

**DISTRIBUTED SEDIMENT YIELD MODEL (DSYM) USING GIS
FOR SUSTAINABLE WATERSHED PLANNING IN LOWER
BHAVANI CATCHMENT**

*Thesis submitted in part fulfilment of the requirements for the degree of Doctor of Philosophy
(Agricultural Engineering) in Soil and Water Conservation Engineering to the
Tamil Nadu Agricultural University, Coimbatore - 641 003*

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2001

CERTIFICATE

This is to certify that the thesis entitled “**DISTRIBUTED SEDIMENT YIELD MODEL (DSYM) USING GIS FOR SUSTAINABLE WATERSHED PLANNING IN LOWER BHAVANI CATCHMENT**” submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURAL ENGINEERING)** in **SOIL AND WATER CONSERVATION ENGINEERING** to the Tamil Nadu Agricultural University, Coimbatore is a *bonafide* record of research work carried out by **Ms. I. SUMATHI** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles and that the work has not been published in part or full in any scientific or popular journal or magazine.

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I. SUMATHI

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Abstract

ABSTRACT

DISTRIBUTED SEDIMENT YIELD MODEL (DSYM) USING GIS FOR SUSTAINABLE WATERSHED PLANNING IN LOWER BHAVANI CATCHMENT

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The excessive siltation of reservoirs due to rapid erosion is threatening the useful life of many multipurpose reservoirs in India. Therefore, Soil conservation measures are being applied for reducing runoff and soil erosion and consequent sediment production in the catchment areas. All parts of the catchment do not erode uniformly and all eroded materials do not get in to the reservoir. Hence direct collection of data in the entire catchment is time consuming and it is not possible to gauge all parts of the watershed. Methods of estimating sediment yield are useful for identifying critical source areas of soil erosion and evaluating effectiveness of various conservation measures for watershed planning. Many models developed elsewhere in

the world, are so rigorous that those are site specific and rarely applied in India. These necessitated the development of a model to estimate sediment yield of the watershed.

The Distributed Sediment Yield Model (DSYM) is GIS based event model consists of three modules viz., Peak runoff rate module, Sediment yield module and Sediment routing module which were written in Microsoft Visual Basic. It is capable of simulating peak runoff rate and sediment yield of the sub-watersheds and route the sediment to the watershed outlet. The model requires 10 fixed inputs and one variable input. The parameters namely “m” (MUSLE exponent) and “ α ” (portion of total rainfall that occurs during time of concentration) are tuning parameters. The DSYM was calibrated on the real watershed, Ebbanad of Lower Bhavani Catchment, Nilgiris, Tamil Nadu with 10 storm events. The optimized values of the parameters were 0.29 and 0.28 for smaller storm events and 0.41 and 0.35 for larger storm events respectively. The sediment storage coefficient (Ks) was varied from 1.06 to 2.83 and 1.40 to 2.19 respectively. The per cent error of DSYM was in the range of -6.65 to 13.66 with the correlation coefficient of 0.99. The performance of the model was 0.98 (Nash and Sutcliffe’s coefficient of efficiency) and the coefficient of determination was 0.9826.

The DSYM was validated on Ebbanad watershed with four storm events. DSYM was also validated with another watershed namely, Katteri in Lower Bhavani Catchment, Nilgiris, Tamil Nadu. It was determined that the predicted sediment yield closely agrees to the measured value with a per cent error of 15.89. The results of the modules were pictorially viewed in GIS to spatially identify the critical areas of erosion. It was found that DSYM is capable of providing alternate land use management and conservation practices to reduce sediment yield.

Introduction

CHAPTER – I

INTRODUCTION

Soil, Water and Plant resources are nature's gift to mankind. Overgrazing, deforestation, faulty cultivation, shifting cultivation and carelessly built roads in the catchment areas have led to devastating effect down streams. The problem has been aggravated due to high rate of population growth-both human and livestock. This continuous degradation of production base causing an imbalance in land-water-plant, human-animal systems which lead to ecological imbalance and economic insecurity, through soil erosion. Soil erosion is a serious environmental problem affecting large areas of the agricultural landscape in our country. Land and soil degradation will perhaps be the main challenge to sustainable development for future generation. (Hurni, 1997)

Accelerated erosion encompasses a series of complex and interrelated natural processes that have the effect of loosening and moving away soil and rock material under the action of water. Surface runoff is the chief agent for causing erosion entrainment and transportation of eroded material. The surface runoff and its consequent sediment production in the catchment is mainly dependant upon the factors like rainfall, Landuse/Landcover, soil and slope. Sediment has a threefold effect on the environment: 1) depleting the productive capacity of the land from which it is transported, 2) impairing the quality of the water in which it is transported, and 3) aggrading the land on which it is deposited. The problem of soil erosion in India, their extent, severity and nature vary largely in different parts of the country depending upon climate, topography, soil and landscape. In India about 81 M ha of lands are affected by erosion problem out of total geographical area of 326.8 M ha. Out of these about 40 M ha lands are badly affected and needed immediate control measures (Das, 1985). The rate of soil erosion in different soils by sheet erosion is estimated as 4 to 10 t/ha/yr in red soils, 17 to 43 ton/ha/yr in black soils and 4 to 14 ton/ha/yr in alluvial soils.

The rate of soil erosion from gullies is computed as 33 ton/ha/yr in ravine regions (Dhuruvanarayana and RamBabu, 1983). They have also reported that, annual soil erosion rate in India was estimated as about 5334 M ton due to agricultural activities and its associates. And about 1572 M ton soil as sediment per year is carried away into the sea by rivers of the country.

A large number of irrigation and power projects have been commissioned since independence to provide infrastructure for increased agricultural production and industrial growth besides flood control. Recent surveys (SubbaRao and Karale, 1993) on these revealed the loss of storage capacity due to sedimentation resulting from the accelerated soil erosion in the catchment areas. A scheme on soil and water conservation on selected River Valley Projects (RVP) involving 86 M ha is launched by GOI.

In Peninsular India, soil erosion and sedimentation is widely prevalent in Western Ghats, which forms the real watersheds for the South. Most of the rivers in South India originate from the Western Ghats. Lower Bhavani Catchment of Western Ghats, has high degree of soil loss up to 4500 t/km²/yr. The expansion of area under agricultural and plantation crops, up and down slopes and unscientific ways of terrace formation have compounded the problem. This soil erosion in the hills and transportation of sediment creates siltation in the Lower Bhavani and Kunda reservoirs and reduced the storage capacity significantly in the last decade, needing the necessity of adequate soil conservation measures. To control the factors of soil erosion and for preventing this, some measures have to be taken for soil erosion for which a thorough knowledge of geotechnical parameters is essential.

Watershed management has assumed urgency for planned development of land and water resources and to arrest land degradation process to preserve environment and ecological balance. Information on the rate and kind of changes in land resources is essential

for proper planning, management and regularising the use of such resources. Decision support to management planning requires scientific knowledge of resources information, expected runoff and sediment yield, priority classification of watershed for environmental impact assessment and technologies of Geographic Information System for database creation, scenario development and appropriate decision making.

Modeling water balances of watersheds has been the concern of hydrologists for decades. Although theoretically possible, detailed water flow modeling based on basic soil hydraulic properties has been limited application because of large field variability and hence the need for large amounts of data on hydraulic properties. Thus purely physically based water flow analysis may not be practical and therefore use is often made of semi empirical and empirical models. Hydrologists have linked GIS with hydrologic models to facilitate model execution (Vieux, 1991). Integration of distributed hydrological and sediment yield models with GIS have improved capabilities to estimate overland flow and sediment yield in complex landscapes.

Most conservation planning for erosion control in agricultural lands, construction sites, reclaimed mines and forest management, however use empirical models to estimate average annual soil loss because of consideration of long time scale, small areas, low cost, short project span and little risk of failure. Models are being developed to better understand the complex erosion processes that occur on agricultural watersheds.

Sediment yield modeling is more complicated than other types of hydrologic modeling because before the sediment movement can be modeled, there must be detailed information concerning the amount and type of precipitation and the movement of water. Since empirical observations of such information are seldom available on the detail and variety required, a rainfall-runoff model for small watersheds and an in-channel flow routing

model must be operated in conjunction with a sediment yield model for any basin of appreciable size. Sediment transport and flow are so interrelated that it is difficult to discuss sediment yield modeling without mentioning the modeling of the flow.

In Lower Bhavani Catchment, most of the data required for hydrological modeling are available in data banks. The data acquired through field measurements are quite time consuming and laborious. A deterministic structure initiating mathematical model of sediment yield utilizes mathematical relationships to approximate the pertinent hydrologic, physiochemical, and biologic processes of the watershed for predicting the amount of sediment output from the system in a given time period.

Owing to all above, the information on existing land uses, overland flow, channel flow and sediment yield are required in the design and operation of soil and water conservation measures to control non-point source pollution. Hence, this study has been formulated to fulfill the following objectives:

1. To develop mathematical model for prediction of runoff and sediment yield
2. To compare the predicted sediment yield with the observed.
3. To test the validity of the developed model for another watershed.
4. To quantify the areas prone to erosion in a watersheds using Geographic Information System.
5. To study the effect of sediment yield in the watersheds and to develop suitable management practices.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

Of the huge volume and large varieties of literature now available on the hydrologic processes, soil erosion and modeling with GIS only those that are considered of direct consequence for this modeling attempt have been selected and presented.

2.1. Small Watershed

Dalrymple (1964) defines small watershed as one that is so small that its sensitive to high intensity rainfalls of short durations and to land use are not suppressed by the channel storage characteristics, the size of which may vary from few acres to 1000 acres or even up to 50 square miles. Adhikari and Ravisankar (1983) defines small basins as those whose areas were less than 1000 Sq.km. Black (1990) defines a small watershed as one where channel and ground water storages are not sufficient to alternate and flood peak primarily influenced by weather and land use. Small watershed are said to have 'flashy' hydrologic behavior, exhibiting higher high flows and lower low flows. Singh (1992) considers small watersheds as those having areas less than 100 Sq.miles (250 Sq.km) and cautions it as a rough guideline, which may vary from one geological area to another. He has indicated, on the average, small watersheds are more non-linear than large watersheds and small watersheds have dominant land phase and less conspicuous channel phase.

2.2. Rainfall and Spatial Variability

World Meteorological Organisation recommends raingauge density for mountainous regions as one station for 100-250 Sq. km and the Indian standard

(IS: 4987-1968) recommends one station for 130 Sq.km. A true and distribution of rainfall is never really known for sure, nor is a true rainfall volume.

Eagleson (1970) observes, for reasons of accessibility, gauging stations when few in number, are usually located in the valleys near population centers and are therefore at an elevation less than the average for the entire basin. This leads to calculate average precipitation depths over a basin to be lower than the actual depths.

The spatial variability of rainfall was studied by Huff (1970) and observed that more intense storms showed a low rate of variability and the light showers possessed high variability. He further observed that the spatial variability of rainfall rate was more pronounced than that of the total rainfall. Aitken (1973) suggested that proper representation of the rainfall distribution was significant to minimising the error between a sequence of recorded and simulated flow.

Singh and Woolhiser (1976) argued that the rainfall excess (rainfall-infiltration) is the most-sensitive parameter in many models for predicting stream flow. Shanholtz *et al.* (1981) indicated that rainfall is the most sensitive variable and possibly the most difficult to obtain good aerial measurements. They showed that large errors could result when spatial variability of rainfall was ignored.

Quick and Pipes (1982) showed that the nearest meteorological station, which was also near the mid-elevation of the basin gave the best results, superior even to combination of stations. Such a mid-elevation station reduced data extrapolation errors and was more representative of amount, duration and frequency of precipitation and of the actual temperature regime.

Serious errors in hydrograph simulation can be introduced if the one-point rainfall input is used instead of an aerial rainfall input. If the historical single events are to be used in runoff model calibration or in runoff simulations, knowledge of aerial rainfall pattern and rainfall volume is essential (Niemczynowicz, 1984).

The highest deviations between point and aerial rainfall were observed by Niemczynowicz (1984) during rainfalls with long return periods, or during the most intensive rains. The longer the period of averaging the rainfall, the greater is the difference between the average maximum value and the real maximum value of rainfall intensity when averaging is done over a long period, the rainfall volumes obtained by means of simple averaging procedure may be quite different from that actually observed, when different durations are considered for other analyses.

2.3. Spatial variability of soil properties

Cassel and Bauer (1975) reported coefficients of variation of different soil properties, as 7.3% for bulk density and 31% for water content at wilting point.

Ahuja *et al.* (1988) reported that the horizontal or areal coefficient of variation for different or areal coefficient of variation for different depths varied within a very narrow range. The coefficient of variation was less than 5% for bulk density and generally greater than 20% for sand, organic matter, water content and macro porosity and that of other properties were between these values.

2.4.0. Process involved in the Model

2.4.1. Interception

Lull (1964) determined that precipitation at an intensity of 17.5 mm/ha required about 15 minutes to saturate the foliage. When the foliage is saturated, the weight of intercepted water could exceed the dry weight of the entire plant.

Leyton *et al.* (1967) estimated canopy storage values for bracken interception, to range from 1.016 to 2.13 mm for a LAI of 1.32 to 4.36 respectively. Beasley and Huggins (1981) listed the values of potential interception of rain by different crops for use in their ANSWERS model.

Rutter *et al.* (1971) developed an interception model, as

$$Q = (1-P) R - E_0 \quad \text{when } C > S,$$

$$Q = (1-P) R - E_0 (C/S) \quad \text{when } C < S,$$

Where,

Q	=	net rainfall, mm/hr
P	=	free thorough fall coefficient
R	=	rainfall rate, mm/hr
C	=	canopy storage, mm
S	=	canopy storage, capacity, mm
E ₀	=	evaporation rate, mm/hr

Lawson *et al.* (1981) studied the partitioning of rainfall in the forested watershed at the IITA catchment and reported that the monthly interception varied from 11.5 to 39.0 mm (13 to 24%) for a well developed tree, interception of the order of 1.52 mm of

precipitation can be expected on the basis of an average retention of about 20 drops per leaf (Viessman *et al.*, 1989).

Thomas and Beasley (1986) estimated interception in the FHM, using modified form of Mernam's equation as

$$\text{INT} = \text{PIT} * (1 - \exp(-\text{RAIN}/\text{PIT})) * \text{PER}$$

Where

INT	=	Volume of interception
PIT	=	Potential interception storage volume
RAIN	=	Rainfall volume during the period
PER	=	Percentage of maximum canopy cover

Interception is that part of precipitation that is caught and held by vegetation or structures and then lost by evaporation only (Gupta, 1989). Viessman *et al.* (1989) reported that the amount of water intercepted is a function of

- a. The storm character
- b. The species, age and density of plants and trees and
- c. The season of the year

Usually about 10-20% of the precipitation that falls during the growing season is intercepted and returned to the hydrologic cycle by evaporation. Under closed forest stands as much as 25% of annual precipitation is intercepted, grasses, crops and shrubs which have often leaf area to ground area ratios similar to forests, have as much as 7 to 60% interception of rainfall.

Susanto and Kaida (1991) assumed that the rate of interception decreased exponentially with increase in interception storage and adopted the relationship,

$$IC = A1 [1 - \exp(-P/A1)]$$

Where

IC	=	rate of interception
A1	=	interception storage capacity
P	=	rainfall

Singh (1992) recommended an equation, based on Hortons work to estimate interception loss, as

$$I = S (1 - \exp(-P/S) + KED)$$

Where,

I	=	interception loss per storm
S	=	interception storage capacity
P	=	precipitation
K	=	lead area index
E	=	rate of evaporation
D	=	duration of rainfall

2.4.2. Infiltration

Viessman *et al.* (1970) reported that when the simple ϕ index was used for infiltration, the tendency of the model was generally to over predict with rising limb of the hydrograph and under predict the recession, because of neglect of initial depression storage loss.

Sensitivity analysis on the Green-Ampt equation parameters have indicated that infiltration and runoff amounts were most sensitivity to porosity and hydraulic conductivity and less sensitivity to capillary potential across the wetting front (Skaggs and Khaleel, 1982).

The Green-Ampt infiltration model was used probably because of a clear physical basis of the model and of the existence of Green-Ampt parameter values for a wide range of soils (Rawls and Brakensiek, 1983).

The generally accepted assumption that the Richard's equation describes the infiltration process exactly is not correct, due to simultaneous flow of water behind air during the process (Sander and Parlange, 1984).

Devaurs and Gifford (1986) investigated spatially varying infiltration characters on rangeland sites. Green-Ampt parameters predicted from soil texture data describe infiltration rates less than 3 cm/hr. Results also indicated that texture predictive triangles, developed to describe infiltration on agricultural soils, need revision to adequately describe infiltration patterns on range lands

The Green-Ampt infiltration model for a 3-layered soil system was verified with measured runoff and infiltration data. The observed and predicted infiltration rate showed very good agreement. The predicted runoff was more sensible to the effective hydraulic conductivity of the low permeable layer (Tan *et al.*, 1987).

The infiltration is allowed to occur only during the period of rainfall while infiltration happens during the whole period of surface runoff, or as long as water is over the ground. Hence in order to compensate for infiltration accounted for after the period of

rainfall, infiltration has to be allowed to occur at a rate higher than that at which it actually occurs (Singh, 1992).

James *et al.* (1992) recognized that the Green-Ampt model has been applied to small range land and Agricultural watersheds (typically 10^{-1} to 10^2 km²). The major attraction of the Green-Ampt model is the involvement of physically meaningful parameters and the potential of using data on soil properties collected during standard soil surveys to estimate these infiltration parameters.

Helmut *et al.* (1992) formulated hypotheses concerning the link between K_{sat} and topography. They observed the K_{sat} decreased from 46 to 0.1 mm/h at steep lower side slope and 462 to 0.1 mm/h on the intermediate terrace.

The effective hydraulic conductivity parameter (K_e) in Green-Ampt equation is needed to obtain reliable estimates of infiltration and runoff. Risse *et al.* (1994) estimated effective hydraulic conductivity from five different parameter estimation methods based on relationships involving common soil properties and were used in Green-Ampt/WEPP model to predict runoff at each of the locations. GA/WEPP tended to over predict runoff on small events and under predict runoff on the larger events.

Zhang *et al.* (1995) identified and examined the major variables which affect the adjustment of the Green-Ampt K_e . The correlation analysis on these calibrated values showed that total effective surface cover, storm rainfall and the product of the two were highly correlated to K_e under meadow conditions. Effective hydraulic conductivity

estimated for row crops were multiplied by a factor of 1.81. The regression line between the mean optimized K_e and the mean predicted K_e fit the data well ($r^2 = 0.82$).

In Water Erosion Prediction Project, the Green-Ampt infiltration model (Green and Ampt, 1911) as formulated by Mein and Larson (1973) was used to determine surface runoff for both the hills top and watershed models (Flanagan *et al.*, 1995 and Ascough *et al.*, 1997).

In runoff prediction to drive physically based soil erosion models, Yu *et al.* (1997) used an infiltration model that takes into account the spatial variability of the infiltration characteristics at the plot scale, while the temporal decrease of the infiltration rate was assumed negligible once runoff commences. They used measured 1-min rainfall and runoff data from six sites in Australia and Southeast Asian countries to estimate model parameters and to evaluate the model performance. It has been suggested that the infiltration model be compared with other infiltration models with a similar degree of complexity, which have been widely used in the context of runoff and soil loss predictions.

2.4.2.1. Infiltration model

Singh (1977) has reviewed different versions of the hydrologic models and commented: the infiltration estimated by a model will differ from the true infiltration for the following reasons, which no model seems to account for,

1. Heterogeneous watershed characteristics in space and time.
2. Heterogeneous antecedent soil moisture condition over the watershed
3. Heterogeneous, computed nature of the rainfall event over the watershed
4. Interaction of some or all of them.

Chu (1978) has applied Green-Ampt equation for unsteady rainfall. The infiltration equation is

$$f = K \left(1 + \frac{n\psi}{F} \right)$$

and its integrated form,

$$Kt = F - n\psi \ln \left(1 + \frac{F}{n\psi} \right)$$

where

n	=	Porosity
ψ	=	Wetting front suction head
K	=	Hydraulic conductivity
T	=	Time interval

McCuen *et al.* (1981) found that the parameter values of Green-Ampt and Books-Corey models vary significantly across soil textural classes. For Green-Ampt model, they furnished $\ln K_s$, $\ln \psi$ and ϕ values distributed over the USDA textural triangle, with respective mean and standard deviation values. They found that the mean values of a parameter of a soil texture when used in watershed modeling, predicted rainfall excess successfully.

Slack and Larson (1981) stated that the GAML infiltration model fulfills all the requisite criteria, including rainfall at constant, variable and intermittent application rates. It has the added advantage that the equations are relatively simple and therefore, large amount of computer time are not required as may be the case with the Richards equation.

