in erosion rates from the susceptible levels.

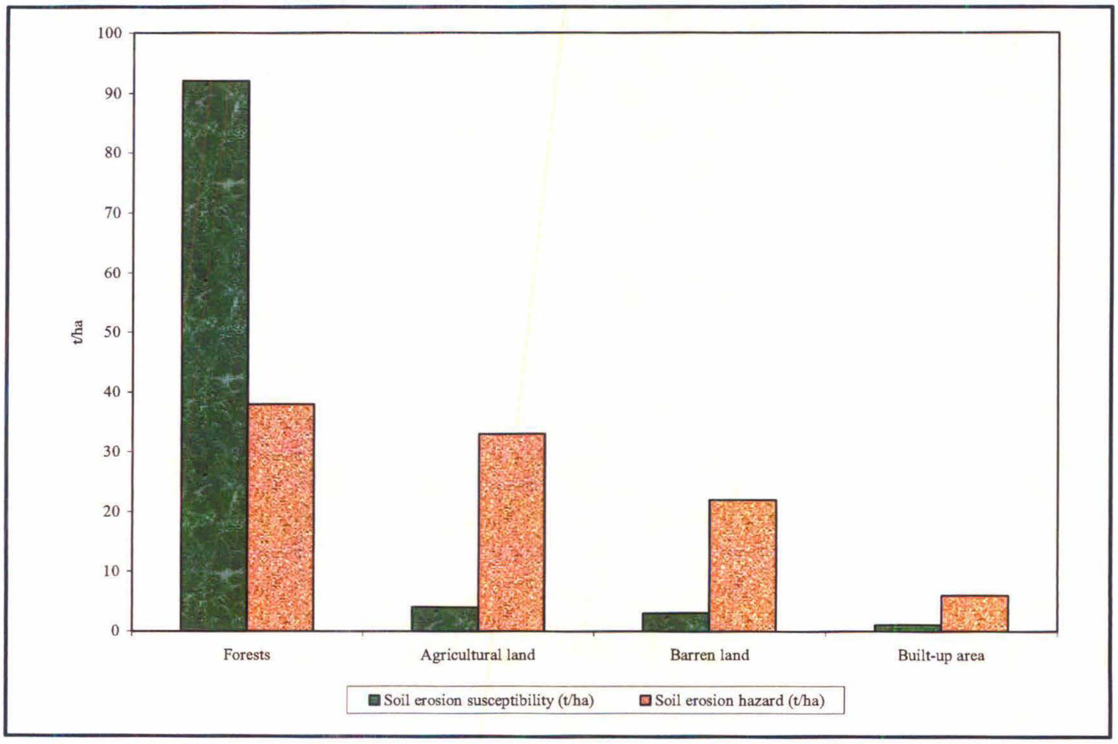

Fig. 3.4: Percentage of soil erosion susceptibility and actual amount of soil erosion to total amount of soil erosion in the watershed under different types of LULC. (The increase or decrease in the percentages is indicated by the positive and negative values given along the bar. The coloured bars with arrow heads show the direction of change.)

The steeply sloping areas in the north and west, the escarpment in the south-west and the southern undulating plain have been kept under forest cover. Hence soil erosion in these areas is less (Fig. 3.2). In fact, soil erosion susceptibility from these areas ranged from moderate (31-50 t ha^{-1}) to extremely severe (>81 t ha^{-1}). But the actual rates are drastically reduced; very low rates of soil erosion (<12 t ha^{-1}) occur in these areas. However, there has been no similar striking decrease in soil erosion rates in the low lying areas (Fig. 3.1 and 3.2) as in the steeply sloping areas. The low lying areas have been brought under cultivation, primarily paddy. During early monsoon or rainfall regime, these fields are not covered by crops. They may be either under preparation or very nascent stage of growth. Thus surface cover is either absent or very little leaving the soil surface exposed to erosive rains. Hence it may be inferred that land put to agricultural use is prone to high rates of soil erosion and most vulnerable when left fallow and exposed to erosive rains.

Therefore it may be concluded that the impact of LULC on soil erosion depends on the 'protection efficiency' of an LULC type. 'Protection efficiency' may be defined as how effectively and efficiently an LULC is able to protect the soil surface from the erosive action of rainfall, thereby reducing the rate of soil erosion. It is determined by percentage cover of the land and density of foliage of the vegetation. It can be numerically expressed by the C factor values. It is to be noted that the efficiency of an LULC to protect the soil surface decreases with the decrease in the area of soil surface being protected.

An overlay (Fig. 3.5) has been created using the LULC map (Fig. 2.11) and the soil erosion hazard map (Fig. 3.2). The overlay depicts that the areas of very low erosion rates are superimposed over the areas under dense forest cover. Areas of low erosion rates are identical with the open forest areas. Erosion rates in the cultivated areas are relatively higher and in the areas of barren land the rates are extremely high (>81 t ha^{-1}). Thus it can be concluded that forest cover is a more efficient LULC than other LULC types. Based on the 'protection efficiency', the LU/LC classes can be arranged in descending order as follows: Waterbodies or flooded fields, dense forest, open forest, built-up area, cultivated areas under crop cover, fallow or current fallow and barren land.