Rawls and Brackensiek (1982) compiled soil water and hydraulic properties for different textural classes with the mean and the range for mean \pm one standard deviation. These soil hydrologic data are being widely used in modeling studies, including the WEPP model.

Rawls *et al.* (1983) furnished the Green-Ampt infiltration parameters for various soil classes, as defined by the USDA textural triangle. The mode and the range with \pm one standard deviation around the parameter values were also given.

Chow *et al.* (1988) explained the methods of finding potential infiltration rate before and after ponding, cumulative infiltration before and after ponding and time of ponding, when employing Green-Ampt, Horton and Philip's models.

Stone *et al.* (1992) modified the Green-Ampt version of infiltration and used there in their IRS model. When the measured values of the parameter were not available, default values for the parameters reported by Rawls *et al.* (1983) were used in modeling for post-ponding conditions, the average infiltration rate for a time interval was computed as:

$$f_{i-1} = \frac{F_i - F_{i-1}}{t_i - t_{i-1}}$$

where i indicated the current time and $i-1$ indicated the previous time.

2.4.3. Surface storage

Detention storage, in its short life is however, an important regulator of subsequent fluxes of water, providing for partitioning into infiltration and runoff. The depression is distinguished from detention storage, as it is that portion of the liquid-water layer that is trapped in micro-depressions and cannot flow away. It remains trapped until it eventually infiltrates or evaporates (Miller, 1977). He reported the approximate sizes of the depression storage for various land uses as:

Flat pasture	=	1 to 5 mm
Ploughed land	=	> 50 mm
Contour furrows	=	40 mm

The maximum potential surface storage volume is dependent on surface topography of the field, tillage practices on the field and soil surface conditions. Although this parameter has real physical significance, it is impossible to measure in the field and these can only be estimated. Maximum potential surface depression storage was included in the water balance model as a variable that must be specified by the user and that must remain constant for anyone model run (Anderson *et al.*, 1978).

Detention storage capacity of the field is more important. As it is not easy to measure it in the field, this is often estimated as a calibrated parameter. In water yield model, detention storage was estimated by calibration (Nielsen and Panda, 1988).

2.5. Surface Runoff and Spatial Variability

Knapp *et al.* (1975) in their BHS model, for continuous distributed modeling used unit hydrograph method, to distribute runoff temporally and deliver it as input to the stream network where after Muskingum method of routing was employed to determine

flow at basin outlet. They note that the runoff from the basin moves over the surface in a complicated system of ditches and ephemeral stream, the effects of which to store and route the flow to the defined stream, cannot be deterministically evaluated.

The amount and distribution of rainfall-excess in time and space is really never known. Errors in distribution of rainfall-excess estimates may be large even when the runoff volume is known. Frequently rainfall – excess is either assumed or computed rather arbitrarily, even though this is a major source of error in the model results (Singh, 1977).

Varshney (1979) gave an exhaustive compilation of fifty empirical formulae used for estimating annual field from the catchments. His comparison of different formulae showed that a 20 sq.km. Catchment could produce more to 1500 m³ sec⁻¹ discharge.

Shanholtz *et al.* (1981) used FESH7 model to simulate overland and channel flow, considering spatial variability of soil hydraulic properties and reported that the factors affecting run-off volume were depth of the soil profile, antecedent soil moisture, and vegetative cover. The significant factors affecting runoff timing were the surface roughness coefficient and length of flow path, the shape of the runoff hydrograph depends not only on the catchment characteristics and the time distribution of the rainfall pattern, but also on the dynamic properties of the rainfall, such as the velocity and direction of the rainfall movement

Das (1982) reported that in the Nilgiris surface runoff was mostly around 2% and in rare occasions around 5% of the incident rainfall. Mittal *et al.* (1988) has published runoff data for season for six years, which indicated that a rainfall of 482 mm during 1981 season produced 146 mm runoff (30.3%) and the same amount of rainfall during the same season of 1984 could produce only 111 mm of runoff (23%)

Kirkby (1985) stated that the catchment hydrograph appear to show much less variety than catchment topography and soils so that massive averaging is commonly taking place to suppress local detail.

2.6. Effect of land use changes on surface runoff

Kite and Kouwen (1992) compared a lumped hydrological model and a version of a same model applied successively to different land uses within sub basins. They applied the hydrological model separately to each land cover classes and the resulting hydrographs were routed to the sub basin outlet and then through lower sub basin. It was found that using a semi distributed model gives goodness of fit statistics that are better than the lumped basin approach and it shows variation in storages and infiltration rates that would be expected in the mountain basis.

Douchon *et al.* (1992) stated that the land cover areas, which differentiate the major hydrologically homogeneous response groups in the watershed, are important inputs to hydrologic models.

2.7. Effect of Vegetation and cropping on surface runoff

Raghunath *et al.* (1967), based on the experiments conducted at Ootacamund, reported that by adopting contour-farming for potato on 25% slope, the runoff was reduced from 52 to 29 mm.

Tejwani *et al.* (1975) reported that the annual runoff was reduced to 41.2% of rainfall under contour-cultivation, when compared to 54% under up and down cultivation, when the studies were conducted on silty clay loam soil with 8% slope in Dehra Dun.

Wood (1977) compared the hydrologic properties of soils in forest and agricultural uses and reported that infiltration rates were higher for soils under forest cover (0.30 to 39.7 cm/hr) than that under agricultural crops (0.03 to 9.3 cm/hr), bulk densities of forest soils were found to be less by 11 to 26% of that of agricultural soils, total porosities were larger under forest cover and bulk densities in lower depths were less affected by land use.

Runoff rates are high if vegetation is short and offers little frictional resistance to overland flow. A greater density of plant increases infiltration capacity and surface detention. High density of plant stems and leaves slow the flow of surface water, greater plant activity dries out the root zone, increasing its capacity to take in more water from the next rain causing reduction in runoff (Miller, 1977).

RamaMohanRao *et al.* (1988) observed, based on experiments conducted at the Chinnatakur watershed (Andhra Pradesh) that the runoff were 0.11% and 0.39% of rainfall from forest cover and treated agricultural cover respectively.

Samraj *et al.* (1988) had investigated the effect of afforestation on annual water yield and brought out that the black wattle and bluegum plantation had no significant effect on runoff for the first two years but from the third year onwards reduced the annual runoff by an average of 87mm (16%) which was statistically significant at 1%. Kale *et al.* (1992) reported that intercropping system reduced the runoff irrespective of slope.

2.8. Effect of conservation measures on surface runoff

Rambabu *et al.* (1974) observed at Dehra Dun that as a result of field bunding of agricultural watershed the total runoff was reduced by 62% and the peak runoff rate was reduced by 40%. Sud *et al.* (1977) determined that bunding of agricultural land conserved

on an average of 62 mm of rainfall per year and reduced the runoff and the peak rate of runoff by 36.5% and 41.7% respectively.

Shanholtz *et al.* (1981) used two types of detention structures namely overland flow structure (on ephemeral drainage) and channel flow structure (on perennials drainage) in their FESHM. Their assumption that an identical structure could be located anywhere on the watershed with the same drainage area, although in reality could be highly improbable, was reported as not a constraint on the application of the model.

Singh (1988) had introduced a parameter called “Conservation factor” to describe the effects of several conservation measures in predicting runoff, peak runoff and soil loss from watershed based farming systems.

2.9. Soil Erosion processes and sediment transport

Johnson and Moldenhauer (1970) found instances in Iowa where channel erosion contributed more than 45% of the sediment yield from agricultural watersheds.

The mechanics of the precipitation event are of major importance in determining the amount of sediment yield. Major variables influencing the yield are soil type, soil condition, and soil moisture content at the start of the event, slope and slope length, vegetation and litter cover, and rainfall amount, intensity and duration (Bennett, 1974).

Dillaha and Beasley (1983) developed a spatially descriptive erosion submodel for estimating the particle size distribution of eroded sediment from distributed upland watersheds. The model derives the watershed into a uniform grid of square planar elements. Within each element, the model describes the processes of interception,

infiltration, surface storage, surface flow, subsurface drainage, and sediment detachment, transport and deposition. The continuity equation is used to integrate the individual elemental responses into a system response that describes the watershed as a whole. The erosion process is limited to the over land flow regime.

Onstad (1984) described the relationships of erosion causing factors and how they have been studied and used in developing equations to predict erosion.

Reyes *et al.* (1985) evaluated the simulation performances of GLEAMS, GLEAMS-WT and GLEAMS-SWAT by comparing their soil loss predictions with Louisiana measured data at Baton Rouge. Although the hydrology component of GLEAMS-WT and GLEAMS-SWAT predicted surface runoff more accurately than the original GLEAMS, all three models seriously under predicted total soil losses over a seven-year period (1981-87). Transport capacity limited the soil loss prediction values in the models. Hence, they recommended that any changes or modifications in the erosion sub model be focused on improving transport capacity simulation and changes in the detachment simulation routine may not be needed. A calibration parameter was added to the erosion sub routine to adjust transport capacity. They concluded that even when the models were calibrated for a specific site, there were still substantial annual and monthly differences between predicted and observed soil losses.

Bingner *et al.* (1989) compared the simulated results from the models CREAMS, SWRRB, EPIC, ANSWERS and AGNPS with measured data of runoff and sediment yield on an annual and storm rainfall event basis. The comparisons showed that no one model worked well in every situation of runoff and sediment yield on the watersheds.

Overall, CREAMS and SWRRB produced results that were close on the measured values more often than the other models. AGNPS, a single-event model that has no capability for updating parameters, except for a modification that was made to replace the USLE's C-factor, also produced results that given close to the measured values in many situations.

Finkner *et al.* (1989) represented the sediment transport capacity for shallow over land flow as a quadratic function of down slope distance using the assumption of a linear increase in over land flow distance with down slope distance. This simplified equation for sediment transport applies to complex topography having uniform soil and management characteristics. It approximated the Yalin's equation when calibrated using the average of the hydraulic shear stresses at the end of a constant slope reference profile and the end of the actual profile.

Nearing *et al.* (1989) developed a model for estimating soil erosion on hill slopes by considering detachment, transport and deposition processes. The model uses a steady-state sediment continuity equation for predicting rill and interrill processes. Net detachment in rills is considered to occur when the hydraulic shear stress of flow exceeds the critical shear stress of the soil and when the sediment load in the rill is less than the sediment transport capacity. Net deposition is calculated when the sediment load is greater than the transport capacity. They found that inter rill erosion is represented as a function of rainfall intensity, residue cover, canopy cover, and inter rill erodibility. The model has capabilities for estimating spatial distribution of net soil loss and is designed to

accommodate spatial variability in topography, surface roughness, soil properties, hydrology and land use conditions on hill slopes.

Das and Chauhan (1990) developed a sediment routing procedure for a mountainous Himalayan region in India. The sediment yield from sub watersheds determined through a Modified Universal Soil Loss Equation (MUSLE) was routed to the watershed outlet by using a first order decay function. The procedure outperformed satisfactorily in test routings, and the results compared favourably with measured data.

Ahluwalia *et al.* (1992) developed a distributed mathematical model to simulate over land flow and sediment yield from small watershed. They found that the model agreed with the total soil loss from the over land flow. The Mein and Larson's approach based on the original Green and Ampt was used to estimate the rainfall excess rate.

Dickinson and Collins (1998) explained that the quantity of sediment that is exported from a catchment is generally much smaller than the amount indicated by erosion rates measured or estimated from contributing small land areas. This is due to sediment storage in the catchments, deposition on the land surfaces, at the base of slope, on valley floors and on the beds and banks of channels.

Lindley *et al.* (1998) described and verified the sedimentation algorithms included in the Water Erosion Prediction Project Surface Impoundment Element (WEPPSIE). The algorithms are based on the overflow rate concept. WEPPSIE trapping efficiency results agreed with predictions made using a previously validated continuous stirred reactors

model. WEPPSIE also performed adequately with 11 field data sets. The average trapping efficiency prediction error was 5.5% with a maximum error of 13%.

King *et al.* (1999) compared two methods namely SCS daily curve number (CN) and Green Ampt Mein-Larson (GAML) for simulating excess rainfall with multiple rain gauges. The model used was SWAT, modified to accept breakpoint rainfall data and route stream flow on a sub daily time steps simulated and measured stream flow at the watershed outlet were evaluated and the results were not calibrated. They found that the monthly model efficiency for CN was 0.84 and GAML was 0.69. Results suggest that no significant advantage was gained by using breakpoint rainfall and sub daily time steps.

Grunwald and Norton (1999) modified the sediment yield calculation of AGNPS model by the replacement of USLE' s 'LS' algorithm (S_1) by one based on stream power theory (S_2) and linkage of channel erosion (S_3). Measured median for sediment yield was under predicted by 53.9% using S_1 , under predicted by 38.5% using S_2 and over predicted by 3.3% using S_3 in the watershed.

2.9.1. Effect of rainfall on erosion of soil

Wolman and Miller (1960) indicated from analysis of data from many river systems in the U.S. that maximum sediment loads did not necessarily coincide with peak flood discharges.

The literature on erosion (e.g. Wischmeier and Smith, 1965 and Kirkby (1969) at both the hill slope and catchment scales suggests that sediment yields should vary with the multiplicate effects of rainfall or runoff, topography, cover density and other aspects of land use.

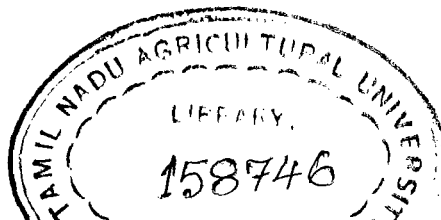
Meyer (1965) described that the rainfall parameters are not only important in splash erosion, but are also related to rainfall erosivity, which is the potential ability of rain to cause erosion.

The soil erosion models use rainfall and runoff rates as the driving force for the soil loss estimation from the catchments. The soil erosion components of these models derive their inputs from some hydrologic models and uses hydrologic routing technique to route the flow. This technique employs the equation of continuity with either an analytic or an assumed relationship between storage and discharge within the system (Viessman *et al.*, 1972).

Young and Wiersma (1973) reported that by decreasing rainfall impact energy by 89%, without reducing rainfall amount, interrill soil loosen were decreased by 90% or more. Even though soil detachment by raindrop impact is the primary factor controlling interrill erosion, the amount of soil splash does not necessarily correlate with interrill soil erosion (Bradford and Huang, 1993).

DinoTorri (1996) estimated that the splash transport in the field scale is generally considered negligible because the large majority of eroded sediments are transported by overland flow.

Panuska *et al.* (1999) used five rainfall-runoff events for the validation of the AGNPS model. They concluded that sediment yield calculations were highly dependent on the quality of the peak flow calculations of the model. The predicted sediment yield values ranged from a maximum under prediction of 60% to a maximum over prediction of 1.4% compared to measured sediment values.



2.9.2. Effect of soil

The Yang (1973) equations estimated sediment concentrations within a factor of 10 of the observed concentrations, if the median soil aggregate diameter was within the range of diameters used by Yang to estimate the equation parameters. When median aggregate sizes were less than 0.15 mm, the lower limit of Yang's calibration range tended to reduce the estimates of sediment concentration.

Moore and Burch (1986) developed theoretical equations for calculating the unit stream power of both sheet and rill flow to predict the sediment transport capacity of such flows. The results suggest that a unique value of critical unit stream power for rill initiation exists that is independent of soil type. For non-cohesive loams or fine sands and finely aggregated clay soils the sediment transport can be accurately predicted from knowledge of the physical characteristics of the soil or bed material alone. For aggregated clay soils this requires information on the aggregate size distribution and the effects of soil particle size differentiation as flow rates and unit stream powers increases with the transition from sheet to rill flow.

Soil hydraulic property information is important for watershed modeling of runoffs, water quality and erosion. The hydrological and soil characterisation data were analysis and suggest that the soil characteristics and moisture difference in areas upstream from watershed outlet are responsible for atleast some of the difference in watershed response to precipitation. Geological conditions in the higher yielding watershed may also be a factor. The results suggest that deterministic and random spatial variability of soil information within soil map units would be necessary for modeling (Bonta, 1997).

2.9.3. Effect of slope on erosion

McCool *et al.* (1993) estimated that the accurate erosion prediction on rainfed cropland of the Northwestern wheat and range region has been severely hampered by lack of suitable slope length and steepness. Relationships derived from data from the humid regions of the United States over-predicted the effects of slope steepness for the steep slopes commonly cultivated in the Pacific North West. Data from more than 2100 slope segments were used to develop new slope length and steepness relationships, which significantly improved erosion prediction in this region. They developed new relationship for LS factor as $LS = (\lambda/22.13)^{0.5} (10.8 \sin \theta + 0.03^\circ)$ where $S < 9\%$ and $LS = (\lambda/22.13)^{0.5} (\sin \theta / \sin 5.143^\circ)^{0.6}$ where $S \geq 9\%$ and found that the new relationship significantly improve erosion prediction in this region.

2.9.4. Effect of land use / land cover

Williams (1975) modified the USLE by replacing the annual rainfall energy factor with the storm runoff factor and suitably amending the equation for its application to large watersheds.

Bennett and Selby (1977) indicated that for a small stream draining 36.2 km² a change in land use from forest to more intensive uses caused a general widening of the channel, with an accompanying increase in the width-to-depth ratio.

Dunne (1979) analysed the sediment yields from 61 Kenyan catchments allows the refinement of regional relationships between the yields and their major controls. Land use, which has been ignored in earlier regional analyses, is the dominant control, but within each land use category it is possible to recognize the effects of the climate and

topographic variables. The long term geologic rate of erosion in these tropical environments were estimated to vary between 20 and 200 t/km/yr, depending mainly upon climate. The analysis of the major sources of sediment in disturbed catchments suggest that rural roads contribute a large and commonly ignored fraction of the sediment leaving agricultural areas. The temporal pattern of sediment transport is also affected by land use, and emphasis the significance of rare wet periods in the removal of soil from tropical catchments.

Suwardjo and Abujamin (1983) estimated that the soil loss could be as high as 200 t/ha in steep vegetable growing areas, where farmers cultivate up and down slope.

Yin and Chen (1989) analysed over 4000 observations on 58 small watersheds with basin area from 0.193 to 329 km². The data, covering the period (1954-1982, including 21 variables. They related erosion intensity to a composite index of basin surface characteristics. The USLE was used by Rachman *et al.* (1991) and Kurnia *et al.* (1991) to calculate sediment yields.

Sinukaban *et al.* (1994) explained that orienting the ridges along the contour and planting vegetable crops with a massive canopy, such as potato, could reduce soil loss to the acceptable limit (25 t/ha/yr). Suganda *et al.* (1994) reported similar results but they included the alley cropping treatment in vegetable growing areas.

Digital classification techniques through stratification approach, with limited ground truth, could be used for mapping broad categories of forests and their density classes with areal extent and location (Sudhakar *et al.*, 1994).

Turner (1995) stated that the land use or land-cover change is critically linked to the intersection of natural and human influences on environmental change. The changes in the state of the biosphere and bio-geochemical cycles are driven by heterogeneous changes in land use and continuation of those uses.

Murtalaksono and Nugroho (1996) used the USLE to predict soil loss and recommended soil conservation measures in the 130,000 ha upper solo sub-watershed.

Wolfgang *et al.* (1996) quantified the increase in soil erosion and sediment yield within the overall Alpine basin of the Austrian Danube. The USLE is used to calculate soil erosion rates and by applying an adapted sediment delivery ratio, the sediment yields for the sub-catchments of the major basins were estimated. The increasing trend of sediment yield was explained by change in land use as well as agricultural management practices, especially the expansion of areas of maize cultivation, often onto the steep hill slopes of the sub-Alpine regions.

RUSLE is an erosion model designed to predict the long time average annual soil loss carried by runoff from specified field slopes in specified cropping and management systems as well as rangeland (Renard *et al.*, 1997).

2.9.5. Effect of crop on soil loss

Suresh *et al.* (2000) evaluated the soil loss potential of various orchard's activities in the Nauvar watershed of Kumaon hills on steeply sloping lands. The linear relationship between soil and land slope was developed to see the behaviour of orchard lands for generating soil loss at different land slopes in the watershed. They found that mango, to be the lowest soil loss generating fruit species whereas the Citrus and Banana were found

to be the highest. The orchards located on steep slopes (35 to 50% slope) at 1200 to 1800 m elevation, the Apricot appeared as the lowest soil loss generating fruit species.

2.9.6. Movement of sediment

Meyer and Wischmeier (1969) describe a steady state model that segments a slope into a finite number of increments and for each increment compute detachment capacity and transport capacity of rainfall and detachment and transport capacity of runoff. Depending upon whether load transport capacity is greater than or less than the sediment available for transport, the model either routes all the sediment available, in one increment to the next down slope increment or routes it to the next increment at transport capacity. This model shows considerable promise as a basis for development into a general upland erosion algorithm.

Sediment load is the result of the balance between sediment intake into the flow and sedimentation (Raudkivi, 1976). He explained that the grain and flow characteristics determine both the amount of sediment load and the way in which sediment is transported.

Moss (1982) examined the break up of shallow overload flow into small channels or micro-rills. They found that, in addition to the main flow path down slope, secondary flow paths developed with a lateral component where these converged, the increase in discharge intensified particle movement and small channels or trenches were cut by scouring. Since rain drop impact increase the transport capacity of the flow and, through the detachment of soil particles, increases the sediment concentration.

A positive relationship will exist between water discharge and the magnitude of the coarse fraction or the median particle size, because the increased shear velocities associated with increased flows will permit the transport of larger particles (Horowitz, 1985).

Factors influencing the sediment movement are the particle size distribution, the form and weight of the particles, the cohesion between particles, the arrangements of particles within the channel, the geometry of the channel, the turbulence of flow, the discharge volume as well as plant and root growth (Anderson, 1998).

2.10. Geographic Information System (GIS)

Geographic Information systems are computer based systems, designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis. GIS technology, integrates common database operations such as query and statistical analysis with the unique visualization and geographical analysis benefits offered by maps (Aronoff, 1989).

Burrough and Frank (1995) noted that there is a large gap between the way that spatial and temporal phenomena can be perceived and modeled on the conceptual foundation of current commercial GIS.

Bennett (1997) stated that GIS offers a virtual environment within which decision makers and scientists can explore theory and evaluate competing management strategies.

GIS does not only serve a database for parameter data. Qualitative and quantitative data can be integrated through spatial relationships rather than through relationships between attributes that may not exist (Frost *et al.*, 1997).

Distributed models can take advantage of the implicit topology of geographic entities in the vector model or can consider the effect of surrounding cells in a raster-based model (Kiremidjian, 1997).

2.11. Application of GIS tool on watershed modeling

Foster *et al.* (1985) described that with the increasing capabilities of computers, many researchers have been able to study the complex systems involved in erosion and sediment yield. Researchers from many locations have developed erosion models for general and specialized watershed conditions.

Hopkins and Clausen (1985) used computerized geographical overlays of weekly land use data, classifications of soil hydrological groups and the area within 63 m of a drainage network to determine 'runoff and erosion production zones' and identify changes in water quality from agricultural land use and Best Management Practices.

Graetz *et al.* (1986) suggested that GIS procedures have been used to evaluate management practices for grazing lands. By tracking grazing type and intensity over time and collecting data on vegetation condition and weather data, grazing practices can be assessed and improved.

Gilliland and Potter (1987) used a GIS to produce three-dimensional maps of runoff potential, sediment transport, and bacterial pollution potential. They noted that the GIS had the advantage of retaining the geographical character of information on pollution potential and conveying, in three-dimensional graphical terms, the effects of topography, soil type, land use and management practices.

Simard *et al.* (1988) discussed the automated generation of elevation data from SPOT satellite imagery and the DTM data are mostly provided in a grid format in which an elevation value is stored for each of a set of regularly spaced ground positions.

Hession *et al.* (1989) linked the AGNPS event based Agricultural Non point source model with the Geographic Information System (GIS) ARC / INFO and simulated effects of several best management practices assuming average input values. Linkage of the AGNPS model to a GIS was also presented by Tim *et al.* (1995) and emphasis was on data handling and automation of the modeling process rather than model validation.

Feezor *et al.* (1989), Vieux *et al.* (1996) and Panuska *et al.* (1999) investigated the effects of grid size selection through a sensitivity analysis of inputs. The study area was discretized using different grid sizes, and the effects on hydrology, sediment, and nutrient components were analysed. Model grid size was found to be the most important factor affecting sediment yield calculations.

Mrutyunjaya Rao *et al.* (1991) studied the soil erosion of Jolapur Reservoir catchment with multi-disciplinary approach comprising remote sensing, Geological, Geomorphical, Geotechnical and hydro meteorological techniques. Various erosional zones are identified by superimposing the thematic maps of rainfall, slope, land use / land cover and soils. They have also been identified by studying the morphometric parameters of the 5th order streams in the same area and priority zones of soil conservation are delineated by superimposing the resulted maps.

The Geographic Information Systems can be used to reduce data collection demands by extracting valuable information from existing databases. One important application is in estimating slope steepness, which is a critical factor in estimating soil loss movement. Srinivasan and Engel (1991) used four algorithm/techniques namely, (1) Neighbourhood method, (2) Quadratic surface method, (3) Maximum slope method and

(4) Best fit plane method to predict slope from elevation data sets for each grid cells and then compared with the site observations. They found that in the flat areas, the differences was negligible between observed and neighbourhood method estimates. In the steep areas, there was a more significant difference in average slope values between the observed and neighbourhood method. Of the method tested, the neighbourhood method mostly closely approximates observed slope values.

Chakraborti (1993) explained that the decision support system for watershed management planning requires scientific knowledge of resources information, expected runoff and sediment yield, priority classification of watersheds for planning. The GIS techniques are now-a-days used for database creation, scenario development and appropriate decision making.

Subba Rao and Karale (1993) integrated wide range of variables associated with prioritisation of watersheds by application of geographic information system. The modeling capability enables planning decisions on sedimentation control measures in the catchment areas. It also allows testing of the option and evaluation.

Shyan *et al.* (1994) developed a system of extracting the channel network directly from a grid Digital Elevation Model. They applied this technique to rainfall runoff modeling in a watershed. The pits were removed and the DEM data is smoothed out. The drainage direction and the value of accumulated flow of each grid point are calculated. Unconnected flow paths are linked after searching the outflow points at the margin of sub basins. This system generates an ordered channel network together with over land flow paths and the range of the drainage basin.

Geographic Information System have been successfully integrated with distributed parameter, single event, water quality model such as AGNPS. These linkages proved to be an effective way to collect, manipulate, visualize and analyse the input and output data of water quality models. However, for continuous – time, basin large scale models, collecting and manipulating the input data are more time consuming and cumbersome due to the method of disaggregation (Srinivasan and Arnold, 1994).

Rosenthal *et al.* (1995) linked GIS and SWAT to predict runoff stream flow for the Lower Colorado River basin of Texas. With no calibration, simulated monthly stream flow volume was under estimated for the extreme events, but the relationship was significant ($R^2 = 0.75$) and they suggested that this system is enough to be applicable to other river systems.

Adhinarayana and Ramakrishna (1996) described a methodology to compile agricultural land use map of a hilly watershed using Geographic Information Systems. They used multi seasonal and multi sensor remotely-sensed data for mapping a land use pattern of the watershed.

Schmann and Roland (1996) described the utilisation of GIS for the parameterization of three process-oriented physically-based hydrological model components. The heterogeneity of soil and vegetation in a catchment can be expressed with distribution functions of soil storage capacities. The two-dimensional impulse response function describes the concentration of runoff in river. The model components and their parameterization by GIS were successfully applied to seven catchments with an area between 18 and 576 sq.km.

A geographic information system in hydrological modeling is presented for topographic modeling of a river basin, and it is combined with a distributed rainfall runoff simulation system. Water movement represented by combined surface-sub surface kinematic wave equations considering a change of slope gradient and slope width, and discharges from distributed slope elements are routed to a basin outlet through a channel network (Tachikawa *et al.*, 1996).

Mitchell (1997) used AGNPS / GIS system to compare simulated and measured values for 50 rainfall-runoff events. The deviations between the arithmetic mean of measured and simulated values were 6.3 mm for runoff volume, 0.09 m³/s for peak flow rate, and 1.65 t for sediment yield.

Grunwald and Norton (1999) investigated the effects of grid size selection through a sensitivity analysis of inputs. The study areas were discretised using different grid sizes, and the effects on hydrology, sediment, and nutrient components were analysed. Model grid size was found to be the most important factor affecting sediment yield calculations.

Fisher *et al.* (1997) analysed the sensitivity of two distributed non-point source pollution models (AGNPS and ANSWERS) to the spatial arrangement of the landscape. The sediment yield and nutrient outputs values of the AGNPS model inhibited little or no sensitivity to the spatial distribution of the most input data. Only infiltration related inputs produced variations in the model outputs.

A geographic-based hydrologic and sediment transport model was embedded into a raster based GIS by Mashriqui and Cruise (1997). They also concluded that GIS was used as a link between cartographic data and model parameters. Techniques used in this

study provided an efficient way of estimating the effects of spatial variation of slope, soil type, and land use of a watershed on the runoff and sediment yield.

Jain and Soni (1998) applied TOPMODEL in a catchment in Western Ghats to determine streamflow by inputting DEM of the study basin to ILWIS. The pixel size chosen for the DEM was 300 m. TOPMODEL is a simple but physical hydrological model that aims to represent the effects of catchment heterogeneity and particularly, topography on the dynamics of hydrological response. They estimated the encouraging simulation results with model efficiency of more than 0.84 for both model calibration and validation

Floras and Sgouras (1999) processed the satellite image to identify, map and classify the land cover types and areas of intense erosion. The geoinformation products from principal component analysis, digital elevation model and Gaussian maximum likelihood classifier could be used by the local decision makers at local and regional levels in planning sustainable land management and sustainable development.

The hydrologic model SWAT was used for simulate flows, sediment on a 9000 km² watershed in central Texas. The model is a continuous, daily time step model that predicts surface runoff, percolation, lateral subsurface flow, groundwater flow, transmission losses and flood routing. Sub-watersheds demonstrating areas of highest per acre flows were identified from model output. The correlation coefficient between observed and simulated streamflow was 0.83, while the Nash Sutcliffe was 0.57 indicating the model is a better predictor than using the mean. The results demonstrated that a hydrologic model and available spatial databases can be aid in locating sites. (Rosenthal and Hoffman, 1999)

Yitayew *et al.* (1999) combined (ARC/INFO) with soil loss models (RUSLE) and found that the soil loss estimation was enhanced. Spatial data from different sources provided input for GIS based procedures in computing the combined slope length and steepness factor in RUSLE for determining soil erosion estimates. Results indicated that GIS based RUSLE provided soil erosion estimates are less than the observed/measured sediment yield on most years. Application of a sediment delivery ratio, which varies with watershed area, is addressed as possible explanation for the differences in estimated erosion and measured sediment yield. They interpreted that GIS can be used with RUSLE to get a good estimate of soil erosion. The results show the need for more work in using GIS and RUSLE for soil erosion estimation.

2.12. MODEL TESTING AND EVALUATION

The literature relating to the optimisation of model parameters, calibration and validation of the model, the different model evaluation criteria used and the performance evaluation of different hydrologic models are presented in this section.

2.12.1. Model Parameter Optimisation

Naylor *et al.* (1966) have treated the terms ‘validation’ and ‘verification’ as synonyms while Dent and Blackie (1979) have considered verification as a process whereby the computer programme of the model is checked for logical consistency and validation as the process whereby the model is checked for representativeness of the real system. Verification is the process of ensuring that a model behaves as the modeler intends it to and validation is the testing for agreement between model-behaviour and real system behaviour.

Dent and Blackie (1979) argue that as the modeler wishes to establish the sameness of model output as the historical record, there is probability of committing a Type II error (the error of accepting that these are the same, when in fact, they are not). They have advised that the probability of a Type II error can be reduced by increasing the chance of a Type I error (by increasing the confidence limits of outputs).

A long term objective associated with the developments of process models is concerned with using them to estimate flows at ungauged sites (McMahon, 1979).

Jha *et al.* (1983) used Rosenbrock's optimisation technique, to determine optimised parameter set for the conceptual model. The objective function used in automatic optimisation was minimisation of the sum of squares of the difference between observed and estimated runoff, as

$$MinF = \sum_{i=1}^N [R_{obs,i} - R_{est,i}]^2$$

2.12.2. Model Calibration

Wagner and Linsley (1975) who have applied SWM IV to the Wagli catchment in Rajasthan, opine that as the end result of a hydrologic analysis is to produce frequency curves of runoff volume and peak flows, calibration of the model shall not be aimed to reproduce exactly every peak flow or every runoff volume in the time interval.

Anderson *et al.* (1978) observed that the model, calibrated with 0.1 hour interval, when run with 0.25 hour interval predicted significantly less runoff.

Determination of appropriate values for the model parameters, which are fixed characteristics of the catchment, is called calibration of the model for a given catchment (Morris, 1981). If we have a model, which is designed as deterministic and physically grounded, and if all parameters are accurate, the output calculated by the model should also be accurate. The concept fails however, in practice because the input data, estimated parameter values and numerical methods of calculation are not accurate enough. Hence in practical applications it is often necessary to calibrate the model, which means that the output hydrographs calculated by the model are compared with measured hydrographs and in the case of disagreement, the parameters are adjusted (Niemczynowicz, 1983).

2.12.3. Model Validation

A model is scientifically valid if its assumptions conform to basic scientific principles. A model can be logically and scientifically valid within itself and yet may fail to be realistic, simply because of the continual impact of factors disregarded in the analysis which may obscure the phenomena of direct interest to us. Without proof of validity, a model, however elegant may be nothing but a tentative exercise in abstract logic. The problem of how to validate a model remains, however, the most critical, difficult and elusive of all problems associated with computer simulation (Hillel, 1977).

Rasmuson and Fluhler (1990) opined that model validation in its rigorous and narrow sense required a model to be run with completely independently determined system parameters, a prerequisite which was rarely met in field case studies.

2.12. 4. Model Evaluation Criteria

Since no model is expected to fit the data exactly, the question is whether the discrepancies are sufficiently small to be tolerable. Also the question is whether the errors are random or systematic. The fit and the forecasting ability of the model may be better for some variables than for others. In a dynamic model, the errors may oscillate and die-down or may progressively accumulate worsening the forecast (Hillel, 1977).

Cunningham and Sinclair (1979) used the following evaluation criteria, in their groundwater model:

$$\text{Sensitivity Index, } S = \frac{1}{N} \left(\sum \frac{|O_i - P_i|}{O_i} \right) 100, \quad i = 1 \dots n$$

$$\chi^2 \text{ - square test: } \chi^2 = \sum \frac{(O_i - P_i)^2}{P_i}, \quad i = 1 \dots n$$

O and P from same population.

Jain and Singh (1986) used the following method to compute model efficiency.

$$E = \frac{F_0 - F_1}{F_0}$$

$$F_0 = \sum (Q_{\text{obs},i} - Q_{\text{obs,avg}})^2, \quad i = 1 \dots n$$

$$F_1 = \sum (Q_{\text{obs},i} - Q_{\text{est},i})^2, \quad i = 1 \dots n$$

A model should be assumed suspect until it is proven correct. A standardised model evaluation protocol, though not absent, is really necessary to catalog model performance for different models and applications (Loague and Green, 1990).

ASCE (1993) discusses the need to evaluate the usefulness of watershed models and to evolve standards or criteria to compare the performances of the models. For continuous models, 1. Deviation of runoff volumes (Dv); 2. Nash-Sutcliffe coefficient (R^2) and 3. Coefficient of gain from daily mean (DG) have been recommended as simple evaluation criteria.

2.13. Performance of Watershed Models

Viessman *et al.* (1970) studied error distribution in their runoff model and reported that the absolute average error was 9% and the average error in peak discharge prediction was 13.8%. About 80% of the computed peak outflows differed from the gauged peak flows by less than 20% while about 75% of the computed peak flows were in error by less than 15%. Errors of this magnitude were considered to be reasonable. Wagner and Linsley (1975) applied SWM IV to Wagli catchment in India and observed that the error between simulated and observed flow varied from – 76% to + 35%.

2.14. MODELING LIMITATIONS

There is controversy over the degree to which the transformation of rainfall to flood flow in a natural drainage basin, with its complicated geometry and soil conditions, can be understood in a deterministic way. Some hydrologists feel that present knowledge is too small to let us analyze the transformation deterministically, and that we must resort to stochastic methods. Others are more confident, recognizing that the relations are non-linear and temporally variant, though the relations are seldom simple (Miller, 1977).

A mathematical model of a given system is designed to simulate the response of the system to specified inputs. But the range and complexity of hydrologic processes in a

watershed are such that, at the present stage of hydrologic science, it is difficult to simulate all of them with adequate precision (Sachan and Srivastava, 1988). It necessitates simplifications and assumptions, of varying degree, which preclude their universal use.

The forecasting of rainfall induced floods is one of the most complex problems of hydrology. As it is a formidable task to account for the physical processes involved in runoff generation, the development of practical methodology of flood forecasting in an objective manner remains an unsolved problem (Adhikari and Ravishankar, 1983).

Bhargava *et al.* (1986), in case of flood estimation for Lakhwar dam, narrated that deficient and inaccurate hydrologic data more often gave problems to engineers in India while deciding the basic design parameters of dams, spillways and appurtenant structures. The application of appropriate methodology was a difficult task as each one approached the output through specific nature of processes and input data.

Pilgrim *et al.* (1978) studied surface and subsurface runoff processes under natural and artificial rains and reported that the dynamics and spatial variabilities of these two runoff processes was so great that a truly deterministic model would be difficult to develop even on small study plots.

“We should not abandon the task of seeking to understand as much about these systems as we possibly can. We can have no hope of understanding determinate heterogeneous systems unless we first understand homogeneous ones, and to take this further, we shall have no hope of understanding stochastic heterogeneous systems without first understanding determinate ones” (Philip, 1980).

Materials and Methods

CHAPTER - III

MATERIALS AND METHODS

The details of the study area, methods of preparation of thematic maps, use of GIS technology for integration of maps and data, statistical analysis and the development of erosion model employed for the present investigation are presented in this chapter. The work was carried out in two phases. In the first phase resource mapping was carried out during 1999-2000 and in the second phase computer based erosion modeling was performed during 2000-2001.

3.1. Methods of Modeling

The model development procedure recommended by Hillel (1977) is adopted for developing the erosion model. The various steps of the model development are:

- i. Examine the system's behaviour
- ii. Define the problem requiring simulation
- iii. Formulate the mathematical model
- iv. Develop the necessary algorithm
- v. Check the algorithm
- vi. Write the program for computer model
- vii. Estimate the parameters
- viii. Check the program for its sufficiency
- ix. Check the parameters for its usefulness
- x. Check the simulation experiments
- xi. Check the results of simulation
- xii. Compare the prediction with the actual
- xiii. Accept the simulation model

The flow chart depicting the different steps of model development and the decision cells is given in Fig. 3.1.

3.2. Modeling framework

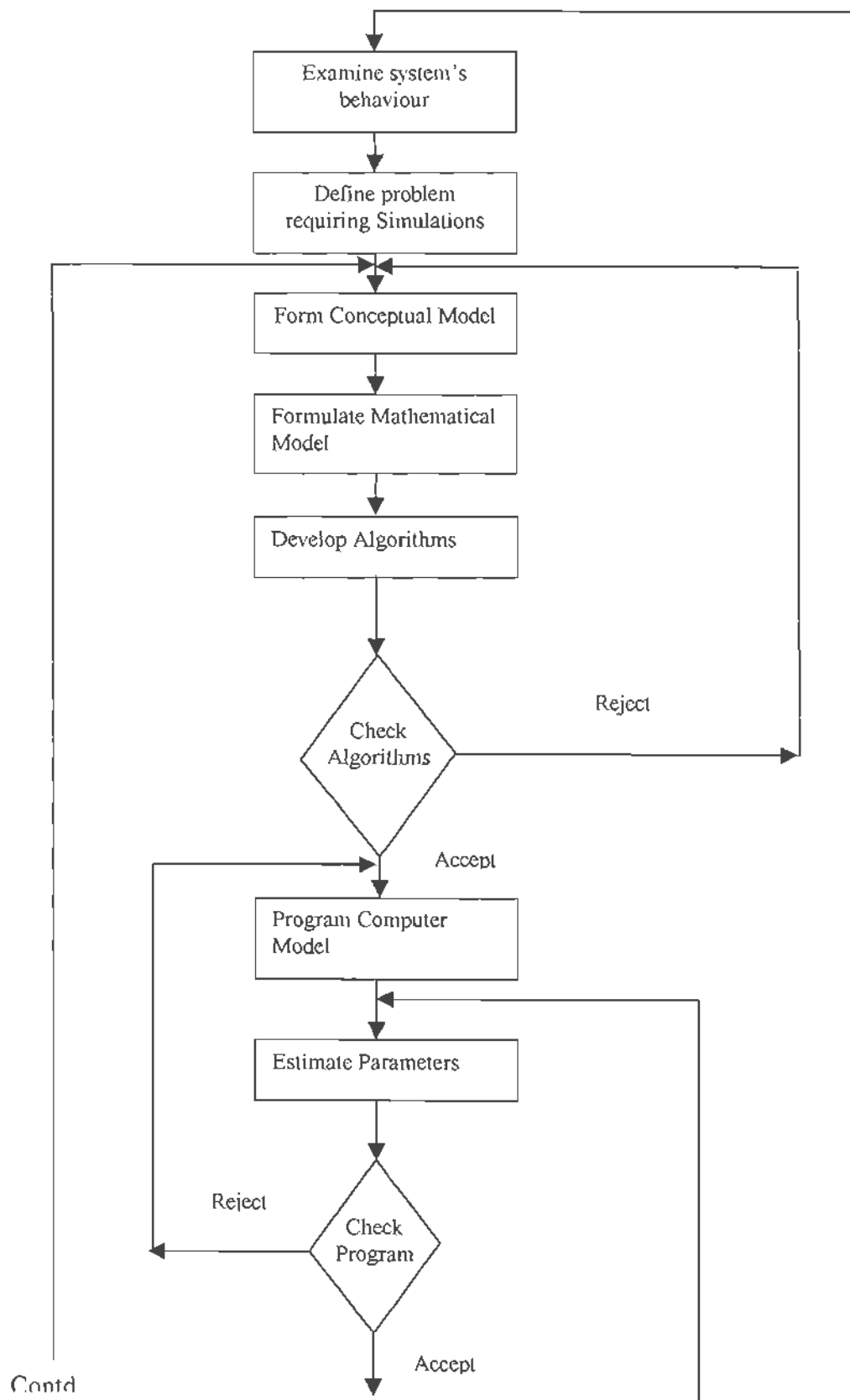
Anderson et al (1978) used a number of specific objectives, as guidelines in the development of hydrologic model. These are:

- a. The model should use accepted theories concerning the hydrologic processes when these theories are known and when they could be made compatible with other modeling objectives. Also wherever possible, the model should use measurable physical parameters for which values could be determined or predicted for a watershed.
- b. The model should require only data that would generally be available for any watershed being considered.
- c. The model should be capable of predicting surface runoff and soil erosion.
- d. The model should be adaptable to modification for the addition of water quality data in the future.
- e. The model should not require an unreasonable amount of computer time and storage. It should be easily revised to change any component, without major revision of the entire model.