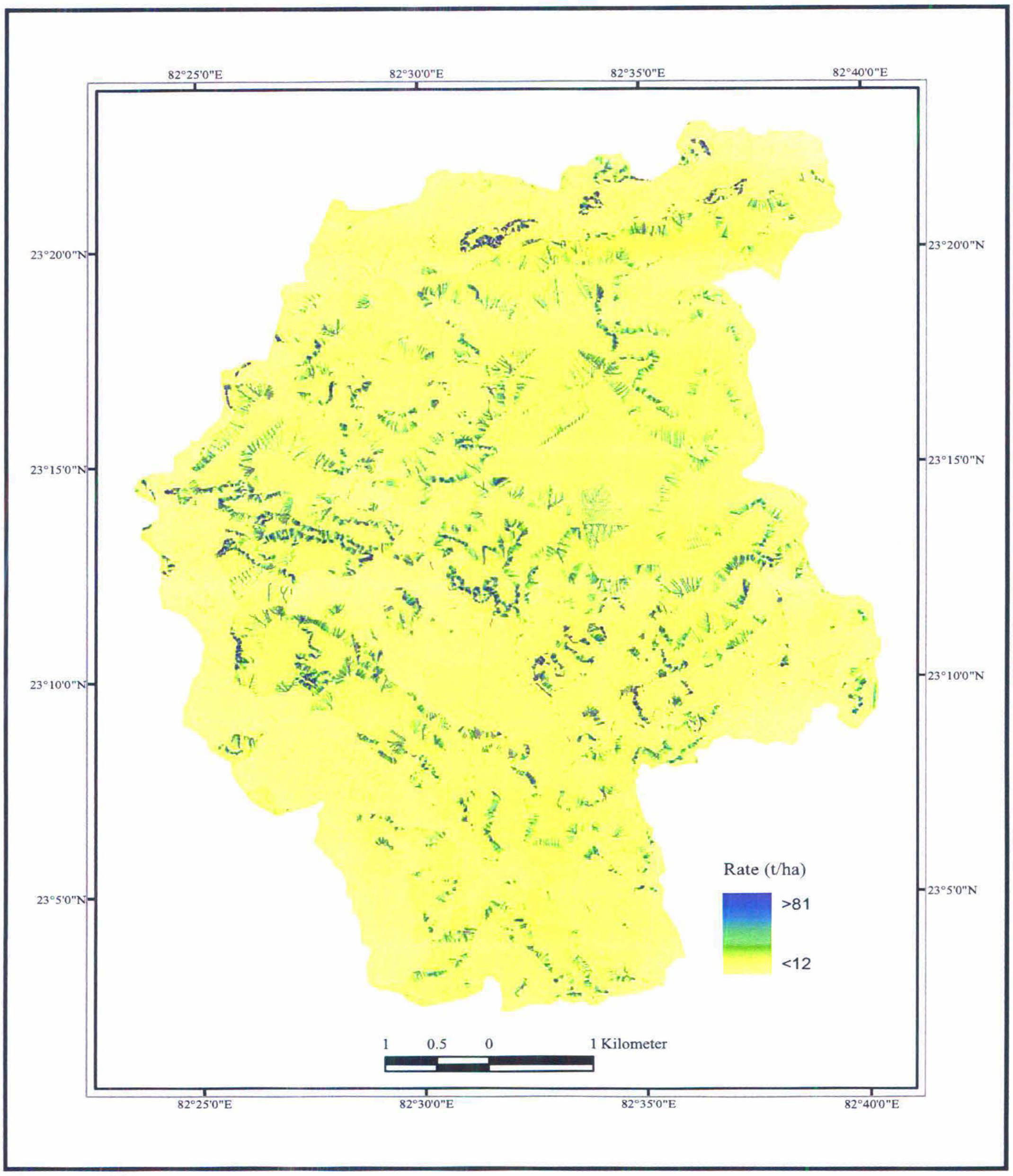

Fig. 3.5: Soil erosion hazard in areas under different LULC

Soil erosion can, therefore, be reduced if the soil surface is put under efficient cover. Average rate of erosion is lower (2 t ha^{-}1) in areas under forest cover than the barren land area (32.4 t ha^{-1}). Soil is eroded from the agricultural land areas at an average rate of 8.76 t ha^{-1}. Soil erosion is least (1.2 t ha^{-1}) from built-up areas as the land surface is mostly covered by concrete.

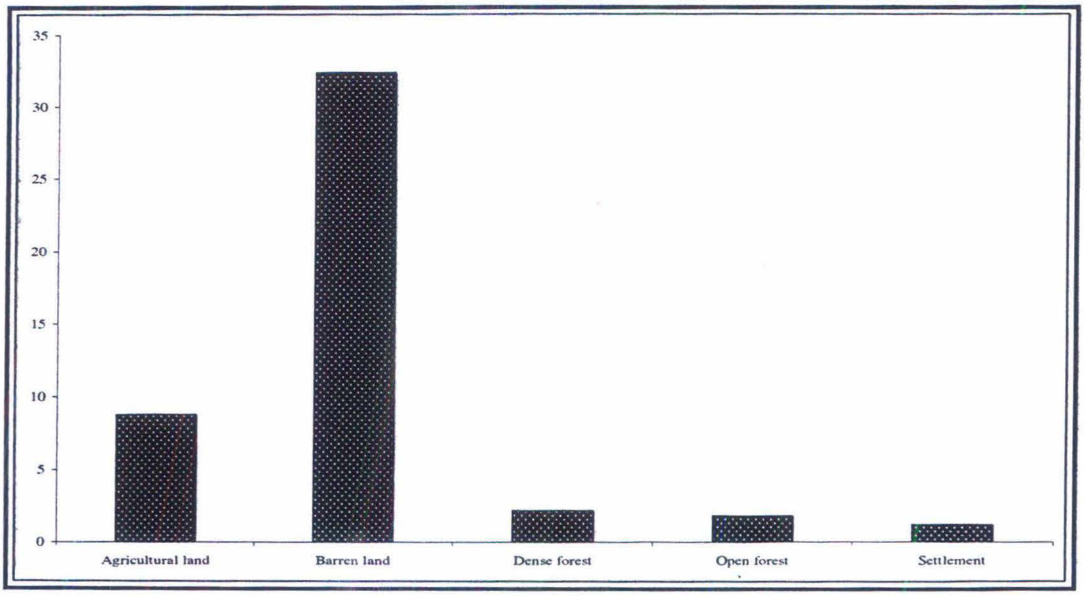

Fig 3.6: Average ate of soil erosion from different LU/LC types in the Gej watershed

Soil erosion in the study area is, in fact, much higher than the soil loss tolerance limit which is 12 t ha^{-1} yr^{-1} for Chhattisgarh (NBSS & LUP, 2003). Therefore the soil degradation ratio[*] (Hurni, 1983) is greater than 1 which implies that soil erosion is a serious problem in the area and hence soil conservation measures are required. Proper vegetation cover can be the most efficient measure to reduce soil erosion in the watershed.

In order to check whether the entire amount soil eroded in the watershed is lost to the streams, the total amount of soil erosion has been compared with the sediment load data available for the CWC station at Bamnidhi ($21^0$53'55"N, $82^0$32'37"E), located to the south of the study area. Sediment load data for the station is available from 1993-94. Therefore the total amount of soil detached by rainfall impact during the period 1993-94 to 1999-00 was compared with the sediment load data. Fig. 3.7 shows that overall the total amount of eroded soil in the watershed is much higher than the sediment load. This implies that the total amount of soil that is eroded is not carried away by runoff. Therefore it may be concluded, following Lal (1994), that a part of the eroded soil gets deposited within the

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[*] Soil degradation ratio is calculated by dividing the actual rate of soil erosion by the soil loss tolerance limit.

watershed. However, soil erosion within the watershed will incur on-site effects, viz. reduced soil fertility, decrease in crop productivity, etc. which should be mitigated.

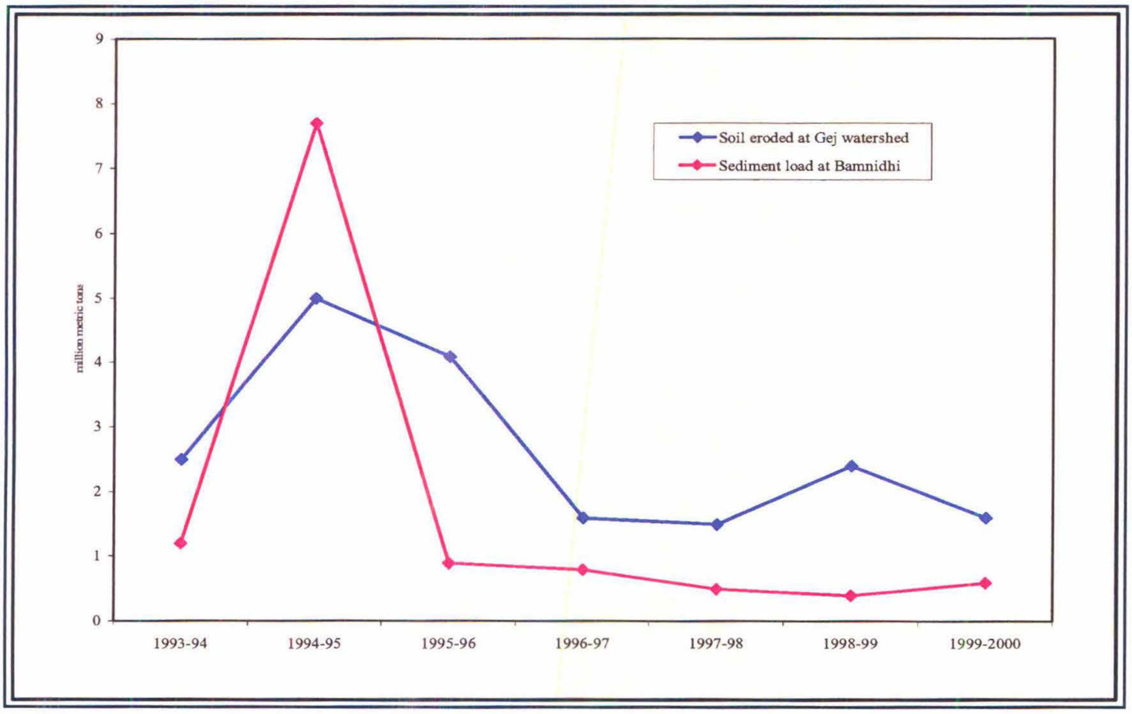

Fig. 3.7: Amount of soil eroded in the Gej watershed and sediment load measured at Bamnidhi during the period 1993-94 to 1999-00

Overall it can be concluded that while slope factor determines the spatial variability (35 percent) of the susceptibility of the area to soil erosion, LULC determines the actual rates of soil erosion. Proper land cover reduces the possibility of very high erosion on steep slopes, whereas improper land use increases rates of soil erosion even on gently sloping land.

High rates of soil erosion do not necessarily mean high rates of soil loss from the watershed. Not all the soil that is eroded contributes to the sediment load of a river. The eroded soil may be displaced and distributed within the watershed. But this has its adverse on-farm effects that need to checked, especially if the rates of erosion are higher than the soil loss tolerance limit. High rates of soil erosion can be minimized by the implementation of proper cover management practices.