3.3. Model Components

The Distributed Sediment Yield Model (DSYM) developed under this study considers the following:

- i. Watershed physiography
- ii. Climate and rainfall
- iii. Interception
- iv. Surface detention



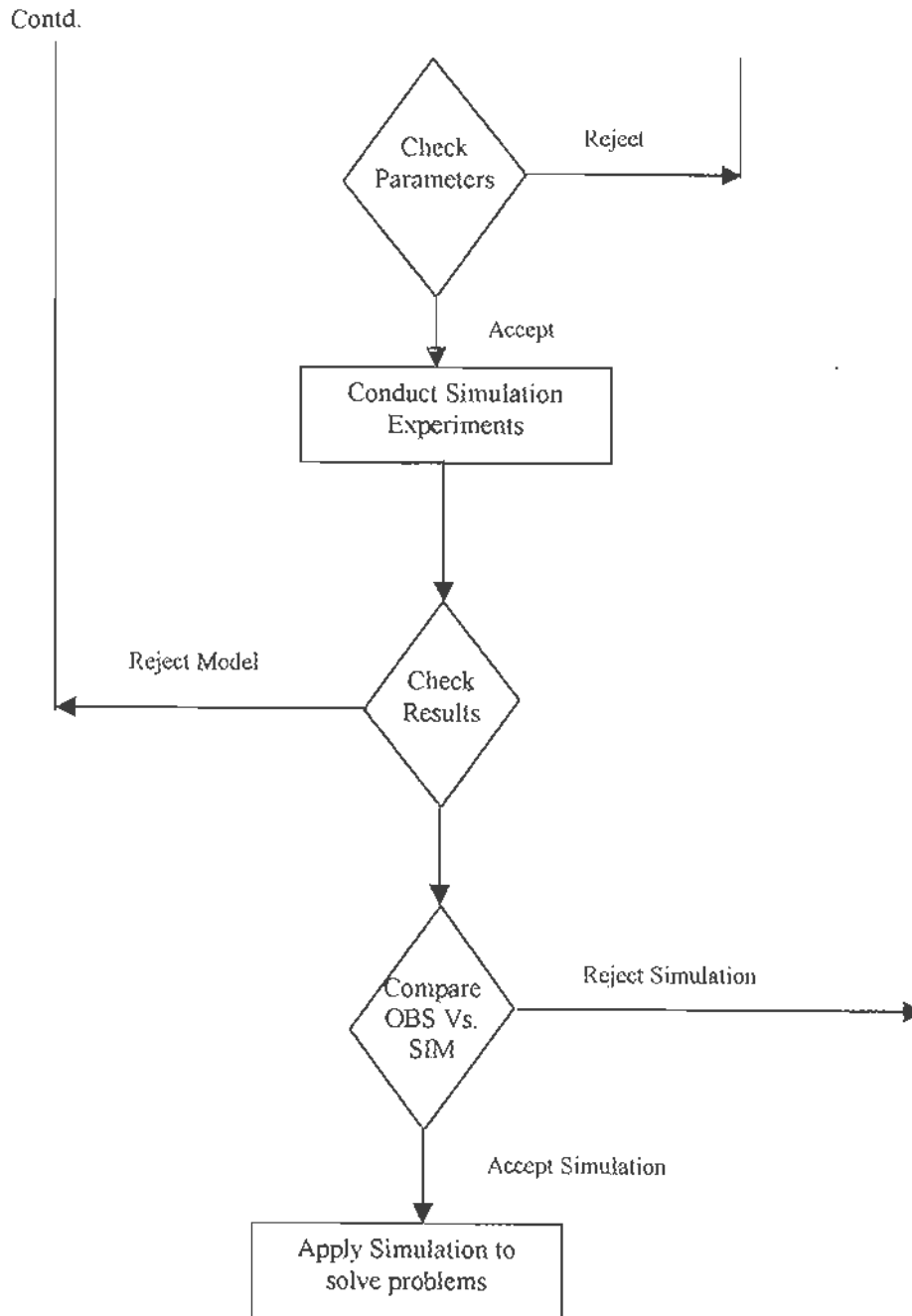


Fig. 3.1. Flow Chart for Model Building Procedure

- v. Base flow
- vi. Overland flow
- vii. Channel flow, and
- viii. Erosion by Water

3.4. Details of the Study Area

The study was conducted in two of the watersheds namely Ebbanad and Katteri of Lower Bhavani Sub-Catchment in Nilgiris district, Tamil Nadu. The location map is presented in Fig. 3.2.

3.4.1 Ebbanad Watershed

Ebbanad watershed in Nilgiris district has been taken up for calibrating the model. The Ebbanad watershed in the Nilgiris hills is a part of the Moyar Catchment of the Bhavani river sub-basin and coded as Bh3c. The watershed starts from the Dodabetta peak near Udthagamandalam town and ends at about 14 kms near the Silt Monitoring Station of Ebbanad.

The watershed area is located between the Dodabetta peak and the Bikkapattimaund reserve forest ranges at an average altitude of 2064 m above msl. It lies between $11^{\circ} 24' N$ and $11^{\circ} 29' N$ latitudes and between $76^{\circ} 40' E$ and $76^{\circ} 50' E$ longitudes covering an area of 3917 ha. It includes Thuneri, Thummanatti, Ebbanad and Kagguchi villages and part of Ooty rural. The watershed is of fern leaf shape. The slope of the watershed ranges from 25-55 per cent. The watershed receives mean annual rainfall of 1000 mm and the annual maximum and minimum temperature are $20^{\circ}C$ and $4^{\circ}C$ respectively.

The watershed covers parts of Dodabetta and Jakuntha reserve forests in the south, parts of Kagguchichiyada hills ranges in the North, parts of Dodabetta reserve

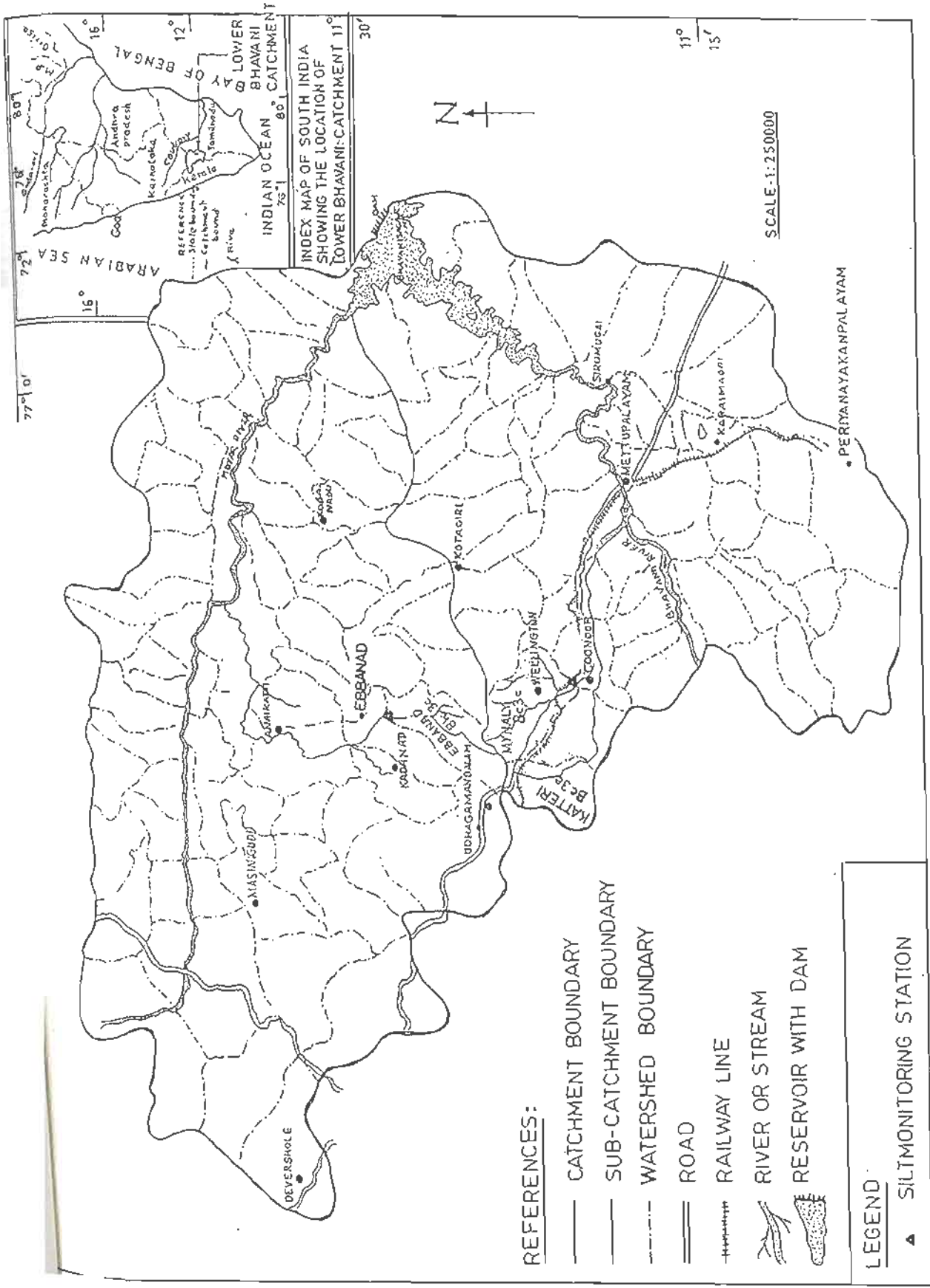


Fig. 3.2. Location map of Ebbanad and Katteri Watersheds in Lower Bhavani Sub-Catchment

forest in the West and Hokkalbetta and Ukkundubetta in the East. The Ebbanad stream, which originates from the Dodabetta hills flows through a deep valley.

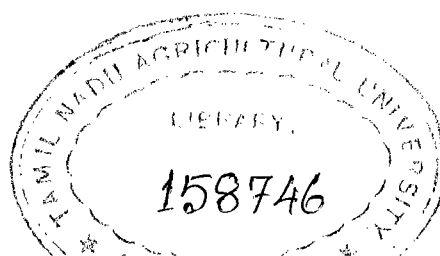
3.4.2. Katteri Watershed

The Katteri watershed near Coonoor in Nilgiris district has been taken up for validating the model. The Katteri watershed is located in Lower Bhavani sub-catchment at about 10 km from Coonoor, at the threshold of the Udthagamandalam town on the Southern boundary and coded as Bc3e. In the geographical map its latitude being $11^{\circ}20' N$ to $11^{\circ}25' N$ and longitude is $76^{\circ}41' E$ to $76^{\circ}44' E$ and covering an area of 2911 ha. The maximum elevation of the watershed is about 2053 m above msl. It includes Ketti and Adigaratty villages. The mean annual rainfall of the watershed is 971 mm and mean maximum and minimum temperature are $28.7^{\circ}C$ and $4.8^{\circ}C$ respectively.

This watershed drains the water to the two reservoirs built across the Katteri river. These Kattery reservoirs constructed across the Kattery river at the drainage point is being silted up heavily.

These watersheds are selected for automatic hydrologic observations under the Indo-German Bilateral Project and the following instruments are made available at the watershed monitoring station.

1. Computerised automatic rain gauge
2. Computerised automatic water-level recorder.
3. Computerised anemometer
4. Data logger
5. Solar panel with accessories.



3.5. Model Development

3.5.1. Spatial Variability of Rainfall

Rainfall varies greatly in both time and space. The variability can be visualized by analyzing rainfall records of different gauging stations. Rainfall varies during the rainfall event, from one event to another and from one time period to another (Singh, 1992). The spatial variation in rainfall is caused by spatial differences in rainfall setting due to heterogeneity in cloud cell distribution (Eagleson, 1970) and by topographic differences in the basin.

The spatial variability of rainfall or the reliability of rainfall measured at one gauge in representing the average depth over the area is a function of the following: (Viessman et al., 1989)

- i. The distance from the gauge to the center of the representative area
- ii. The size of the area
- iii. The topography
- iv. The nature of the rainfall
- v. The storm pattern characteristics
- vi. The time period over which the average is calculated.

Availability of more raingauges in the area of interest may reduce the uncertainty associated with the estimate of areal average. The methods of estimating mean areal rainfall from more gauges, reported in hydrologic literature include the arithmetic mean, the weighted mean, the theissen polygon method, the individual area-altitude weighted mean, the triangular weighted mean, the Myer's method, the isohyetal method, the trend analysis, the reciprocal distance squared method, the two-axis method, the double fourier

series method, the modified polygon method, the finite element method, the analysis of variance and the kriging method.

The raingauge density is much low in India and there is every likelihood that the watershed considered for modeling may not have a raingauge at all and in that case gauge readings from out side the watershed need to be used. Even if there is one in the watershed, that reading needs to be adjusted for spatial variability.

Viessman et al. (1989) generalized that the more central the gauge location, the more closely its observations would match the average for a representative area.

Considering the listed literature this model is used with Thiessen polygon method to distribute the spatial variability of rainfall with the available raingauges inside the selected watershed.

3.5.2. Initial Abstraction

The initial abstraction (I_a) consists mainly of interception, infiltration, and surface storage, all of which occur before runoff begins. Jain et al. (1996) estimated the empirical relations suit for Indian conditions, which are used in the model development.

For all other regions,

$$I_a = 0.3S \quad \text{-----3.1}$$

where,

$$S = 254 \left(\frac{100}{CN} - 1 \right) \quad \text{-----3.2}$$

S = Soil Water Retention, mm

CN III for AMC III was calculated by using the following equation,

$$CN_{III} = CN_{II} \exp[0.00673(100 - CN_{II})] \quad \text{-----3.3}$$

And CN II was adjusted for the slopes greater than 5 per cent by,

$$CNII_s = \frac{1}{3}(CNIII - CNII)[1 - 2 \exp(-13.86SL)] + CNII \quad \text{----- 3.4}$$

where,

SL = Slope of the watershed, m/m

“S” is mainly the infiltration occurring after runoff begins. This later infiltration is controlled by the rate of infiltration at the soil surface or by the rate of transmission in the soil profile or by the water-storage capacity of the profile, whichever is the limiting factor. A succession of storms, such as once a day for a week, reduces the magnitude of S each day because the limiting factor does not have the opportunity to completely recover its rate or capacity through evapo transpiration, or drainage. But there is enough recovery, depending on the soil-cover complex, to limit the reduction.

During such a storm period, the magnitude of S remains virtually the same after the second or third day even if the rains are large so that there is, from a practical view point, a lower limit to S for a given soil-cover complex. Similarly, there is a practical upper limit to S, again depending on the soil-cover complex, beyond which the recovery cannot take S unless the complex is altered.

In the SCS method, the change in S is based on an antecedent moisture condition (AMC). With the available three levels of AMC, the average AMC (AMC-II) is used in this model.

3.5.3. Base flow

The replenishment of groundwater storage is through percolation from second layer. The actual groundwater storage and the areal distribution of storage are not exactly known for sure. Measured stream flow is filtered for base flow using a method described by Chow (1964).

3.5.4. Overland flow

Chow (1964) explains that the runoff may consist of surface, subsurface and groundwater runoff. The surface runoff is that part of the runoff which travels over the ground surface and through channels to reach the basin outlet. The part of the surface runoff that flows over the land surface towards stream channels is called overland flow.

As the heterogeneities in the watershed are multidimensional, not permitting accurate mathematical reproduction, the mechanics of overland flow still remains an elusive subject for rigorous adoption from practical and conceptual point of view (Rose, 1988).

In developing relationship for surface runoff the SCS derived the expression,

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \text{-----3.5}$$

where ,

I_a is substituted from the Equation 3.1

P = Daily precipitation, mm

Surface runoff volume is estimated by using a modification of Soil Conservation Service (SCS) Curve Number technique (SCS-USDA, 1972). The technique is selected for estimating surface runoff in this model because a) it is reliable and has been used for many years throughout the world, b) it is computationally efficient, c) the required inputs are generally available, and d) it relates runoff to soil type, land use and management practices. The use of readily available daily runoff data is particularly important attribute of the curve number technique because of many locations. Rainfall variability and runoff computations are most efficient for data taken daily at shorter intervals.

Overland flow is represented by SCS-CN technique in the following simulation models: CREAMS, SWRRB, EPIC, AGNPS and SWAT. Hence the overflow is considered to be represented by SCS-CN method in this model.

3.5.5. Peak Runoff Rate

Peak runoff rate is based on a modification of the rational formula. The time of concentration is estimated by considering both the surface and channel flow times. Channel flow length, channel slope, surface slope length and surface slope are the contributing factor to find out peak flow rate.

The peak runoff rate is estimated by,

$$q_p = \frac{\alpha QA}{360t_c} \quad \text{-----3.6}$$

where

q_p = Peak runoff rate, m³/s

α = Dimensionless parameter, $\left[\frac{t_c}{24} < \alpha < 1 \right]$

Q = Amount of runoff computed from the model

A = Drainage Area, ha

t_c = Time of concentration, hr

Channel time of concentration is calculated by,

$$t_{cc} = \frac{1.1Ln^{0.75}}{A^{0.125} \sigma^{0.375}} \quad \text{----- 3.7}$$

where,

L = Channel Length, km

n = Mannings coefficient

A = Drainage area, ha

σ = Average channel Slope, m/m

The surface time of concentration is calculated from,

$$t_{cs} = \frac{(\lambda n)^{0.6}}{18S^{0.3}} \quad \text{-----3.8}$$

where,

λ = Surface slope length, m

S = Land slope, m/m

3.5.6. Sediment Yield

Soil detachment, transport and deposition are closely related to the concurrent hydrologic processes occurring in a watershed. Detachment and transport can be accomplished by either raindrop impact or overland flow. However, the small amount of sediment transported from a field by raindrop impact was neglected.

Sediment yield from watersheds can be predicted by applying a delivery ratio to the gross soil loss, estimated with USLE. Williams (1975) modified the USLE by replacing the annual rainfall energy factor of the equation with the storm runoff factor,

and with it also eliminated the need for application of delivery ratio and the Modified USLE is given as,

$$Y = 11.8 (Q * q_p)^m KLSCP \quad \text{-----3.9}$$

Where,

Y = Sediment Yield, tons per storm

Q = Runoff volume, m³

q_p = Peak Runoff Rate, m³/s

m = Exponent

K = Soil Erodibility factor

LS = Topographic factor

C = Crop Management factor

P = Conservation Practice factor

The factors KLSCP are the same as defined by Wischmeier and Smith (1978) for the Universal Soil Loss Equation.

SWRRB computes the sediment yield using the MUSLE for a single storm. Hence, in this model MUSLE is used to compute the sediment yield for an event.

3.5.7. Sediment Routing Model

For routing the sediment contribution delivered at the outlets of the sub-watersheds on the main river to the watershed outlet, an exponential decay function of travel time and the sediment storage developed by Das and Chauhan (1990) was used. For conceptual models in runoff studies, storage is considered to be directly proportional to outflow (Chow, 1964). Since runoff is the carrier of sediment, it is assumed that

sediment storage (S_s) is also directly proportional to sediment yield rate (Y'). Expressing mathematically,

$$S_s = K_s Y' \quad \text{-----3.10}$$

Where K_s is the sediment storage coefficient, which includes sediment particle settling properties and has units of time.

The continuity equation may be expressed as

$$I' - Y' = dS_s/dt \quad \text{-----3.11}$$

Where I' is the inflow rate of sediment to the river, and t is the time. Substituting the values of S_s from equation. 3.10 in equation 3.11, the equation may be expressed as

$$I' - Y' = K_s (dY'/dt) \quad \text{-----3.12}$$

A derivation of equation 3.12 gives the sediment outflow rate at time t , and is expressed as,

$$Y' = Y'_o e^{-T/K_s} \quad \text{----- 3.13}$$

Where Y'_o is the sediment outflow rate at an upstream section caused by sediment contributions from the sub-watersheds at time t_o , and T is the time of travel ($t - t_o$) of sediment between the two sections in the river. Equation 3.13 can be further be expressed on a volume of sediment basis as

$$Y = Y_o e^{-T/K_s} \quad \text{-----3. 14}$$

where Y is the volume of sediment yield at a particular section of the river, Y_o is the volume of sediment yield at an upstream section, and e^{-T/K_s} is the first order decay

function of travel time and sediment storage. To determine the total sediment yield at the watershed outlet, an equation can therefore be derived as the summation of contributions from each sub-watersheds represented by equation 3.14. Thus the sediment routing equation for the whole watershed can be expressed as

$$Sy = \sum_{i=1}^n Y_i e^{-T_i/Ks} \quad \text{-----3.15}$$

where Sy is the total sediment yield (metric tons) of the whole watershed at its outlet, Y_i is the sediment yield contribution from sub-watershed i , determination by MUSLE (Equation 3.9), T_i is the travel time of sediment in the main river between the respective outlets of sub-watershed (i) to the watershed outlet in hours, and n is the number of the sub-watersheds. Equation 3.15 determines the spatial sediment contributions of the watershed, and estimates the total sediment yield from the watershed on storm basis.

In Equation 3.15, travel time T_i as assumed to be equal to the time of concentration between the outlets of the sub-watersheds and Ks and Sy are the two unknown values. To determine Ks on storm basis the relationship obtained is,

$$11.8 (Q * q_p)^m \text{KLSCP} = 11.8 \sum_{i=1}^n (Q_i * q_{pi}) K_i L_i S_i C_i P_i e^{-T_i/Ks} \quad \text{-----3.16}$$

Known values of Q , q_p , Q_i , Q_{pi} and T_i from data were substituted into equation 3.16 and the values was determined. The value of Ks is required to be determined for each storm.

3.6. Preparation of source map

The base maps (1: 50,000) for the selected watersheds were prepared with Survey of India (SOI) toposheets 58 A/11 and 58 A/15. Permanent features like rivers, tanks, streams and settlement areas were shown on the base map. The village boundaries were marked on the overlay with the village maps. The soil map, land use map and soil conservation map were derived using the data collected from the Soil Testing Laboratory and Soil Conservation Office at Ooty and Coonoor.

The contour map was also prepared for the watershed boundary from the SOI toposheets.

3.6.1. GIS for Preparation and Integration of Thematic Maps

Preparation of thematic maps in digital format was done by scanning and digitization of base map, soil map, land use map and soil conservation map. The scanned images were used as a backdrop and digitized using Mapinfo software. The Non-Earth projection was used. The resampling of X and Y co-ordinates were done with reference to the scale of the toposheet. After building polygons, the database was updated with map unit symbols using MS-ACCESS database.

3.6.2. Integration of Thematic map

The digitized Landuse, Soil and Existing Soil Conservation maps were integrated under GIS domain of IDRISI software.

3.7. Input data

3.7.1. Soil Data

Raster image of the soil map was linked with the soil attribute table, which was maintained in MS-ACCESS database. The soil map was reclassified for hydrologic soil group with RECLASS module of IDRISI.

3.7.2. Land use Data

The digitized landuse map was linked with the crop composition in MS-ACCESS table, which contained the information on annual crop, perennial crop, reserve forest, trees, pastures, current fallow and major land settlements.

3.7.3. Landuse – Hydrologic Soil cross tabulation

The information on the land use and hydrologic soil combinations was derived from cross tabulation on IDRISI software, to derive the CN map for the AMC-II. The thematic layers were integrated by using the algorithm as mentioned earlier in the chapter to find the surface runoff.

3.7.4. Weather Data

The daily weather data on rainfall and maximum and minimum temperature were collected from seven different weather stations inside the watersheds namely Ooty, Ebbanad, Thuneri, Thummanatti, Ketti, Coonoor and Adigaratti. These weather stations are evenly distributed over the study area representing the different physiographic and elevation conditions. The location of the weather stations was regionalized using Thiessen polygon analysis in GIS environment of IDRISI and linked with the daily weather data.

3.7.5. Digital Elevation Model (DEM) generation

Scanned images of the contour maps were digitized in the Mapinfo software with Non-Earth projection and contour information on each arc was given. The contour lines were exported to IDRISI and then DEM for the study area was generated in 30 m horizontal resolution by using INTERCON module. From the DEM, slope map was prepared using SLOPE module of IDRISI, which was used to derive slope length and slope steepness maps.

3.7.6. Sub-watershed delineation

The DEM of the watershed was used to divide the sub-watershed areas with WATERSHED module of IDRISI. The area of the sub-watershed was extracted using AREA module.

3.8. Sediment Yield Modeling

Distributed Sediment Yield Model (DSYM) was proposed by using soil, landuse, slope and weather data. The flow chart for DSYM is shown in Fig 3.3. DSYM have three modules for simulating runoff and sediment yield: Peak Runoff Rate module, Sediment Yield module and Sediment Routing module which were developed in Microsoft Visual Basic.

3.8.1. Surface runoff

The algorithm described earlier in this chapter was used for estimation of soil retention parameter. The initial abstraction was estimated for each grid cell of 30 m horizontal resolution of the watershed. By SCS-CN method the surface runoff was estimated for each grid cell. Extract module of IDRISI was used to derive the surface runoff of sub-watershed areas of the selected watershed.

3.8.2. Peak Runoff Rate Module

Peak runoff rate was simulated for each of the sub-watersheds by using the algorithm used in SWRRB and EPIC. The module uses the following input values.

Surface runoff data	— derived from Surface runoff map
Drainage area data	— derived from sub-watershed area map
Channel slope data	— derived from channel slope map
Surface slope length data	— derived from surface slope map
Land surface slope data	— derived from land surface slope map

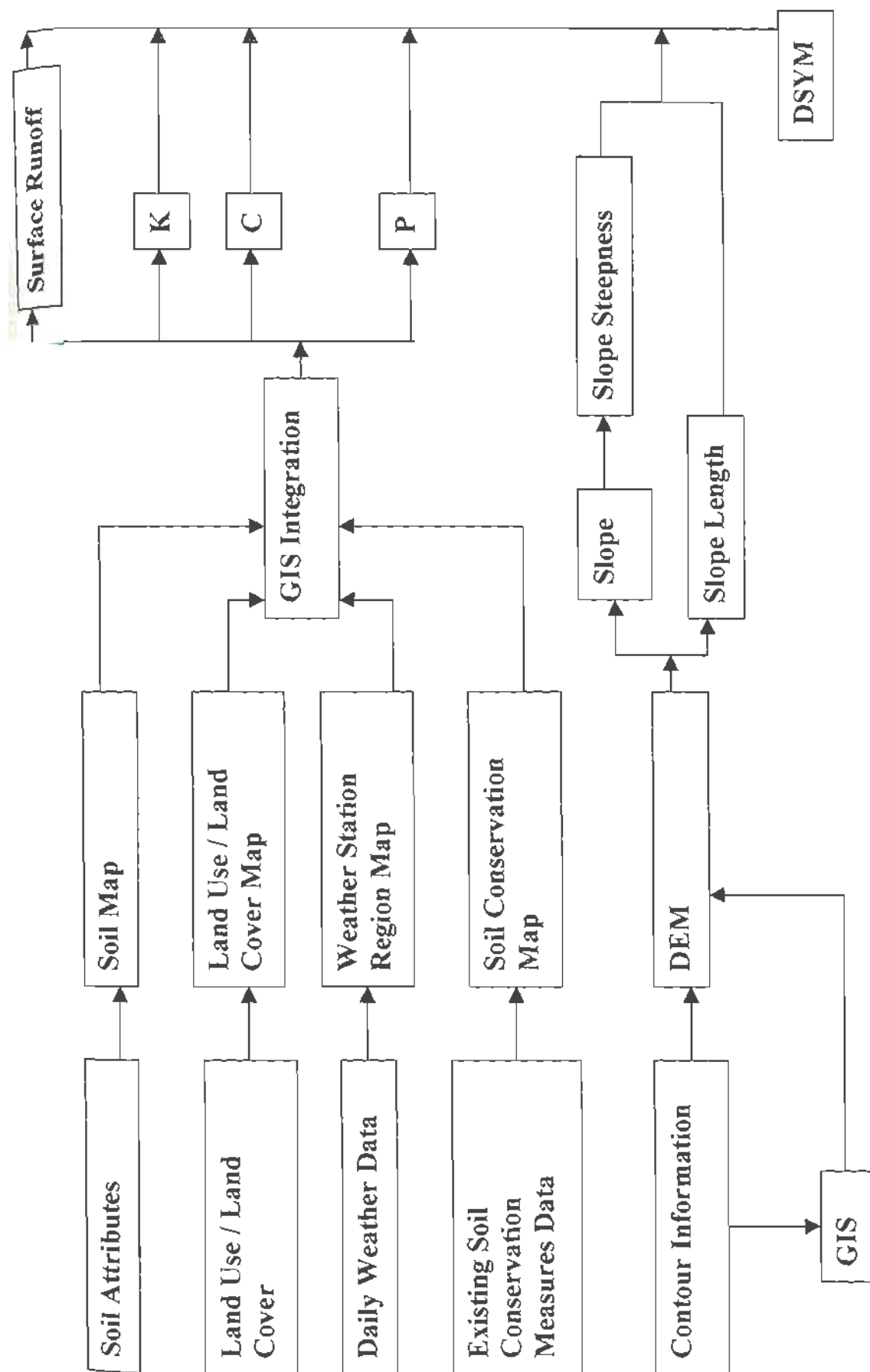


Fig. 3.3. Flow Chart of DSYM

Channel length data — derived from drainage map

One of the tuning parameter (K) of the DSYM was used in this module.

3.8.3. Sediment yield Module

MUSLE was used to compute the sediment yield of each sub-watershed areas.

The module uses the following input values.

Soil erodibility factor data — derived from K map

Topographic factor data — derived from LS map

Crop management factor data — derived from C map

Conservation practice factor data — derived from P map

Peak runoff rate data — derived from Peak Runoff Rate module

Surface runoff data — derived from Surface runoff map

“m” the exponent value of MUSLE was another tuning parameter of this model.

3.8.4. Sediment routing module

The sediment storage coefficient (Ks) was the output of this module, which determines the sediment yield per storm of the watershed outlet.

The model performance was determined using Nash and Sutcliffe, (1970) and Coefficient of Determination (R^2).

Nash and Sutcliffe, (1970)

$$CE = 1 - \frac{\sum (x - y)^2}{\sum (x - \bar{x})^2} \quad \text{-----3.17}$$

Coefficient of Determination (R^2):

$$R^2 = \frac{(N \sum xy - N \sum x \sum y)^2}{(N \sum x^2 - (\sum x)^2)(N \sum y^2 - (\sum y)^2)} \quad \text{----- 3.18}$$

x = Observed Value

y = Predicted Value

\bar{x} = Mean of observed value

Results and Discussion

CHAPTER – IV

RESULTS AND DISCUSSION

The Distributed Sediment Yield Model (DSYM), as it exists now, has undergone many revisions before its finalisation. The results of the finalised version of the DSYM are only presented and discussed.

4.1. Calibration of the model

The results of the DSYM depend on the fixed and variable input values from GIS and on the assumed values of the parameter inputs. The model was developed and applied on a real watershed, viz., Ebbanad watershed of Lower Bhavani Catchment, Nilgiris district.

The objectives of calibration are to estimate the optimum value of the parameters of the watershed for future application of the DSYM. The estimated values of the parameters can be considered optimum only when a simulated output from the model agrees well with the observed output of the watershed.

4.1.1. Inputs from GIS

The boundary of Ebbanad watershed with streamlines is shown in the Fig. 4.1. The total area of the watershed is 3917 ha, with fourth order stream.

4.1.1.1. Landuse map

The landuse and landcover of Ebbanad watershed is shown in Fig. 4.2. Different landuse categories on the study area are: Annual Crops (AC), Perennial Crops (PC), Building (Bldg), Reserve forest (RF), Wasteland (Wl), Trees (Tr), and Current Fallow (CF). Out of the total 3917 ha area, AC and PC cover 1144.17 ha (29.2 per cent) and 1459.17 ha (37.3 per cent) respectively. Pasture and Trees are under 153.18 ha (3.9 per cent) and 160.74 ha (4.2 per cent) respectively. The lowest per cent coverage is wasteland lands (1.4 per cent). The Reserve Forest has spread to the extent of 17.6 per cent (690.66

Fig.4.1 Drainage map of Ebbanad Watershed

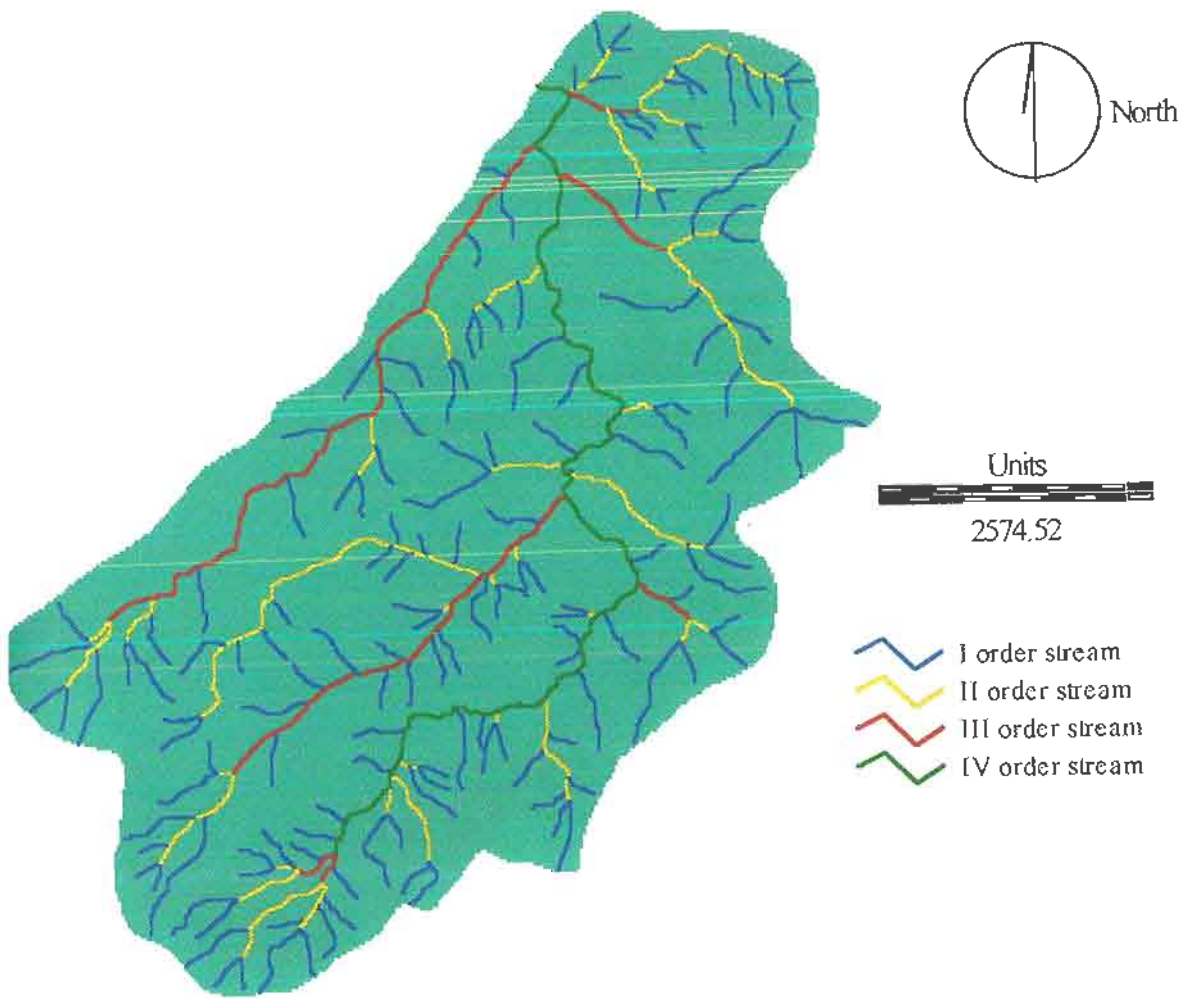
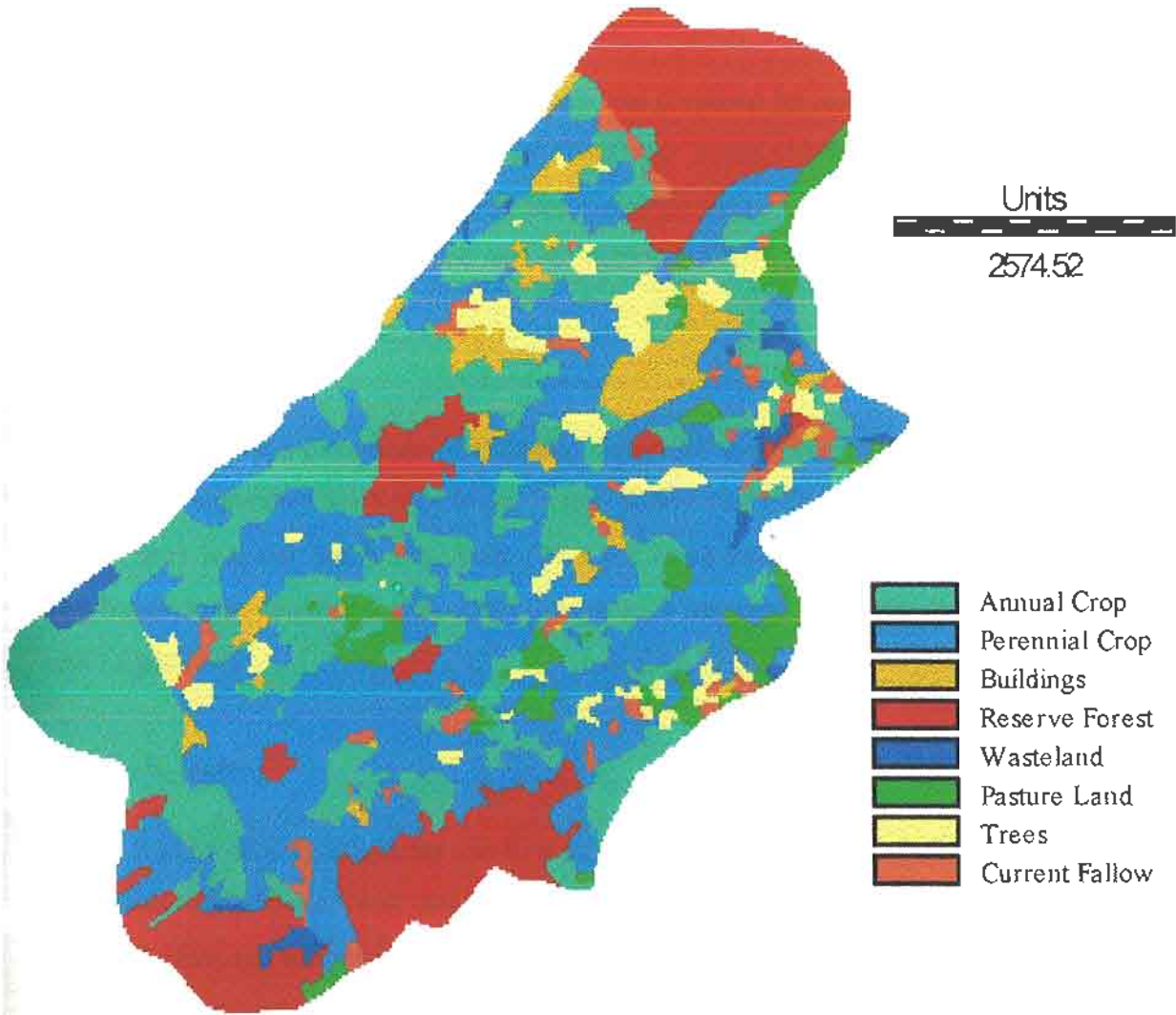


Fig. 4.2 LandUse map of Ebbanad Watershed



ha). The area of 98.88 ha (2.5 per cent) is lying under fallow condition. For a period from 1993 to 1999 the land use / land cover may have some differences from year to year but these were assumed a constant value.