CHAPTER 4

CHANGE IN EROSION: DIFFERENT SCENARIOS

Erosion factors are not static, but change with time (Vrieling, 2007). The most dynamic factors are rainfall and vegetation and soil erosion is likely to be affected by changes in these two factors (Nearing, et al, 2005; Vrieling, 2007). Therefore, an attempt has been made to assess soil erosion under conditions of changing land use and land cover (LULC) and changing rainfall erosivity (EI). Seasonal variations in erosion rates have been estimated considering seasonal changes in EI. Investigation into the effect of the occurrence of extreme rainfall events on soil erosion has also been done. The following scenarios have been considered for estimating change in soil erosion rates over time:

(a) Change in Land use and Land cover
(b) Change in rainfall erosivity:
  - Inter-annual change
  - Seasonal change
  - Occurrence of extreme rainfall events

In the aforesaid scenarios, erosion rates have been estimated by considering all the model parameters constant over time except the parameter the specific impact of which is to be assessed. The coefficients of the model parameters have been estimated with the help of the equations that were used in the previous chapters, and have been converted to raster layers or maps.

While estimating the rate of soil erosion in the first scenario, i.e. under conditions of changing LULC, the temporal variability of the cover management (C) factor has been taken into account, considering other factors constant. The C factor maps of three separate years –

1970, 1990 and 1999 – have been separately multiplied with the other factor maps, viz. rainfall erosivity (R), slope-length and steepness (LS), soil erodibility (K) and support practice (P), for estimating soil erosion rates of the three years. The average annual rainfall erosivity (316.32 MJ. mm. ha^{-1} hr^{-1} yr^{-1}) as had been calculated in the previous chapter, has been considered as the R factor in all the three years.

The impact of change in LULC together with a change in rainfall erosivity has also been analyzed. In this case, the LULC and the annual EI of the respective years – 1970, 1990 and 1999, have been taken into account, considering the LS, K and P factors constant over time.

In the second scenario, i.e. estimation of soil erosion rates under conditions of changing EI, all other factors except the R factor has been kept constant. Annual rates of soil erosion for 25 years have been estimated by substituting annual EI values for R factor; and then inter-annual variations in soil erosion rates have been accounted for.

Soil erosion rates have been estimated for the different seasons – monsoon (June-September), post-monsoon (October-November), winter (December-February) and pre-monsoon (March-May). Summation of monthly EI values of a season produced the seasonal EI.

$$EI_{season} = EI_{month\ 1} + EI_{month\ 2} + \ldots\ldots EI_{month\ n} \qquad (12)$$

where, EI_{season} = rainfall erosivity of a season

EI_{month} = rainfall erosivity of a month in the selected season

The annual average of the seasonal EI was then calculated by dividing the sum of the seasonal EI of the different years by the total number of years, i.e. 25 years in the present study.

$$\text{Average Annual } EI_{season} = EI_{season}(\text{year } 1 + \text{year } 2 + \ldots\ldots n) / n \qquad (13)$$

where, n = number of years

The occurrence of extreme rainfall events, i.e. days with more than 100 mm rainfall, in the study area has been accounted for in the second chapter of the dissertation. The impact of the extreme rainfall events on soil erosion has been analyzed too. The EI of an extreme rainfall event has been calculated using equation 4*. Soil erosion rate during an extreme rainfall event in a year has been estimated by multiplying raster layer of the EI of the event with the C factor map of the respective year and the LS, K and P factor maps.

4.1 Changes in land use/land cover

As has been concluded in the previous chapter, land use/land cover (LULC) regulates the rate of soil erosion in an area. Therefore, it becomes necessary to estimate soil erosion under varying conditions of LULC. LULC of three years – 1970, 1990 and 1999 – has been considered in the present study due to ready availability of data.

The average annual rate of soil erosion was 36 t ha^{-1} yr^{-1} in 1990. This was greater than the 1970 rate (31.5 t ha^{-1} yr^{-1}). The total amount of soil eroded was 7.16 million metric tonnes in 1990 as against 2.5 million metric tonnes in 1970. The increase in the amount and rate of soil erosion during the period 1970-90 is due to the decrease in forest area in the watershed by 7.04 percent from 1970 to 1990 and a subsequent increase in agricultural land by 5.28 percent (Table 4.1). The forests are mainly confined to the steeply sloping areas and the rugged terrains of the watershed, which are most susceptible to high rates of soil erosion. Hence a decrease in the forest cover in these areas resulted in an increase in soil erosion. On the other hand, the 'protection efficiency' of crop cover is less (discussed in chapter 3). Therefore, increase in agricultural land has resulted in the increase in soil erosion rates.

In 1999, however, the average annual rate of soil erosion decreased to 35 t ha^{-1}. But the total amount of eroded soil increased to 7.2 million metric tonnes. The decrease in the rate of erosion might have been due to an increase in the area under open forest by 16% and a decrease in the area under fallow land by 23% (Table 4.1). Moreover, a 43% increase in the

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* ibid 34

area under crop cover provided more protection to the soil surface from the erosive action of rainfall. However, the increase in the total amount of soil loss through detachment might have been due to a decrease in the area under dense forest cover by 23%.

Table 4.1: Temporal change in area under different LU/LC types

LU/LC types	% change	
	1970-90	1990-99
Forest	**-7.04**	**-2.23**
Dense Forest	-4.08	-23.25
Open Forest	-10.8	16.12
Agricultural land	**5.28**	**-0.4**
Field under crop cover	--	43.34
Flooded field	--	-15.45
Fallow	--	-23.98
Built-up area	**27.15**	**25.09**
Barren land	**-42.48**	**-3.8**

Two conclusions may be drawn from the above analysis:

❶ Decrease or increase in the rate of erosion depends on the type of change in LULC, whether positive or negative. Increase in the area under LULC with better 'protection efficiency' and a simultaneous decrease in the area under cover LU/LC with poor 'protection efficiency' may be considered as positive change in LULC. On the other hand, decrease in the area under LULC with better 'protection efficiency' and a simultaneous increase in the area under cover LU/LC with poor 'protection efficiency' may be considered as negative change in LU/LC.

❷ Decrease or increase in the total amount of soil lost through erosion depends on the increase or decrease in the area under dense forest cover, respectively.