4.1.1.2. C-factor

For Crop management factor C, map was prepared by using the landuse map and the C-factor selected from table (Wischmeier and Smith, 1978) for the different land cover categories of the study area. The C-factor map is shown in the Fig. 4.3. The C-factor for the Ebbanad watershed was in the range of 0.01 to 1.00.

4.1.1.3. Soil type

The soil type categories of Ebbanad watershed are given in the Fig. 4.4. The soil types in the watershed are Sandy loam, Loam, Sandy clay loam, Clay loam and Clay. The highest area is under Sandy clay loam (29.9 per cent) followed by Clay (25.2 per cent). The Sandy loam, loam and Clay loam covers 11.8 per cent, 14.8 per cent and 18.3 per cent respectively.

4.1.1.4. K-factor

Soil erodibility values for the five soil series in the study area were selected from the tables (Wischmeier and Smith, 1978). The soil erodibility map (Fig. 4.5) was prepared using the soil map and the attribute information of K-factor for each series. The K-factor for the watershed was varied from 0.01 to 0.34.

4.1.1.5. Existing Soil Conservation Measures

Existing Soil Conservation Measures of Ebbanad watershed are pictorially represented in the Fig. 4.6. The contour trenching and staggered trenching covers an area of 289.6 ha and 488.2 ha respectively. About 448.1 ha and 419.2 ha area are under Bench

Fig. 4.3 C - factor map of Ebbanad Watershed

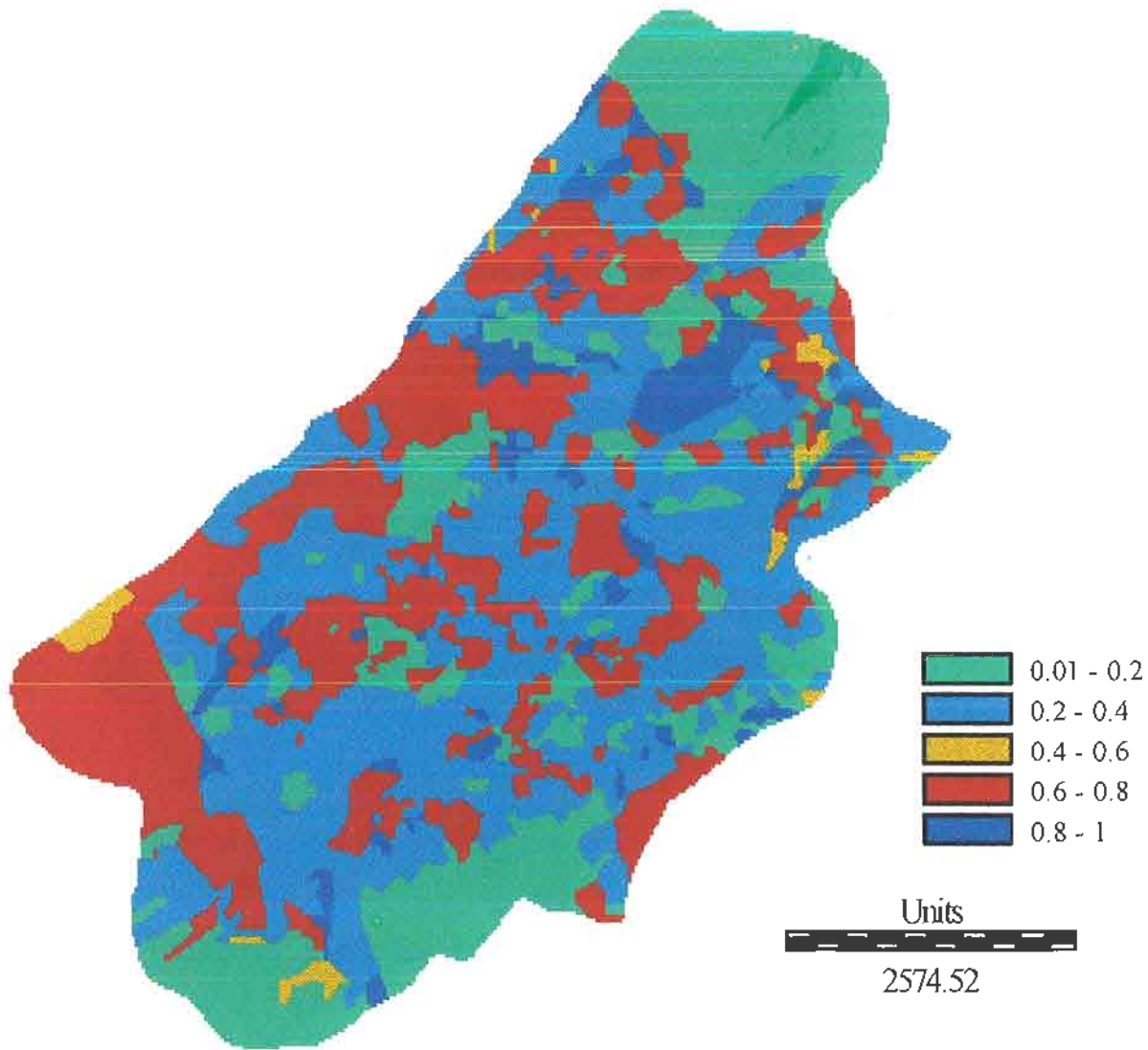


Fig. 4.4 Soil map of Ebbanad Watershed

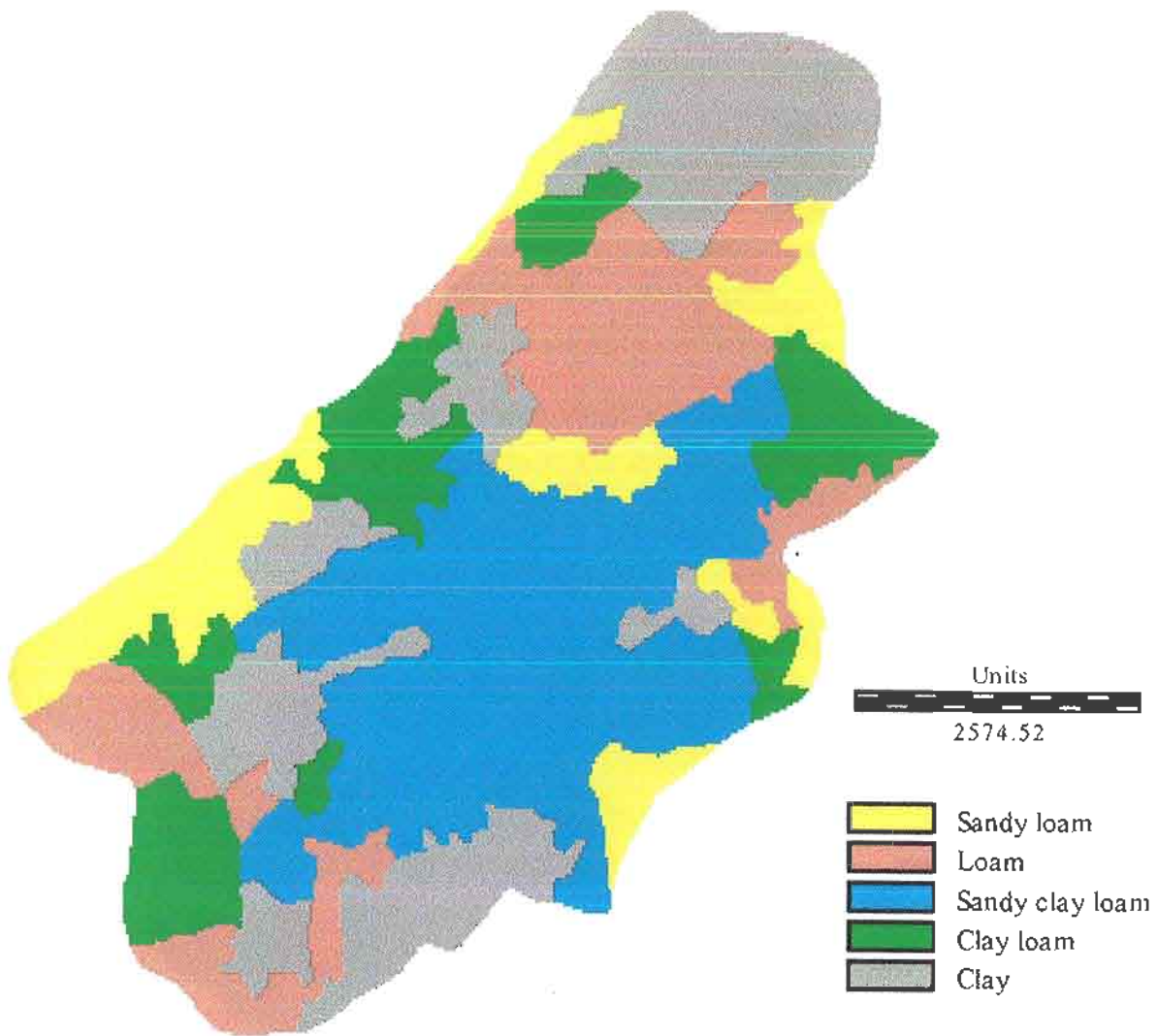


Fig. 4.5 Soil Erodibility map of Ebbanad Watershed

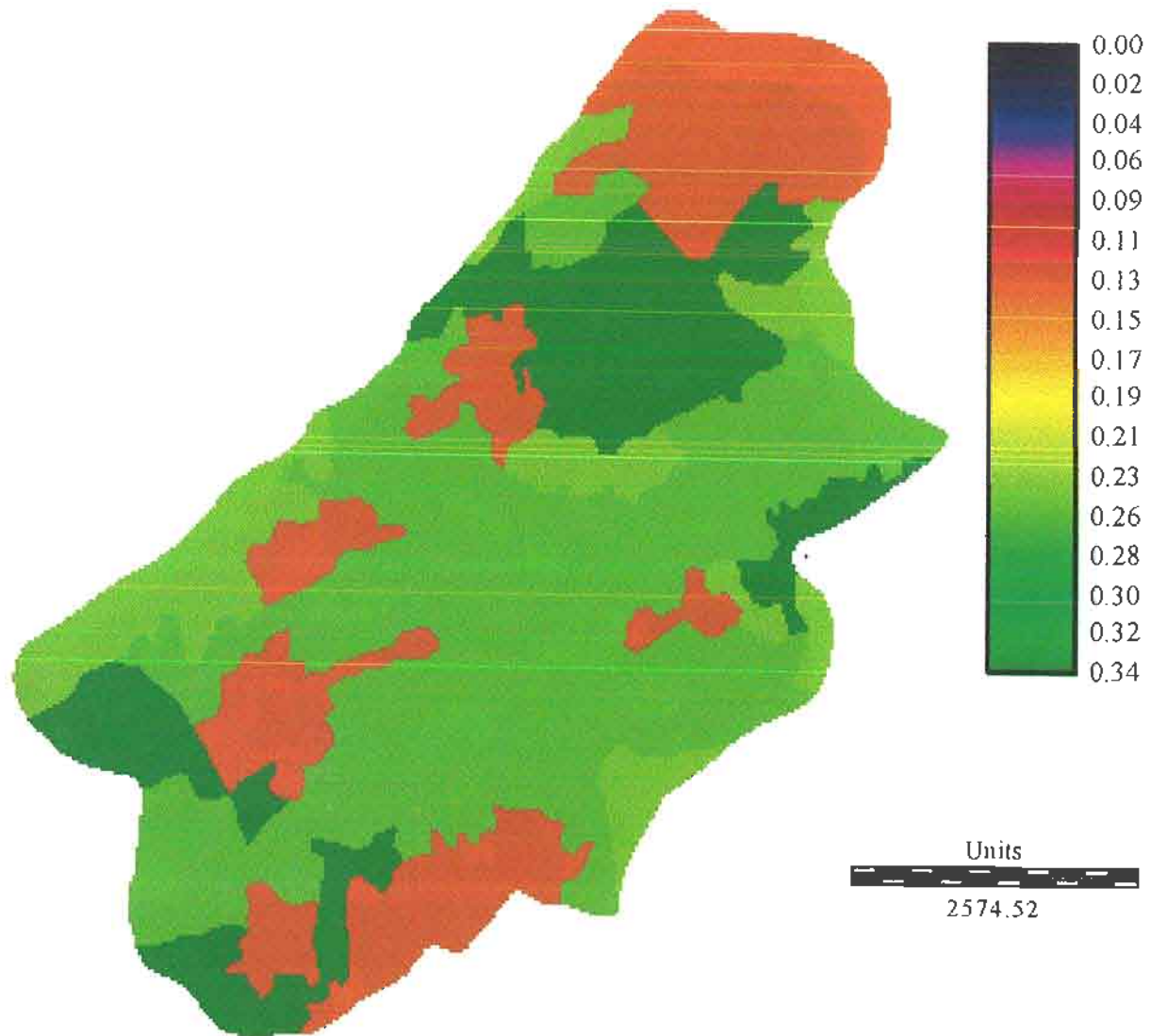
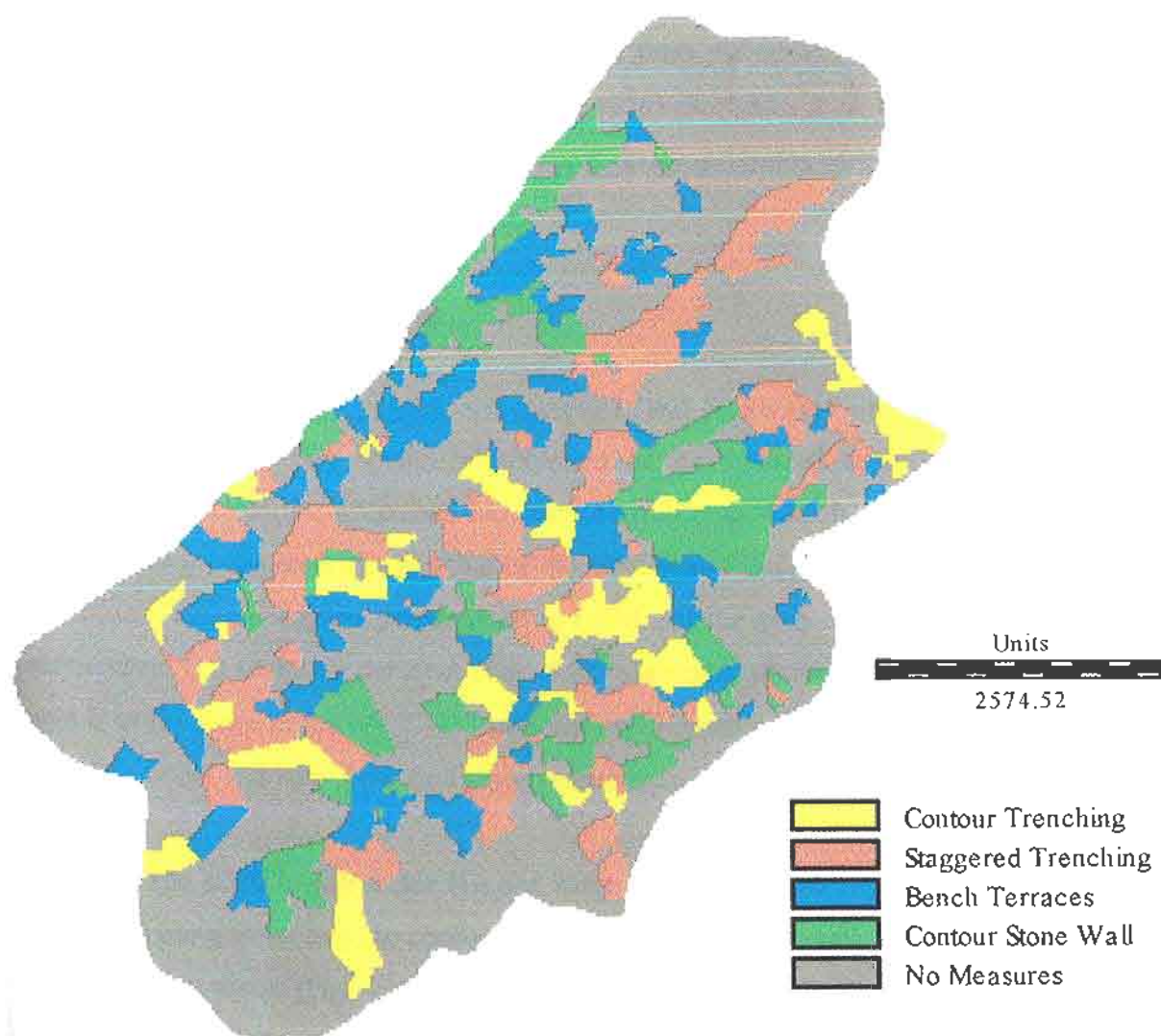


Fig. 4.6 Soil Conservation map of Ebbanad Watershed



terraces and Contour Stone Wall respectively. The major portion of area (58 per cent) is lying without any conservation measures.

4.1.1.6. P-factor

Conservation Practice factor (P) for four categories of mechanical measures under varying land use and slope were selected from the tables (Wischmeier and Smith, 1978) and the past studies by Tejwani et al. (1975) and Sikka et al. (2000). The P-factor map (Fig.4.7) was prepared by assigning the P-factor attributes with the soil conservation map.

4.1.1.7. Digital Elevation Model

Computation of topographical factors L and S are very difficult in the case of complex watersheds. By spatial interpolation of the digitized contour map, a Digital Elevation Model of the watershed has been derived (Fig. 4.8). In the DEM, every pixel (30 m X 30 m) has an attribute value of the elevation of the ground area. The slope map of Ebbanad watershed was prepared using DEM and the percent slope of the watershed varied from 0.0 to 89.67 per cent (Fig. 4.9). Maximum percentage (50.45 per cent) of area is in the slope group of 15 – 33 per cent on Ebbanad watershed. About 1.92 per cent area falls under less than 2 per cent slope respectively (Fig. 4.10).

. The slope length factor (L) and slope steepness factor (S) depends on the land slope. By using slope map, to account for variations in slope length factor (Fig. 4.11) and slope gradient factor (Fig. 4.12) were prepared. The exponent “m” of L-factor varies from 0.2 to 0.5 with slope.

4.1.1.8. Rainfall Variability

Rainfall data from four rain gauge stations within the Ebbanad Watershed were considered for calibration and validation. The theissen polygon for Ebbanad

Fig. 4.7 P factor map of Ebbanad Watershed

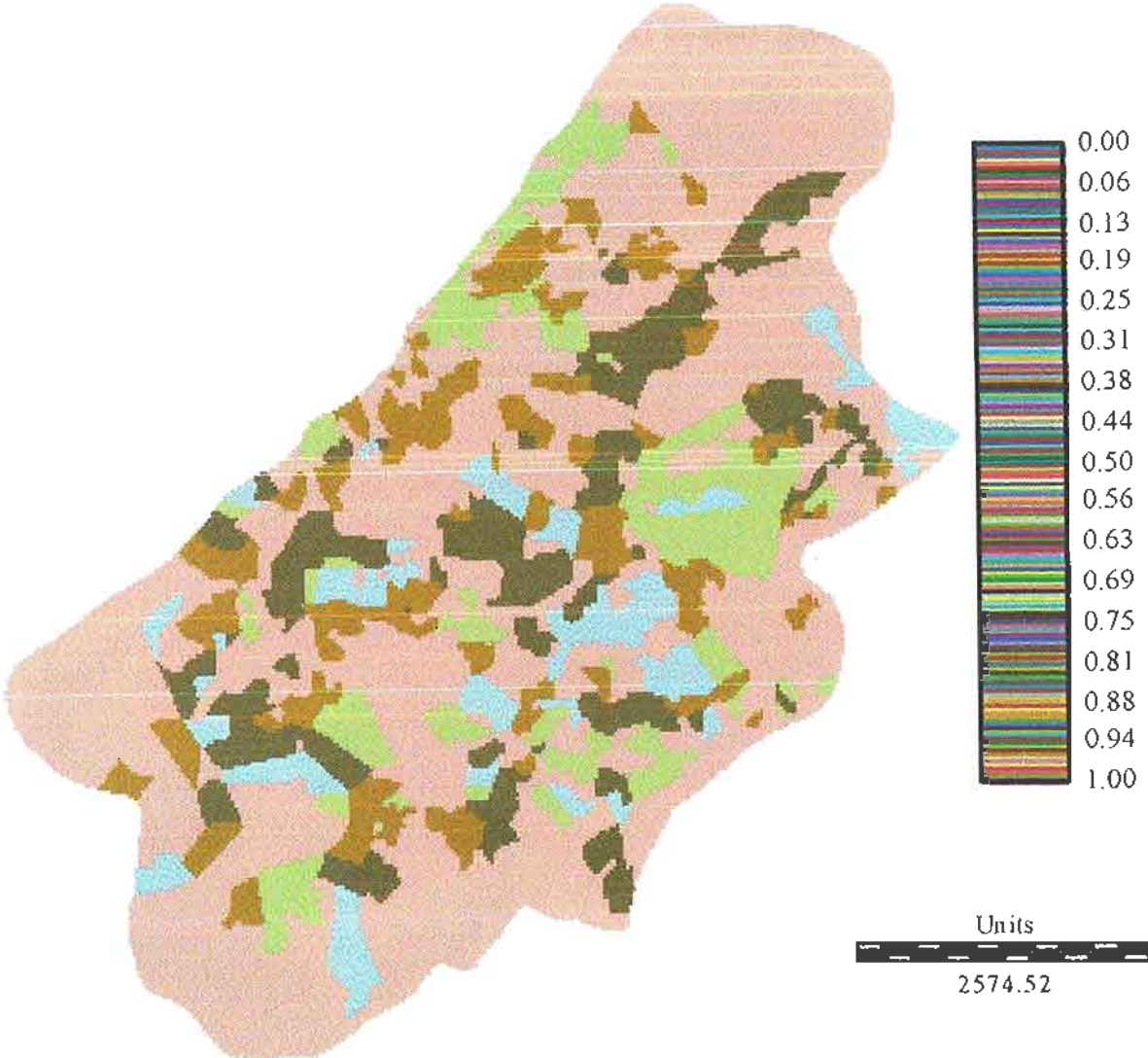


Fig. 4.8. DEM derived from Ebbanad Watershed contour map

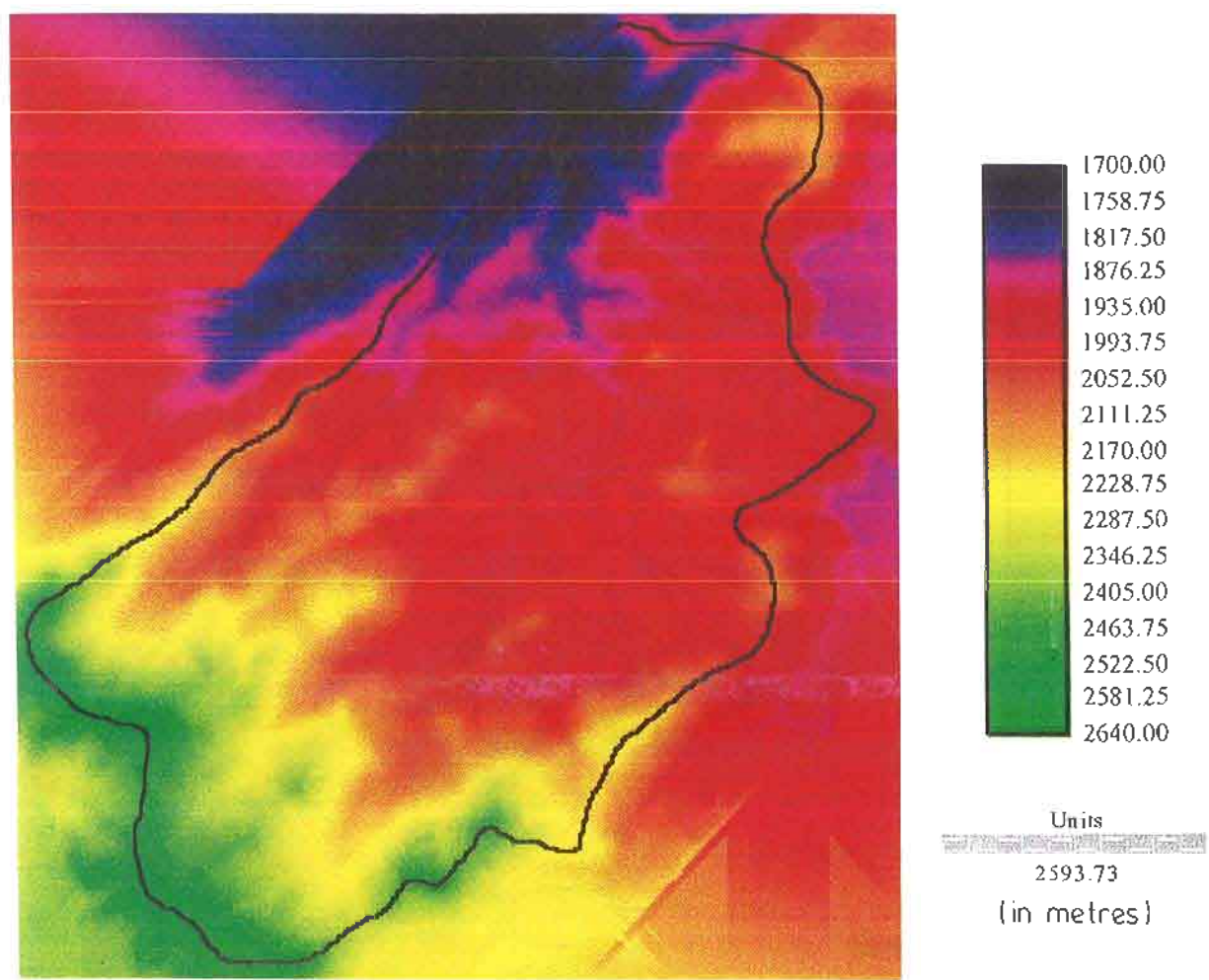


Fig. 4.9 Slope map (per cent) of Ebbanad Watershed

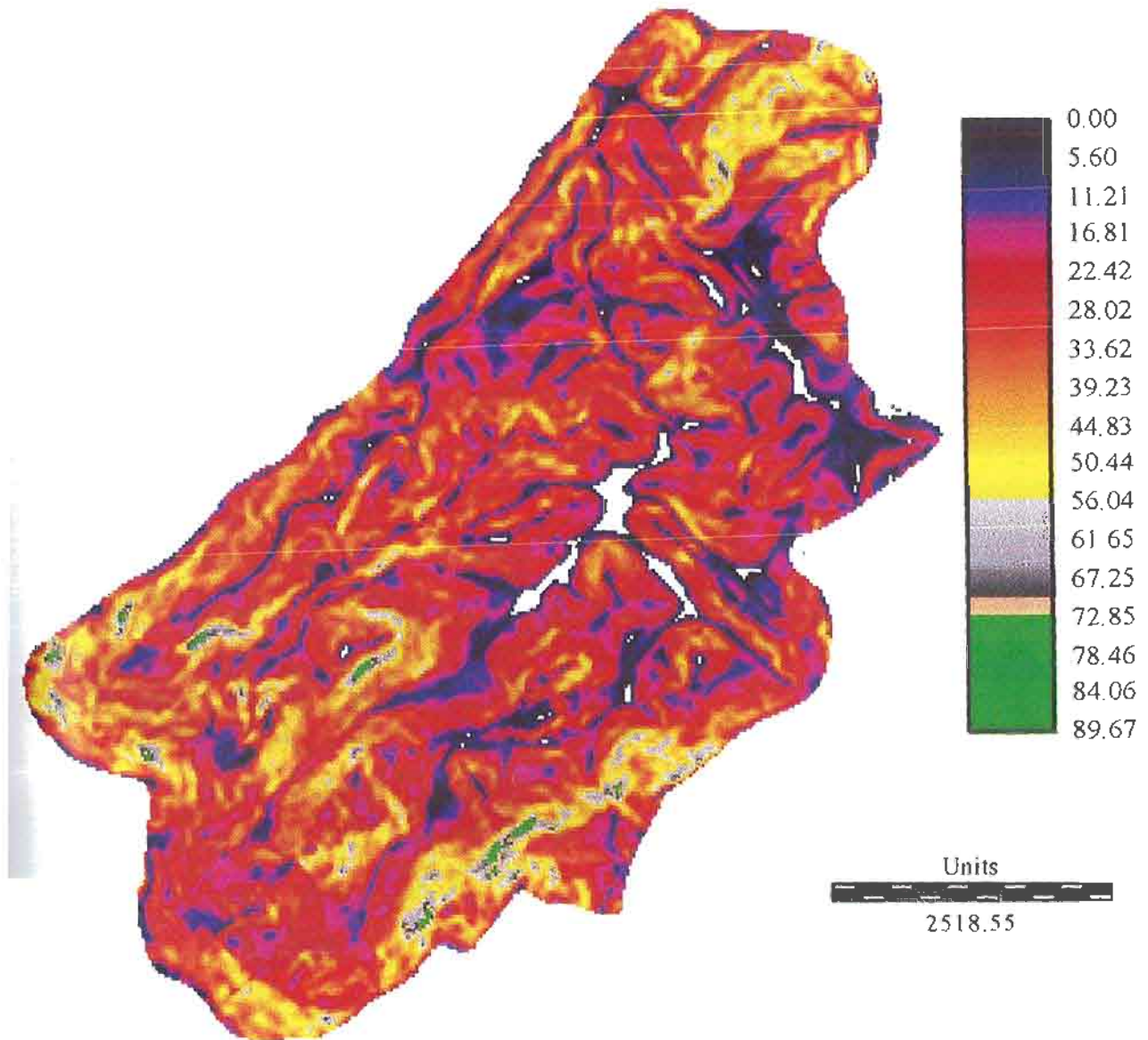


Fig. 4.10 Slope classification map of Ebbanad Watershed

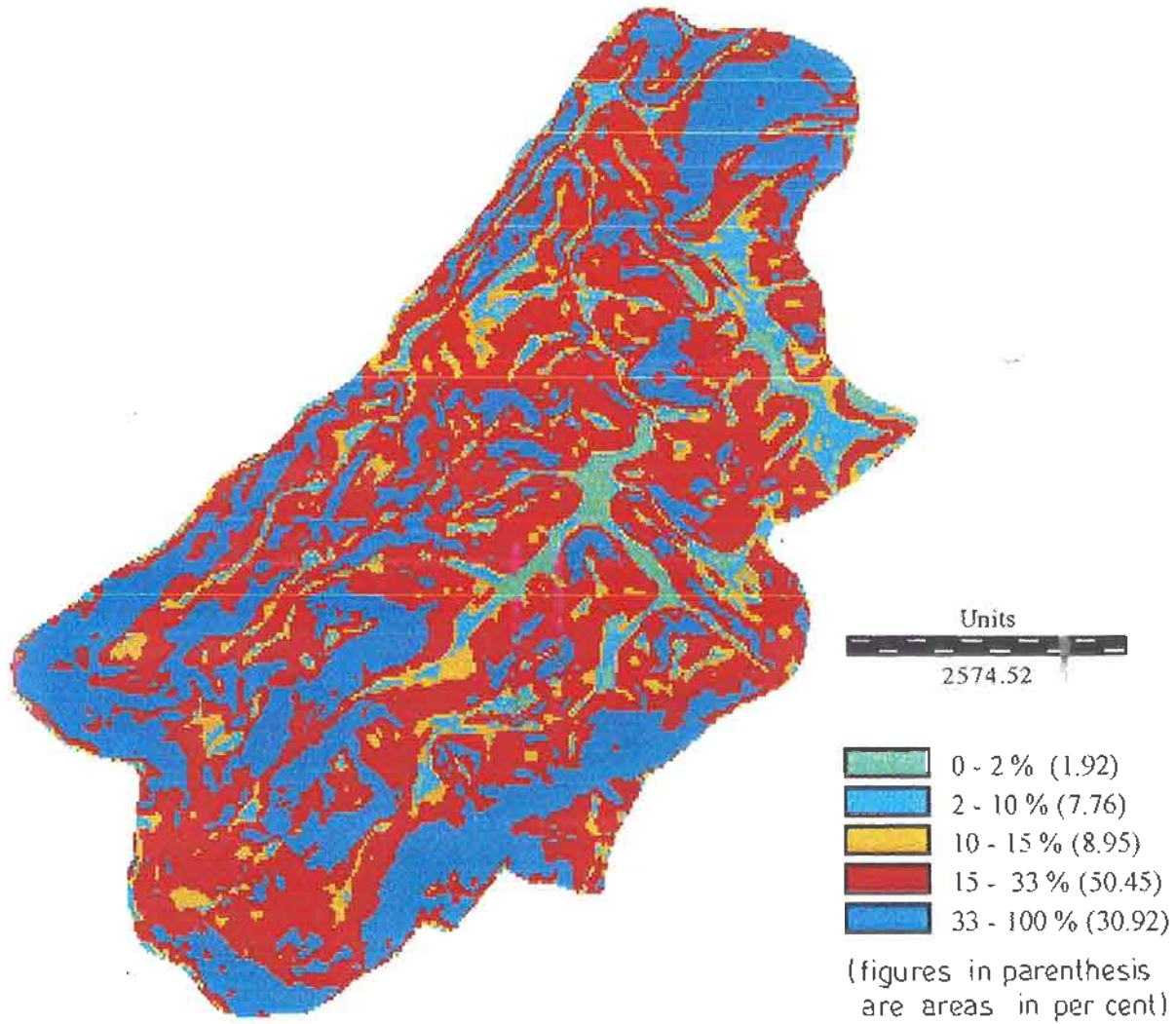


Fig. 4.11 L factor map of Ebbanad Watershed

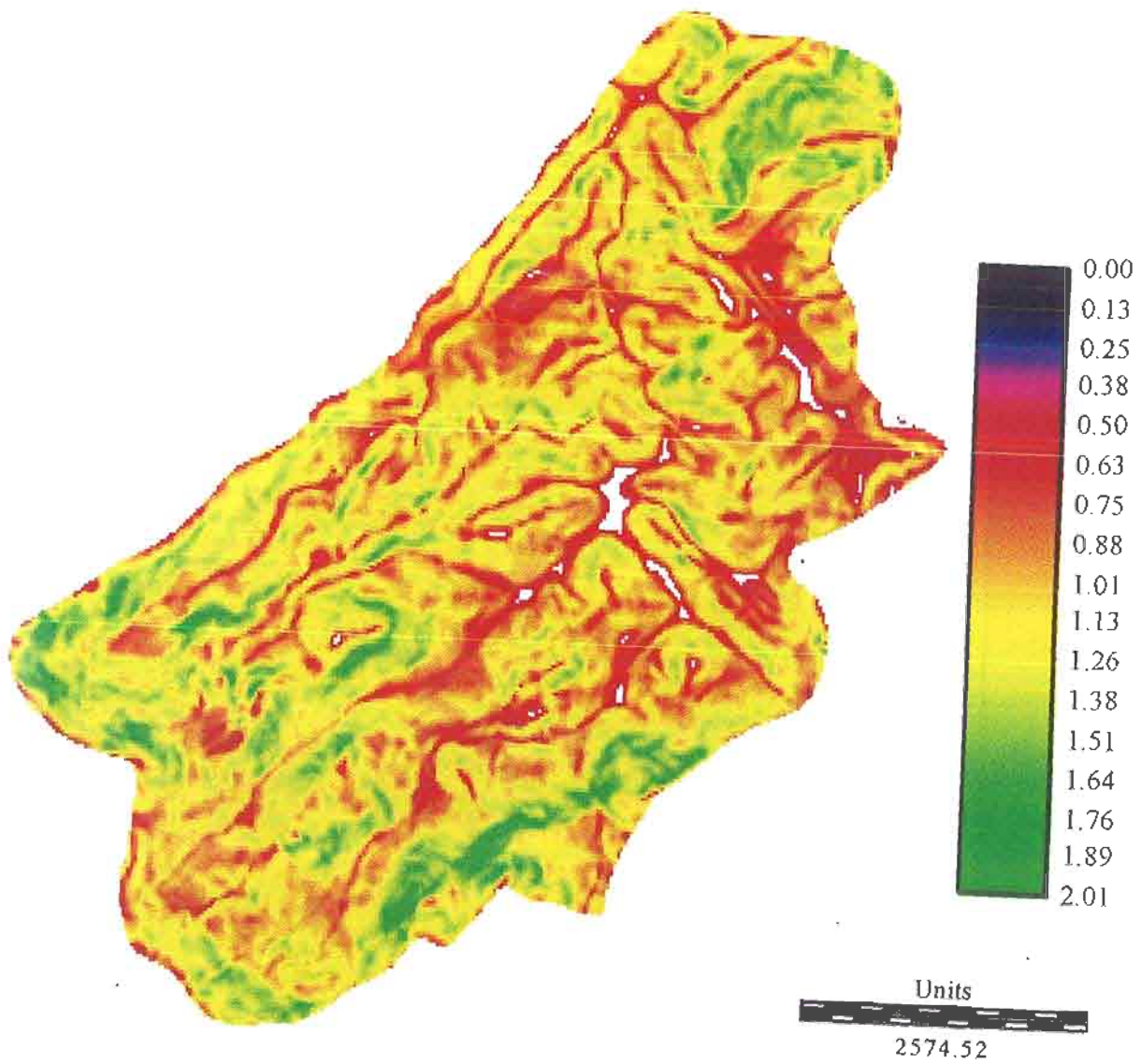
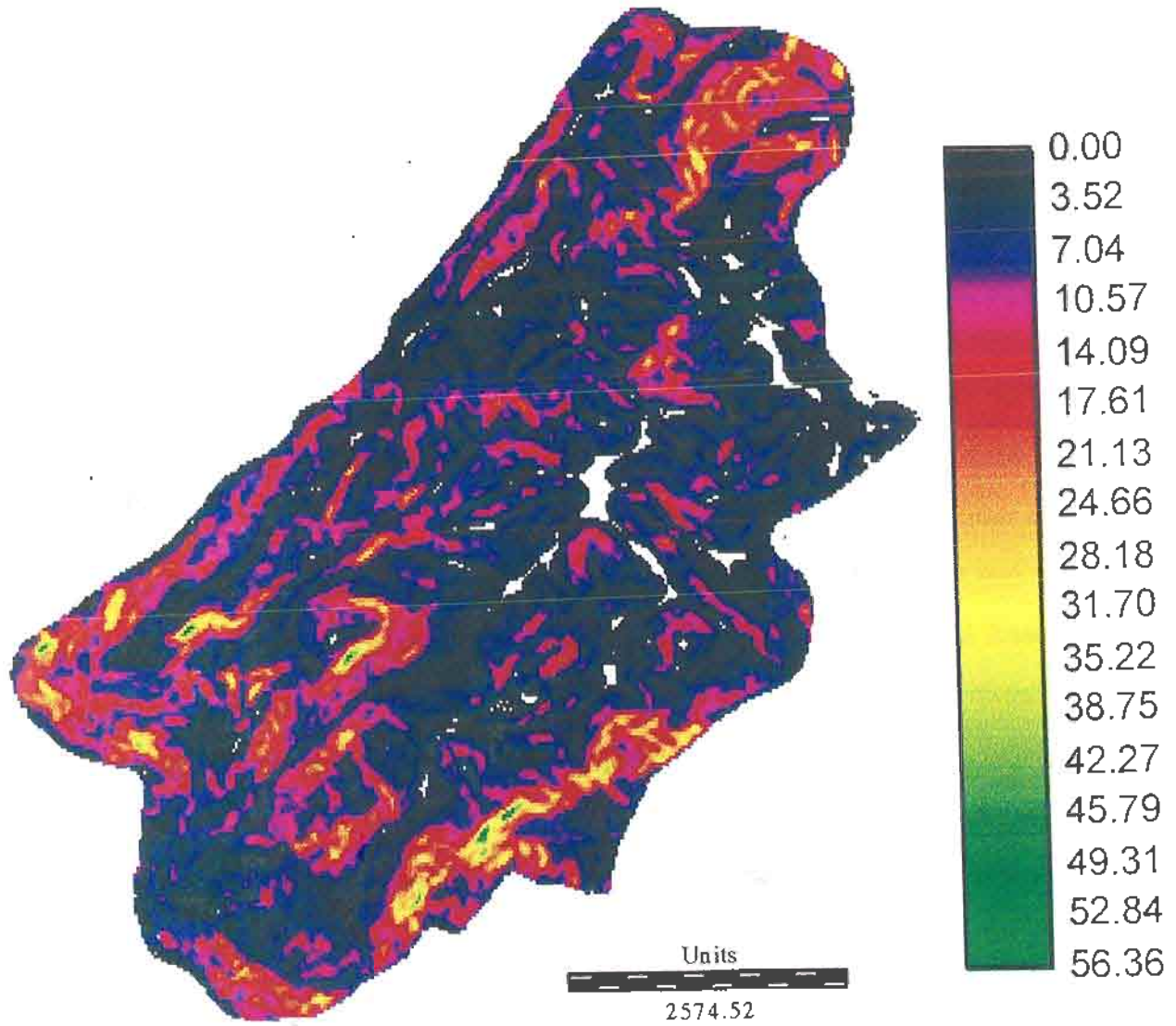


Fig. 4.12. S factor map of Ebbanad Watershed



watershed is shown in Fig. 4.13 was obtained with the location of rain gauge stations of Ebbanad watershed.