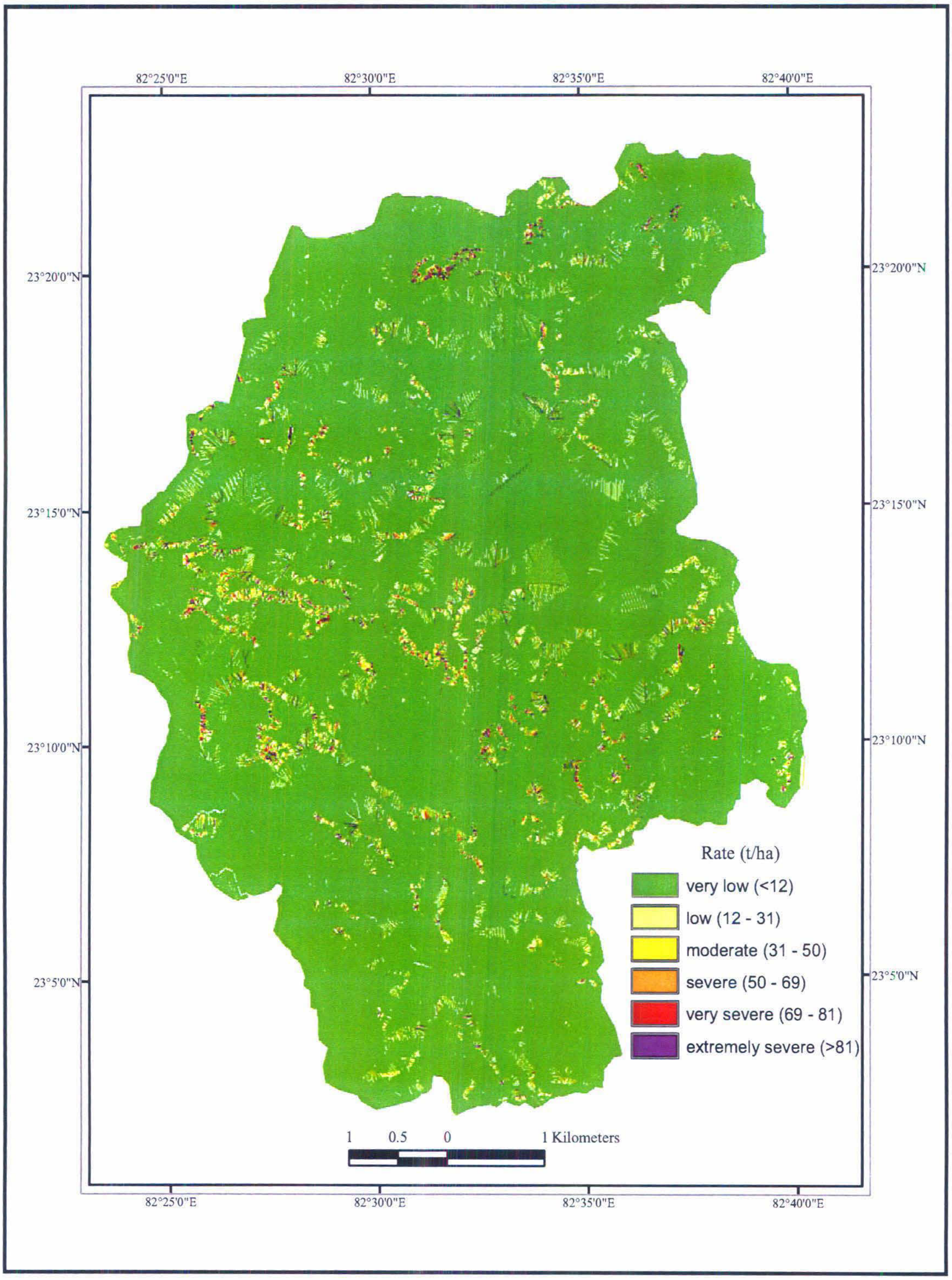


Fig. 4.1: Soil Erosion Hazard map of Gej watershed, 1970

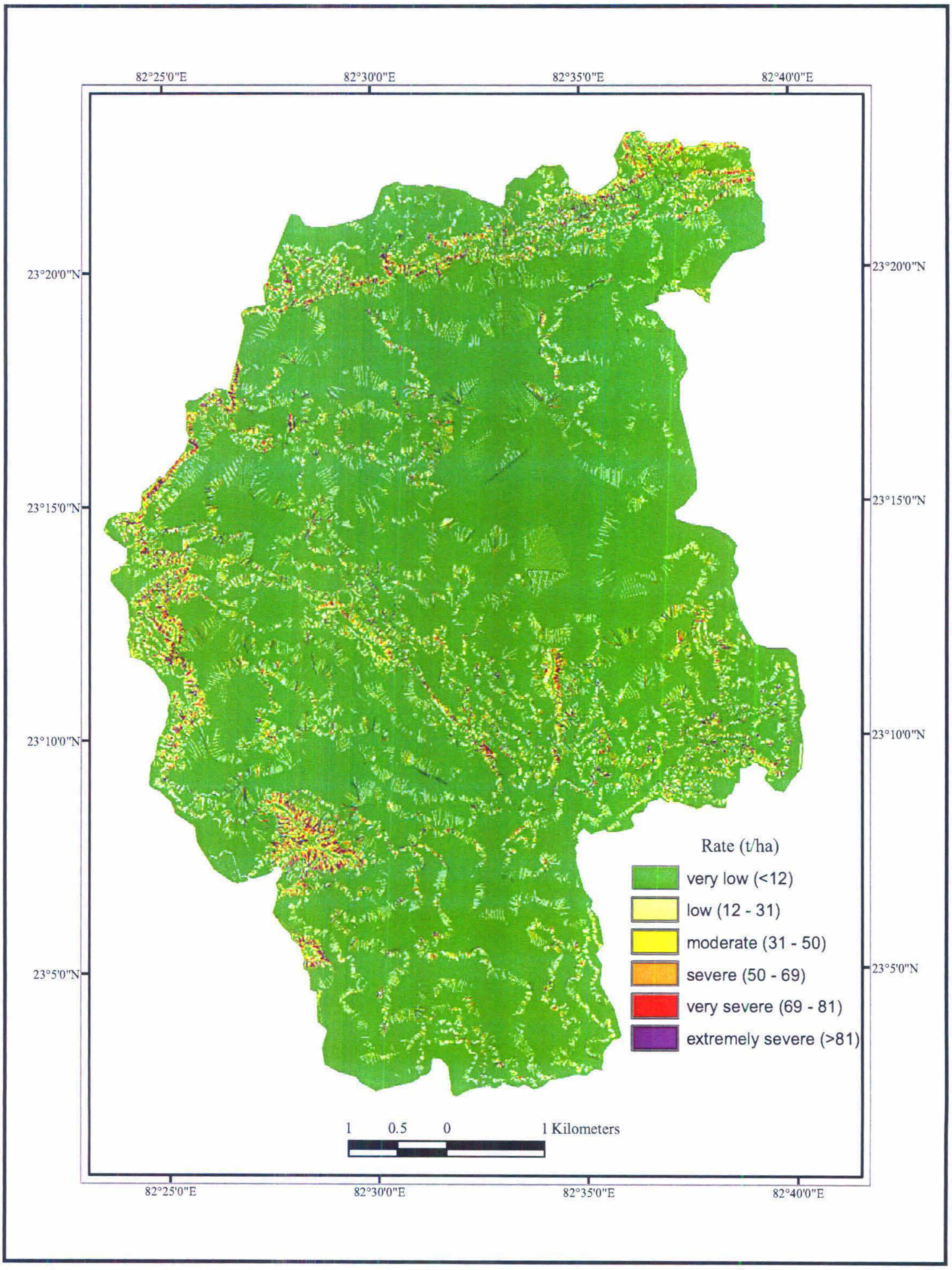


Fig. 4.2: Soil Erosion Hazard map of Gej watershed, 1990

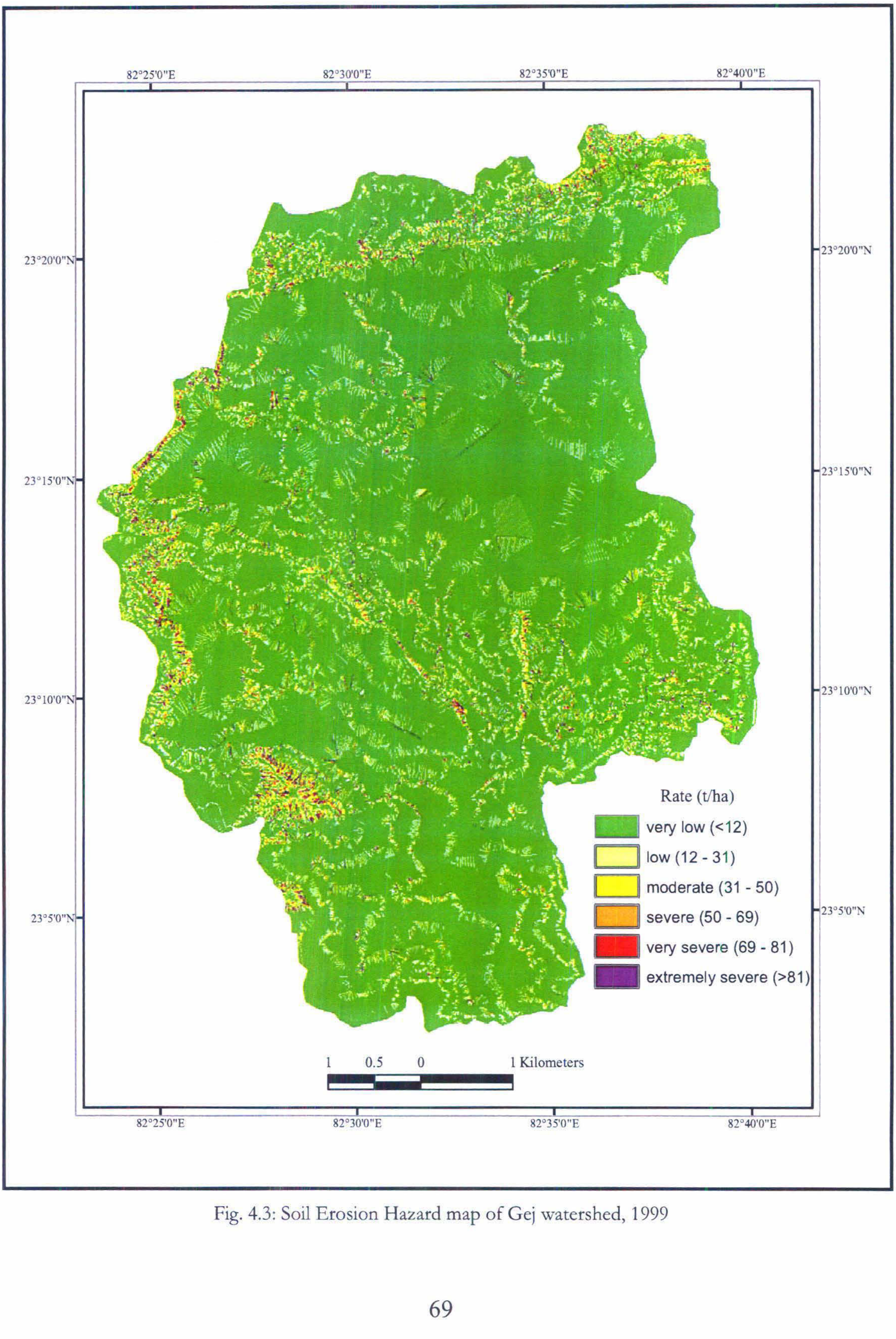


Fig. 4.3: Soil Erosion Hazard map of Gej watershed, 1999

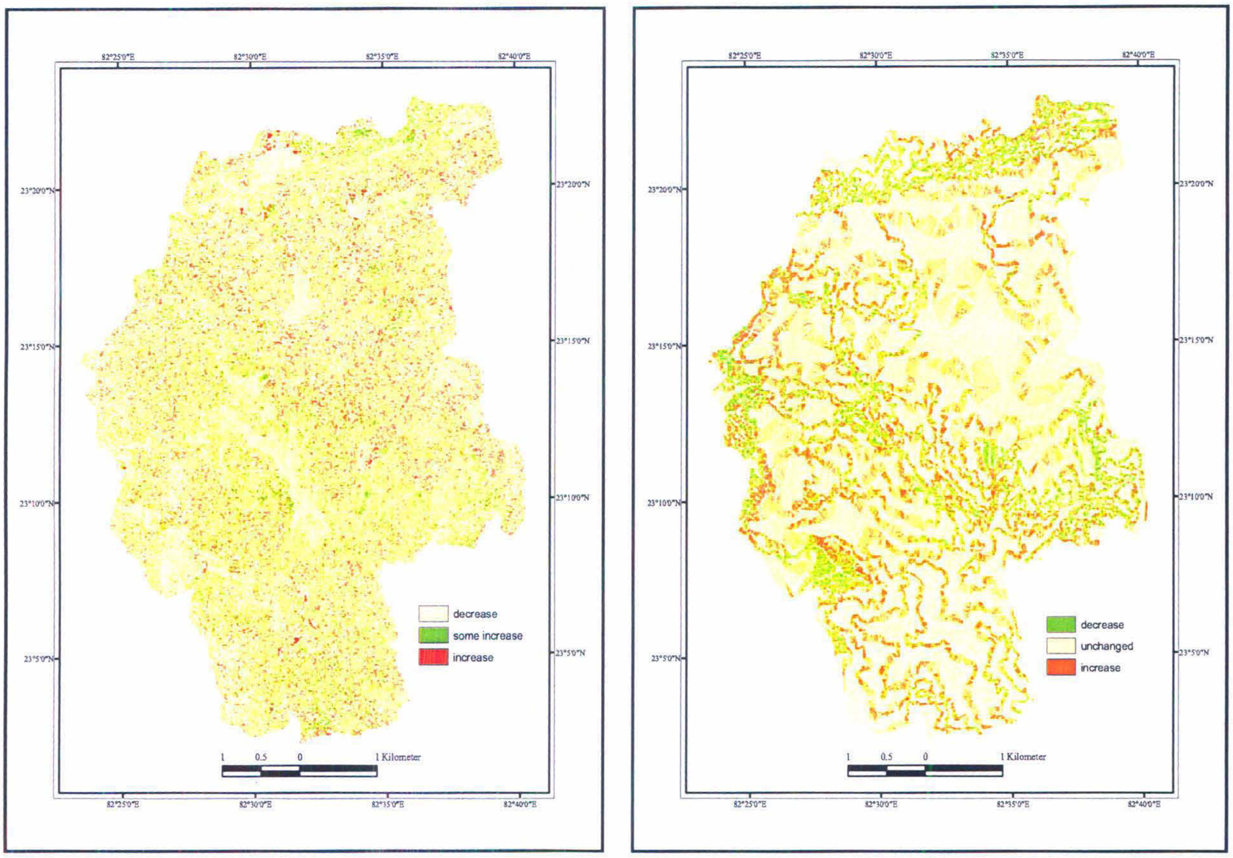
The second conclusion is based on the analysis of 'protection efficiency' of LULC discussed in chapter 3 (Fig. 3.5). The first conclusion can be justified with the help of Fig. 4.4 (a) and (b). The attribute field 'type of surface cover' of the raster layers of LULC of 1990 and 1999 were recoded so as to maintain consistency in data. The most protective LULC was assigned a value of 1 whereas the least protective LULC was assigned a value of 6.

Table 4.2: Recoded values of different LULC

Type of LULC	Recoded values
Waterbodies/ Flooded fields	1
Built-up area	2
Dense Forest	3
Open forest	4
Field under crop cover	5
Barren/ Fallow land	6

The change in LULC from 1990 to 1999 was then detected using the software ERDAS Imagine 8.7. Three types of changes were detected: decrease, some increase and increase. A difference in the recorded value by 1 has been regarded as change in LULC. Since the recoded values have been assigned to the 'protection efficiency' of the LULC that was arranged in descending order, therefore, the category 'decrease' indicates a change from less protective LULC to more protective LULC, i.e. positive change; and the category 'increase' indicates a change from more protective LULC to less protective LULC, i.e. negative change. For example, if barren land (recoded value 6) is converted to open forest (recoded value 4) it indicates a 'decrease' or positive change. But if the reverse of this situation occurs then it indicates an 'increase' or negative change.

The change in the soil erosion rates from 1990 to 1999 was also detected by running the change detection model in ERDAS using the grid data structures of soil erosion rates of 1990 and 1999. Three categories of change were obtained: decrease, unchanged and increase. A comparison between the map of LULC change (Fig. 4.4a) and the map of change in soil erosion rates (Fig. 4.4b) shows that areas where change in LULC has been predominantly positive, rate of soil erosion has decreased; whereas in the areas where mainly negative change in LULC has occurred, soil erosion rates have increased. However, in areas where change in LULC is diffused, i.e. it is predominantly neither positive nor negative, erosion rates have remained unchanged.



(a) (b)

Fig. 4.4: Change in LULC (a) and rates of soil erosion (b) from 1990 to 1999

Soil erosion rates, however, were different for the two periods, if rainfall erosivity is taken into account. Soil erosion rates in 1990 was higher, 37.3 t ha^{-1}as against 35 t ha^{-1} under conditions of constant rainfall erosivity. But in 1999 erosion rates were lower (24.7 t ha^{-1}) than the erosion rates (35 t ha^{-1}) that was estimated considering rainfall erosivity as constant. Annual rainfall erosivity (EI) in 1990 and 1999 was 329 MJ. mm. ha^{-1} hr^{-1} and 214 MJ. mm. ha^{-1} hr^{-1} respectively. Annual EI values was higher in 1990 and lower in 1999 than the annual average rainfall erosivity (316.32 MJ. mm. ha^{-1} hr^{-1}) that was considered as constant value for R factor while analyzing the impact of LU/LC changes on soil erosion. Therefore, it may be inferred that rainfall erosivity is a major determinant of soil erosion.

4.2. Change in rainfall erosivity

Rainfall erosivity has been considered as constant over space in the present study due to absence more number of raingauge stations within or in the vicinity of Gej watershed. But, as stated by Yu and Neil (2000), the temporal variations in erosivity and its effect on soil erosion can be considered.

4.2.1. Inter-annual variations

So far, soil erosion rates in the Gej watershed have been estimated using the average annual rainfall erosivity of 25 years. But this method fails to explain the inter-annual variations in erosion. So in this section the inter-annual variation in rainfall erosivity and its impact on soil erosion rates has been studied.

Inter-annual variability of rainfall in the watershed is 23.8 percent (Fig. 1.6). Since annual rainfall is positively related to annual EI ($r = 0.72$), therefore variations in the annual rainfall will lead to variations in annual EI. Inter-annual variation in rainfall EI in the study area is 69 percent. The impact of such high variations in annual EI on the annual rates of soil erosion needs to be investigated because EI has been considered in literature, as an important factor influencing soil erosion.

A linear regression analysis of the calculated values of rainfall erosivity and rate of soil erosion for 25 years shows that rainfall erosivity explains 99 percent of the variations in erosion rate, considering other factors constant. Thus, rate of soil erosion increases or decreases with increase or decrease in rainfall erosivity respectively, considering other factors constant. In contrast to this, the impact of rainfall amount on soil erosion rates is proved to be relatively weak (r = 0.79). Therefore, it may be concluded that a product of rainfall energy and intensity strongly determines the rate of soil erosion. In fact rainfall erosivity is the energy that initiates soil detachment. Table 4.3 shows the annual values of rainfall, erosivity and soil erosion rates in the Gej watershed for the period 1975-76 to 1999-2000. The relation between annual rainfall erosivity and annual rates of soil erosion has been graphically represented in Fig. 4.5.

Table 4.3: Annual rainfall, erosivity and soil erosion rates, 1975-76 to 1999-2000

	Rainfall	**Erosivity Index**	**Erosion Rate**
Years	**(mm)**	**(MJ.mm/ha.hr)**	**(t/ha)**
1975-76	1539	933	63.5
1976-77	781	133	15.8
1977-78	1126	279	28.9
1978-79	1000	216	23.8
1979-80	564	116	13.9
1980-81	1655	449	40.2
1981-82	1243	262	27.6
1982-83	1120	405	37.4
1983-84	1388	156	18.2
1984-85	1429	385	36.4
1985-86	1104	234	25.2
1986-87	1205	225	24.5
1987-88	1620	633	50.2
1988-89	1131	238	25.5
1989-90	787	108	13.2
1990-91	1356	329	32.3
1991-92	787	126	15.2
1992-93	964	236	25.4
1993-94	1244	315	31.4
1994-95	1686	621	49.4
1995-96	1399	518	43.4
1996-97	1154	274	23.3
1997-98	1296	203	22.5
1998-99	1140	307	30.9
1999-00	1377	214	23.3
Average	**1204**	**316**	**31.5**

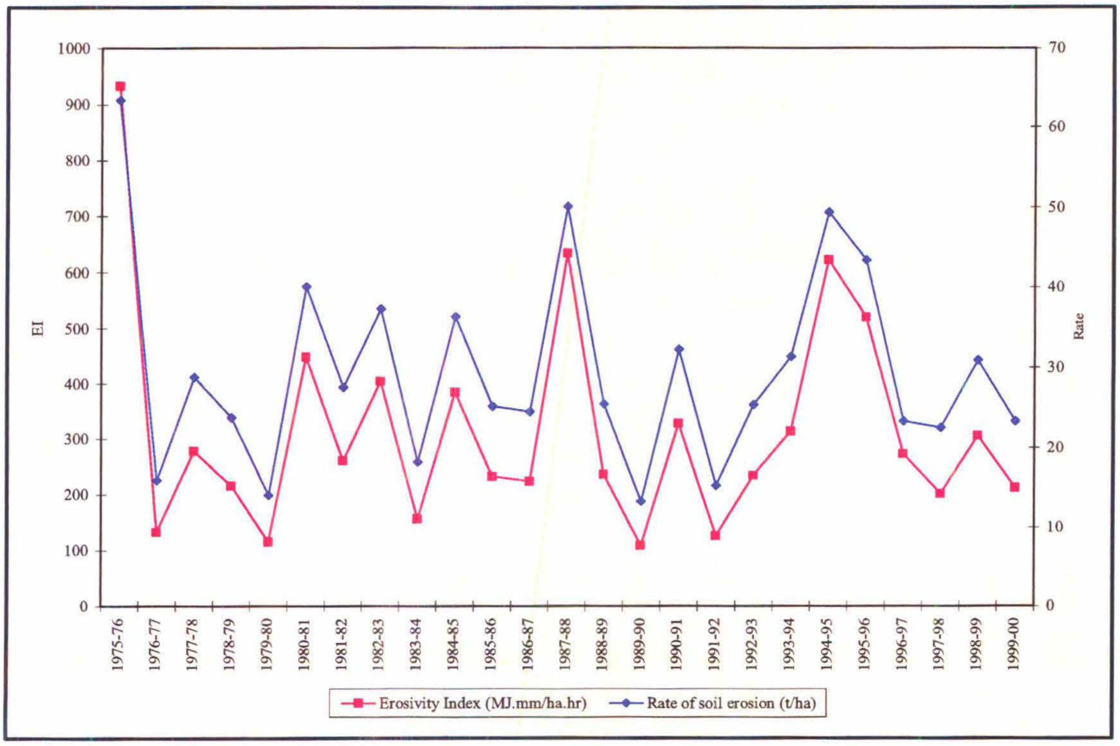


Fig. 4.5: Annual rainfall erosivity and rate of soil erosion, Gej watershed, 1975-76 to 1999-2000

4.2.2. Seasonal variations

Seasonal variations in rainfall amount are noted in the study area[*] which results in seasonal variations in EI (Fig. 4.6). It can be seen that EI in the monsoon season is very high (307 MJ. mm. ha^{-1} hr^{-1}) owing to very high rainfall total (1098 mm). EI is very low in the other seasons due to low amounts of rainfall totals. EI is 4 MJ. mm. ha^{-1} hr^{-1} off 46 mm, 2.73 MJ. mm. ha^{-1} hr^{-1} off 31 mm and 2.81 MJ. mm. ha^{-1} hr^{-1} 21 mm of rainfall during the post-monsoon, winter and pre-monsoon seasons respectively.

Since soil erosion rates are strongly related with EI (0.99), therefore soil erosion rates are likely to vary seasonally due to changes in EI. Considering other factors constant, soil erosion rates were estimated for the different seasons – monsoon (June-September), post-

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[*] ibid 17

monsoon (October-November), winter (December-February) and pre-monsoon (March-May).

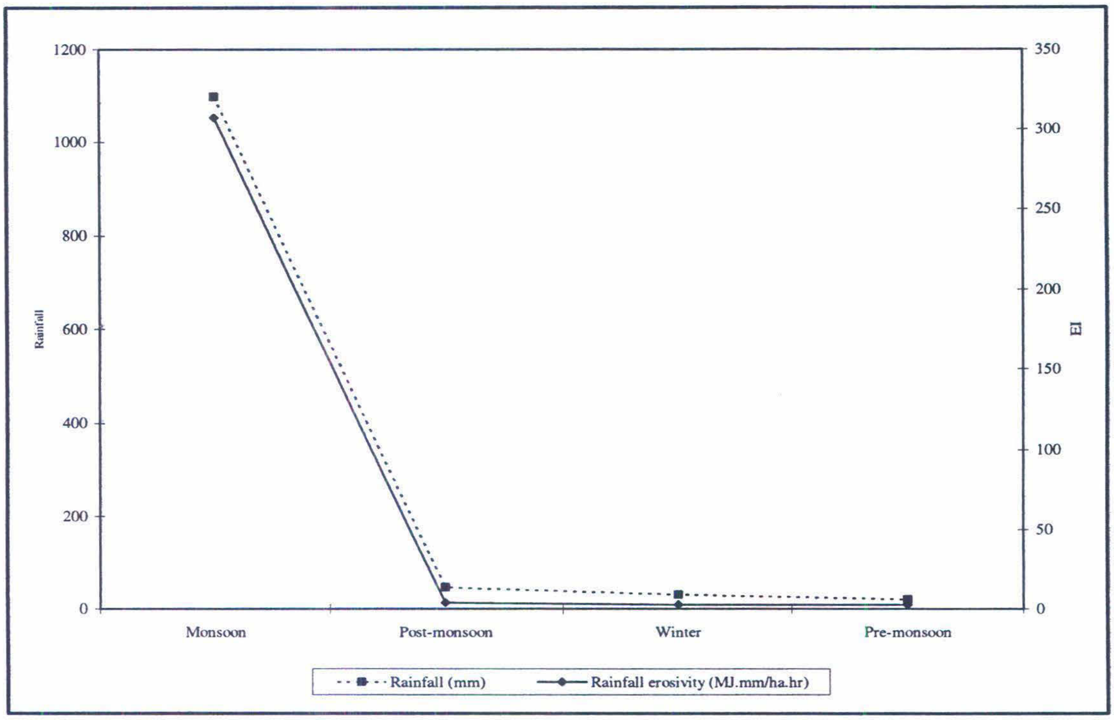

Fig. 4.6: Total rainfall and erosivity during different seasons

The average rate of soil erosion during the monsoon is 30.9 t ha^{-1} owing to a very high EI (323.3 MJ. mm. ha^{-1} hr^{-1}). On the other hand, in the non-monsoon months rates of soil erosion are very low due to low values of EI. Average rate of soil erosion is in the post monsoon season is 1.77 t ha^{-1}. In the winters and the pre-monsoon season, erosion rates are 1.6 t ha^{-1} and 1.5 t ha^{-1} respectively. Fig. 4.7 shows the seasonal variations in EI with consequent variations in the rates of soil erosion. High rates of soil erosion during the monsoon necessitates adoption of measures to protect the soil from the erosive rains during this season

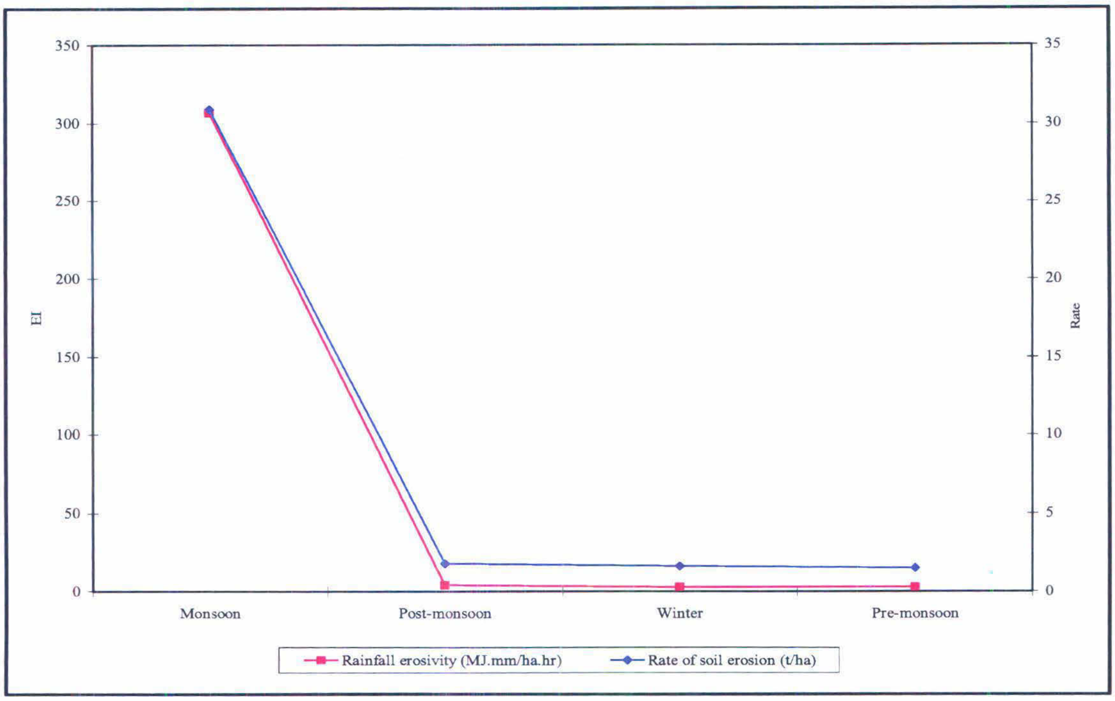

Fig 4.7: Seasonal variations in EI with consequent variations in the rates of soil erosion

4.2.3. Impact of extreme rainfall events

As has been concluded in the previous sections, rainfall erosivity is positively related to rainfall amount (r = 0.72) and has a direct impact on soil erosion (r = 0.99). Hence occurrence of heavy rainfall (≥100mm) in a day will lead to an increase in erosion due to increased erosive potential of rainfall. Two extreme rainfall events have been considered to estimate the consequent soil erosion rates.

In August 22, 1975 approximately 212 mm of rainfall had occurred in 24 hours. The resultant EI was calculated to be 378.96 MJ. mm. ha^{-1} hr^{-1}. Under the 1970 LULC, this extreme event had the potential to detach soil at an average rate of about 35 t ha^{-1} which is greater than the average annual rate of erosion (31.5 t ha^{-1}) in the watershed.

Another extreme event that has been considered here is that of August 19, 1998. A total of 110 mm of rainfall was recorded that day. Erosivity was calculated to be 89 MJ. mm. ha^{-1} hr^{-1}.

The event resulted in the erosion of soil at an average rate of 10 t ha^{-1}. This is less than the average annual rate (31.5 t ha^{-1}) but this is significant too as 33 percent of the average annual rate of erosion has occurred in a single day's rainfall.

It is, however, to be noted that the rate of erosion was low in the 1998 extreme event owing to the comparatively lower rainfall erosivity index (89 MJ. mm. ha^{-1} hr^{-1}) in the 1998 event than in 1975 (378.96 MJ. mm. ha^{-1} hr^{-1}). This further supports the fact that erosion decreases with decrease in rainfall erosivity.

Based on the above analyses, it may be concluded that rainfall erosivity is the driving force that initiates soil erosion through soil particle detachment from the soil matrix. Detachment of soil particles will increase or decrease if there is an increase or decrease in rainfall erosivity. Hence soil erosion is greater during the monsoon months in general, and in days with heavy rainfall of $\geq$100 mm in particular.

However, the rate of erosion and its spatial variation are determined and regulated mainly by the slope of the land and the type of LU/LC. Change in the LU/LC over a period of time, brings about a change in the rate of erosion. Decrease in the forest area in the watershed, primarily due to deforestation, has increased the amount of soil eroded from the steeply sloping areas in the post 1990s. However, conversion of barren land into some usable form that keeps the soil surface covered and protected from the effect of rainfall has resulted in the reduction of the rate of soil erosion in the area.

Therefore, if the steep slopes are devoid of adequate forest cover and the gently sloping cultivated areas are left fallow, then an erosive rain will detach a huge amount of soil that will be readily available for displacement.

CHAPTER 5

CONCLUSION

Soil erosion is the physical process of soil degradation that includes mechanical detachment, displacement and distribution of soil particles from the soil matrix to other places. It is a natural process that supplements the overall process of development and determines the character of soil profile (Miller, 1931). Hence naturally soil erosion is a necessity. However soil erosion turns out to be a menace when the natural rates (0.5 t ha^{-1}) are aggravated. Several studies have claimed the accelerated rates of soil erosion are solely anthropogenic. But as the present study reveals, natural factors viz. rainfall erosivity and slope, have a higher potential than human factors to accelerate or decelerate and bring about temporal and spatial variations in soil erosion rates.

In the present study, rainfall erosivity (EI) is found to be the main determinant of soil erosion. In fact it is the force that initiates the process through soil detachment. Its positive impact on soil erosion rates (r = 0.99) indicates that if EI is low, rates are greatly reduced (in 1979-80 EI was 116 $MJ.mm.ha^{-1}hr^{-1}yr^{-1}$ and consequent erosion rate was 13.9 t ha^{-1}). On the other hand, rates of erosion are very high if EI is high (in 1975-76 EI was 933 $MJ.mm.ha^{-1}hr^{-1}yr^{-1}$ that resulted in 63.5 t $ha^{-1}$of soil erosion). EI, in the present study, has been calculated using daily rainfall data. But the study reveals that the occurrence of extreme rainfall event(s) (day(s) with more than 100 mm rainfall) in a month has a stronger positive impact on EI (r = 0.8). Therefore, in order to calculate annual EI, it is feasible to consider a combination of total monthly rainfall amount (Rf) and number of extreme rainfall events (E_x) as expressed in the following equation that has been developed in the present study:

$$EI = -83.768 + 111.366\ E_x + 0.259\ Rf$$

The average deviation between the EI calculated from daily rainfall amount and the EI calculated using the above equation is 10 percent. Hence the proposed equation works well for computing annual EI as a function of rainfall amount and number extreme rainfall events. The above mentioned relationship is valid only in areas or regions having daily rainfall data and not hourly rainfall data.

Since daily rainfall data for only one station was available for the Gej watershed, spatial variability of the impact of rainfall on soil erosion could not be assessed. Therefore under conditions of 'spatially-constant' rainfall erosivity and 'no surface cover', slope-length (LS) factor is the natural factor that determines the spatial variations in soil erosion. Erosion rates increase with increase in the value of LS and decrease with decrease in LS ($r = 0.6$). The influence of another natural factor, soil erodibility (K), on soil erosion is subdued by the impact of LS to an extent that different rates of erosion occur on different slope areas with same soil type.

The impact of LS factor on soil erosion is, however, reduced ($r = 0.3$) under conditions of surface cover. Surface cover, whether provided by natural vegetation or by crops cultivated by man, and by built-up area, seems to be an erosion-regulating factor. The rates of soil erosion may be accelerated or decelerated depending on the type of surface cover. Forests are the most efficient in reducing soil erosion. But soil erosion rates are higher in areas that have been brought under cultivation by clearing the natural vegetation. Hence crop cultivation is often regarded as a 'necessary evil'. But it is to be noted, as has been established in the present study, that human interference into the surface cover characteristics of the watershed has, in fact, led to the reduction in the average rates of soil erosion in the watershed. Soil erosion rates decreased from 36 t $ha^{-1}yr^{-1}$ under the 1990 land use/land cover (LULC) to 35 t $ha^{-1}yr^{-1}$ under the 1999 LULC. This has been brought about by an increase in the area under open forest by 16 percent and a decrease in the area under fallow by 23 percent. Moreover, a 43 percent increase in the area under crop cover provided more protection to the soil surface from the erosive action of rainfall.

Soil erosion rates, thus, vary under varying conditions of LULC. Rates are increased or decreased if there is positive or negative change in LULC. Positive change in LULC, as explained in the present study, implies a decrease in LULC types which accelerate soil erosion with simultaneous increase in LULC types which decelerate soil erosion; whereas negative change implies the reverse of the condition of positive change. Soil erosion rates vary due to variation in EI. Inter-annual variations in rates of soil erosion were due to variations in annual EI. Moreover it has also been established in the present study that erosion rates in the study area are high during the monsoon months and in days with extreme rainfall events owing to the high EI during these months and days.

Measures should therefore be taken to check high rates of soil erosion during erosive months of the year and under conditions of 'negatively' changed LULC. In fact in an era when increased food production to feed an increasing population by bringing more land under cultivation is a priority and sustainable development a necessity, measures should be taken to increase the 'protection efficiency' of LULC. 'Protection efficiency' has been defined in the present study, as how effectively and efficiently an LULC is able to protect the soil surface from the erosive action of rainfall, thereby reducing the rate of soil erosion. It is determined by percentage cover of the land and density of foliage of the vegetation and can be numerically expressed by the C factor values used in the USLE. Support practices, viz. terracing, cultivation along contours, etc. which are absent in the study area, should be introduced. In the lowlands, the agricultural fields should be, if possible, left fallow for the minimal period of time. Fields should rather be covered with leguminous plants, mulch or any cover crop. Soil surface should essentially be kept protected during the months of erosive rains.

The introduction and implementation of the management measures require prior estimation of soil erosion and its spatial and temporal variations as well as an analysis of the extent of influence of different factors on the rates of soil erosion in the area of interest. Several erosion-prediction models have been developed over the years. However the applicability of the models depends primarily on the availability of adequate data. Data required for the estimation of soil erosion using the USLE is readily available and the calculations are less complex. Hence the USLE was used in the present study. The equations for calculating the values of the input parameters were, however, modified in order to meet the requirements of the analysis using daily rainfall data, remote sensing and GIS.

The average annual rate of soil erosion in the Gej watershed was estimated to be 31.5 t ha^{-1} yr^{-1} which is higher than the national average (16.35 t ha^{-1} yr^{-1}). It is higher than soil loss tolerance limit which is 12 t ha^{-1} yr^{-1} for Chhattisgarh. Therefore the soil degradation ratio is more than 1 which implies that soil conservation measures are required to be implemented in the Gej watershed.

The study also researched the fact that not all the soil that is eroded is lost from the watershed but is distributed and deposited within the watershed. However the high rates of soil erosion within the area will lead to the deterioration of the physical quality of the soil. This will in turn reduce the soil productivity. Hence, even if research, management measures and environmental policies are directed to areas of extremely high erosion rates in the country, for example the Siwaliks; studies should also be done and measures should be adopted to reduce soil erosion in areas which are considered to be comparatively less hazardous. It is not at all wise to assert that such areas "require less attention for erosion control" (Rao, 1962). Moreover, if parts of the area that is considered as the 'rice bowl of India' become less productive due to increased soil erosion, it will be very difficult to support a huge population.

Overall the major findings of the study may be grouped into the following:

- Modifications to the original equation of USLE, for measuring the input parameters have helped in the proper estimation of soil erosion in the Gej watershed despite a serious dearth of data.

- Use of remote sensing data helped to understand the environmental conditions of the area in recent years. It has enabled the study of the temporal variations in LULC which is an important factor that regulates soil erosion.

- Estimation of soil erosion in a GIS environment allowed the study of the spatial variations in soil erosion rates within the watershed.

- Among the five factors that influence soil erosion, rainfall erosivity (EI) is the most important. EI and soil erosion rates are very strongly related ($r = 0.99$) i.e. years or months or days of very high EI result in very high erosion.

- EI is determined by the total amount of rainfall and the occurrence of extreme events of ≥ 100 mm of rainfall. In fact years which had recorded maximum numbers of extreme rainfall events together with very high rainfall total, were the years with very high EI. Hence annual EI should be computed as a function of annual rainfall and the total number of extreme events.

- Considering R as spatially constant, spatial variations in soil erosion within the watershed are determined by the LS factor and are regulated by LULC.

- Under conditions of 'no surface cover', soil erosion increases with increase in LS ($r = 0.6$). However the extent of influence of LS is reduced ($r = 0.3$) by the impact of LULC.

- Temporal changes in LULC lead to changes in the rate of soil erosion. Average annual rate of soil erosion in the watershed increased during 1970-90 due decrease in area under forest cover by 7 percent and a subsequent increase in agricultural land by 5 percent. But erosion rates decreased during the period 1990-99. Decrease in the area under barren land and seasonal fallow have been the causes for the reduction.

- Under conditions of reduced EI and/or positive change in LULC, i.e.; soil erosion rates are reduced greatly.

Briefly, the present study has been successful at estimating the average annual rate of soil erosion in the Gej watershed, using USLE in GIS environment. However the acute lack of adequate secondary data has imposed a handicap on the accuracy of the results. The work is also an attempt study the impact of extreme rainfall events (≥100 mm) on rainfall erosivity. Occurrence of extreme rainfall events leads to increased rainfall erosivity and a consequent increase in soil erosion. Special measures should be taken during the monsoon months which record the maximum number of erosive (≥12.5 mm) and extreme rainfall events.

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