4.1.1.9. Land Use Vs Hydrologic Soil group

Hydrologic soil group categories of A, B, C & D of Ebbanad watershed are presented in the Fig. 4.14. The land use cross tabulated with hydrologic soil group (Fig.4.15) was used to fix the values of CN II, to calculate the slope adjusted CN II (Fig. 4.16) from GIS.

4.1.1.10. Surface runoff

The spatial variability of soil water retention of Ebbanad watershed is presented in the Fig. 4.17. The highest (990.73 mm) of soil water retention was observed from tree, Reserve forest and Perennial crop areas whereas retention between 1 to 100 mm was found at almost all areas of Ebbanad watershed. The areas under pasture and Reserve forest was estimated to be within the range of 200 to 300 mm of soil water retention. Surface runoff from the selected 10 storm events (E1 to E10) for calibration was obtained from GIS. The rainfall greater than 12.5 mm is called as erosive rains (Rambabu et al., 1970). Since the study area was hilly terrain, the amount of rainfall greater than four times of 12.5 mm were considered as larger storms whereas less than 50 mm were described under smaller storm events. The surface runoff map for five storm events is shown in Fig. 4.18 to 4.22. Minimum range of surface runoff (0 – 10 mm) was observed in almost all areas under Reserve forest and some of the areas under annual crops for smaller storms and between 10 to 15 mm for larger storm events. The land cover of buildings, current fallow and some of the land covers of pasture and wasteland were found to be between 10 to 25 mm of surface runoff.

Fig. 4.13. Thiessen Polygon map of Ebbanad Watershed

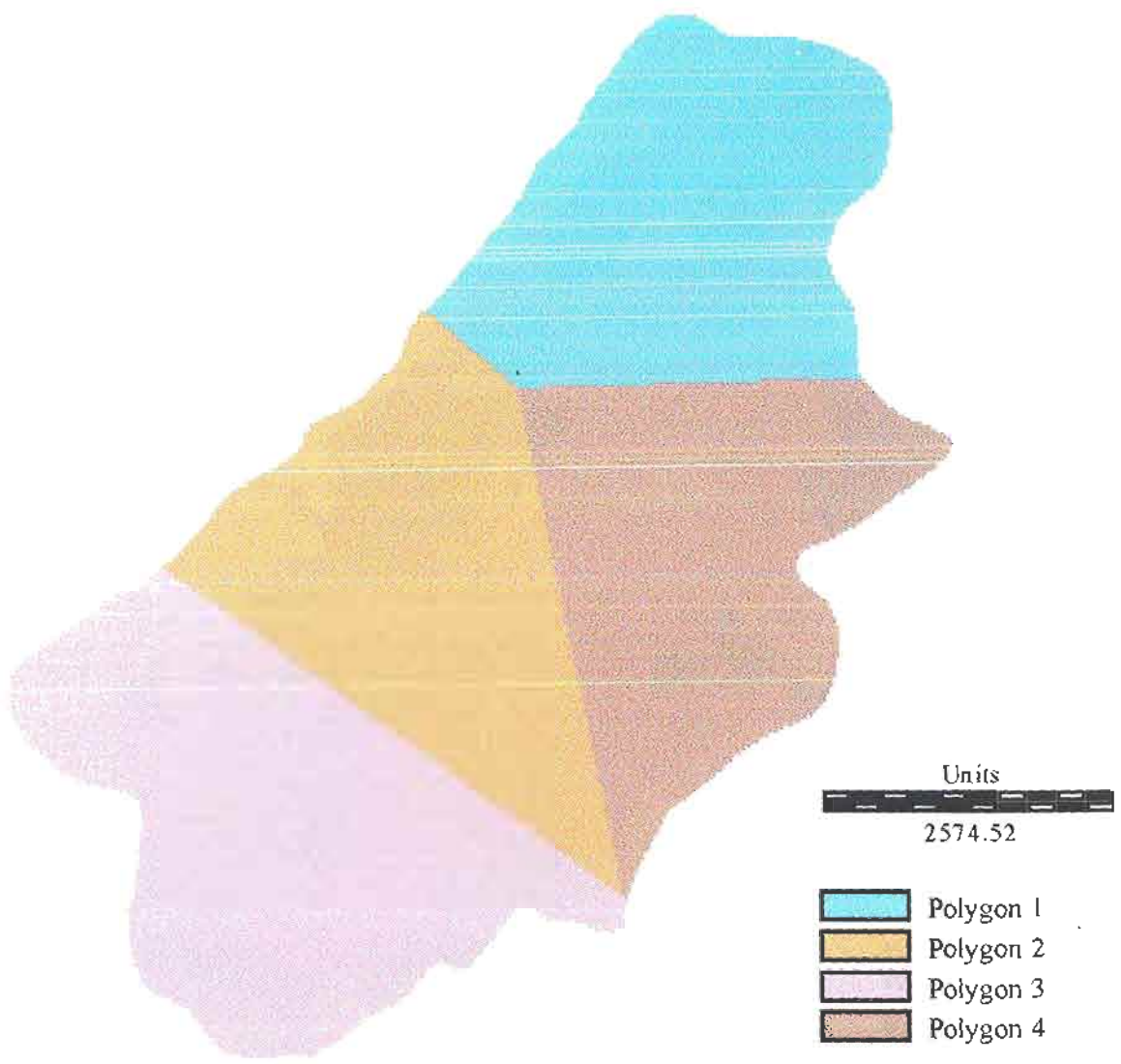


Fig. 4.14. Hydrologic soil group of Ebbanad Watershed

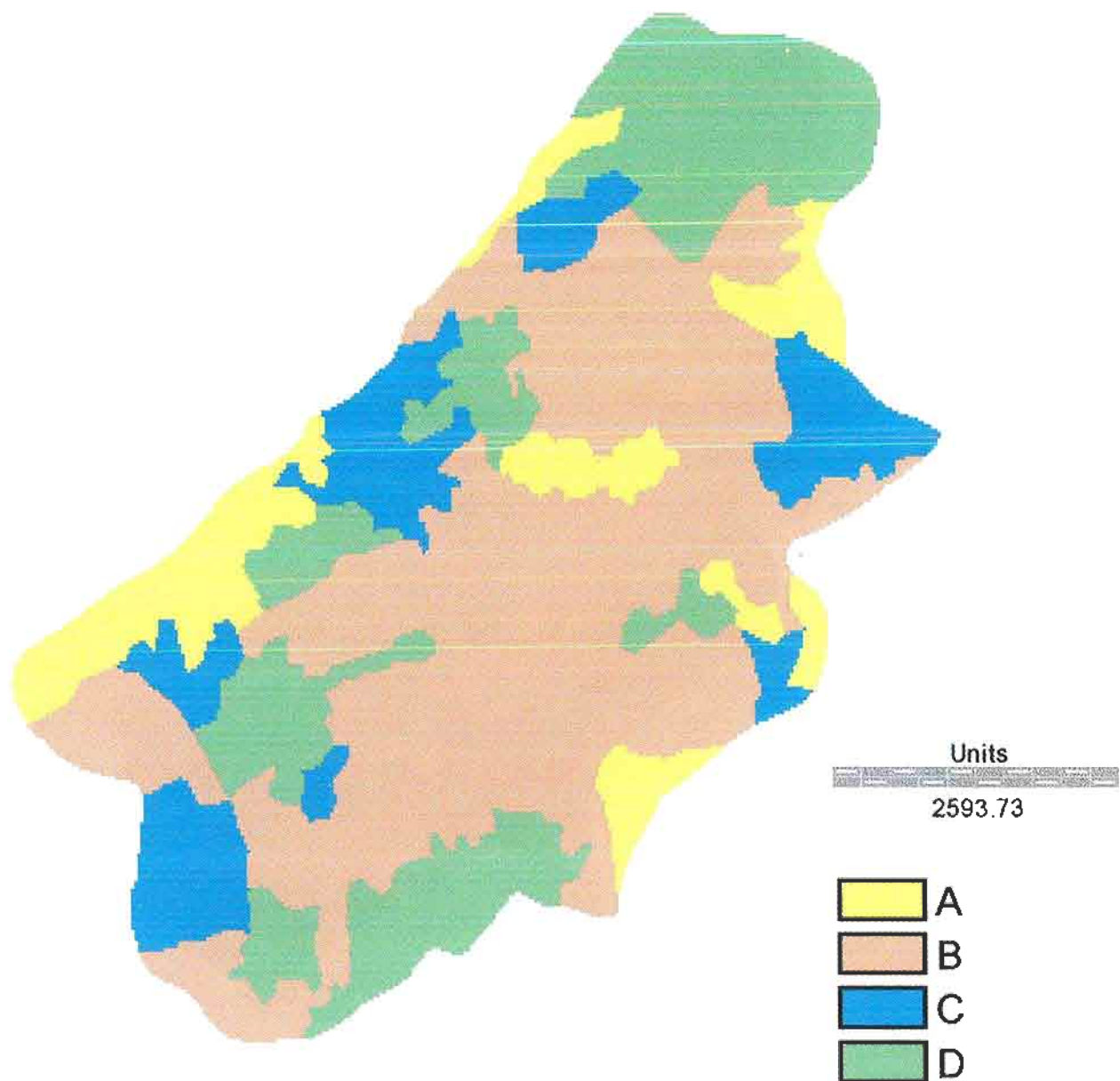


Fig. 4.15. Hydrologic soil Vs. Land use of Ebbanad Watershed

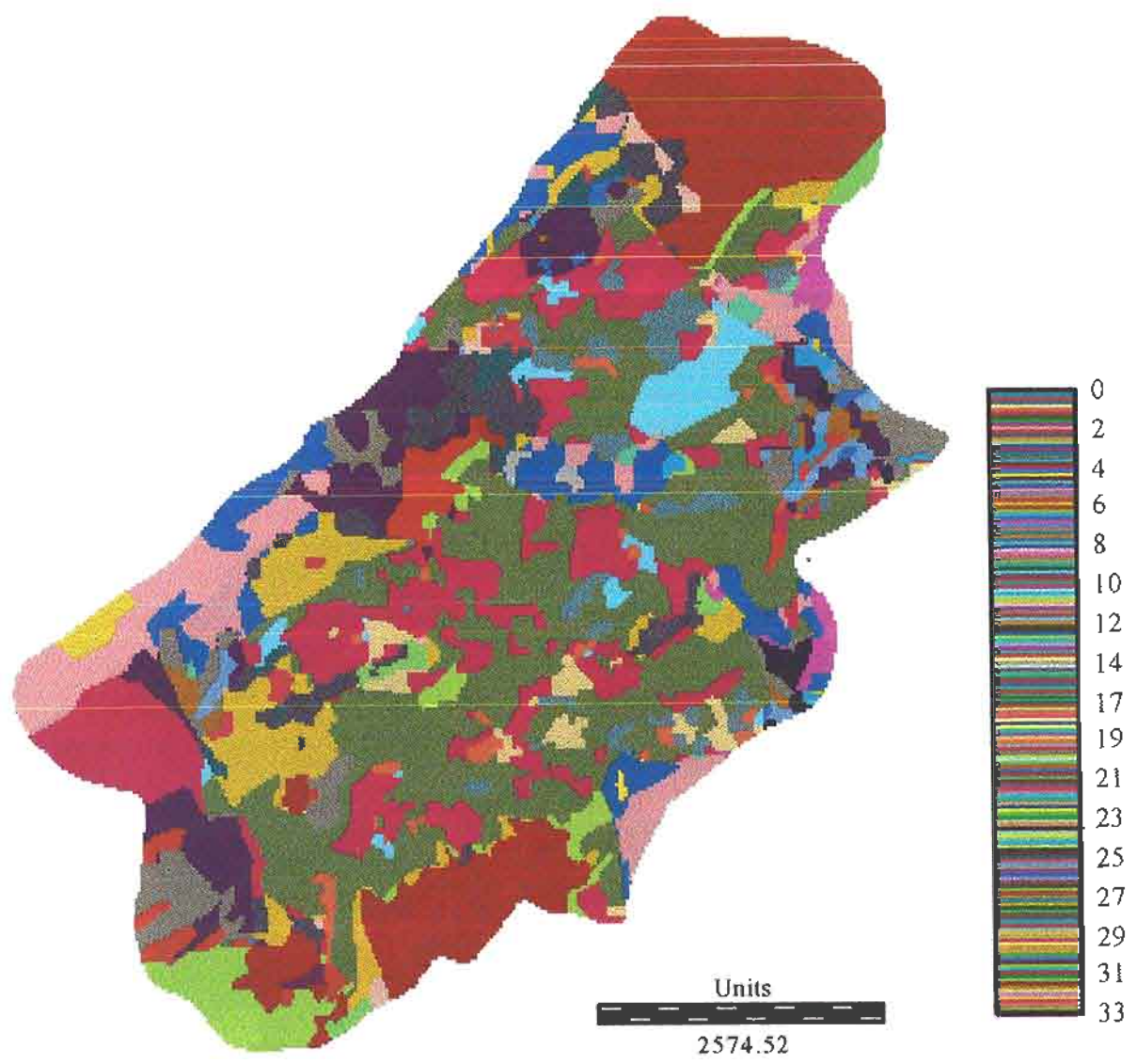


Fig. 4.16. CN II adjusted for slope of Ebbanad Watershed

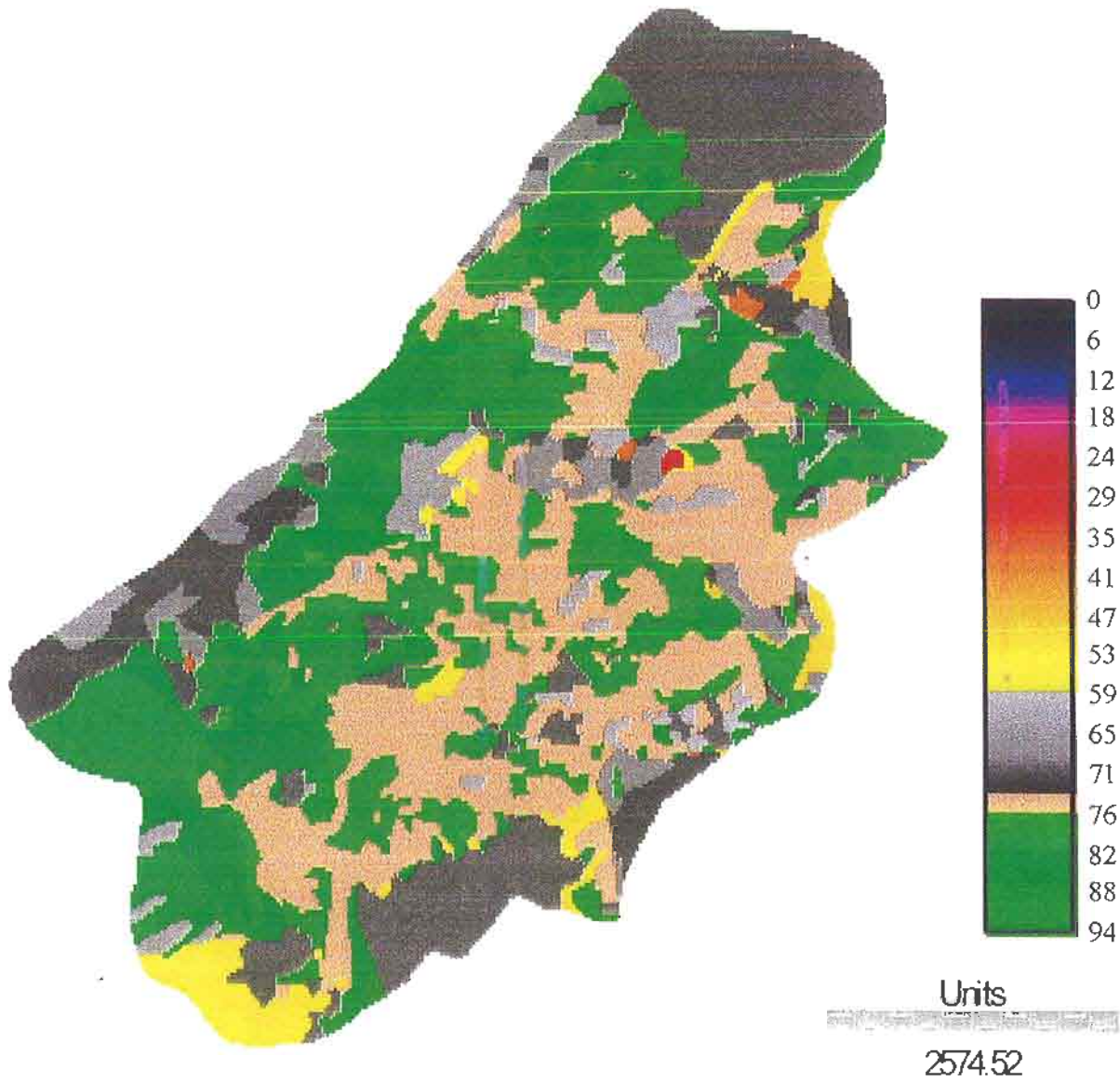


Fig. 4.17. Soil water retention map of Ebbanad Watershed

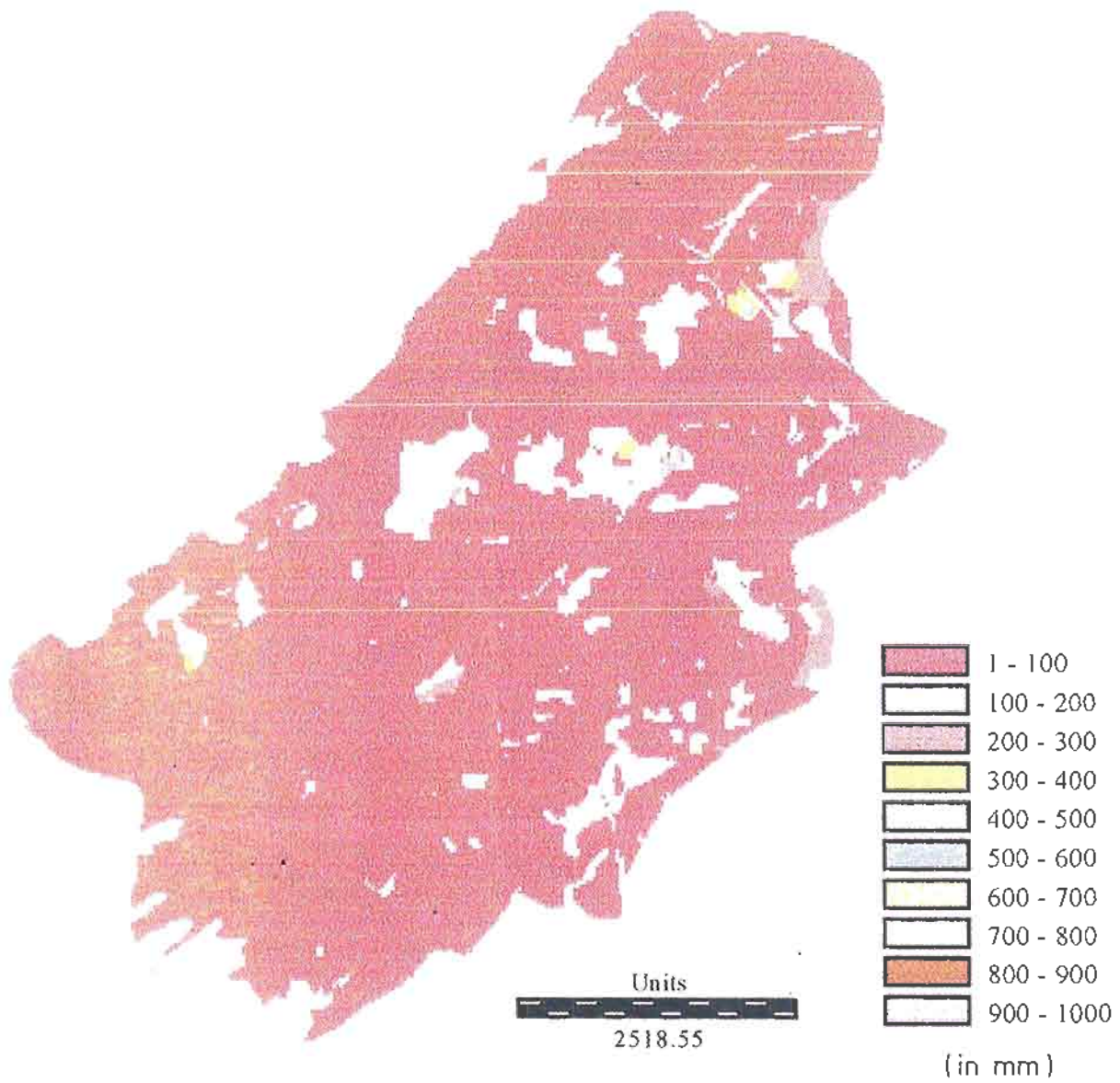


Fig. 4.18. Surface Runoff (mm) of E2 for Ebbanad Watershed

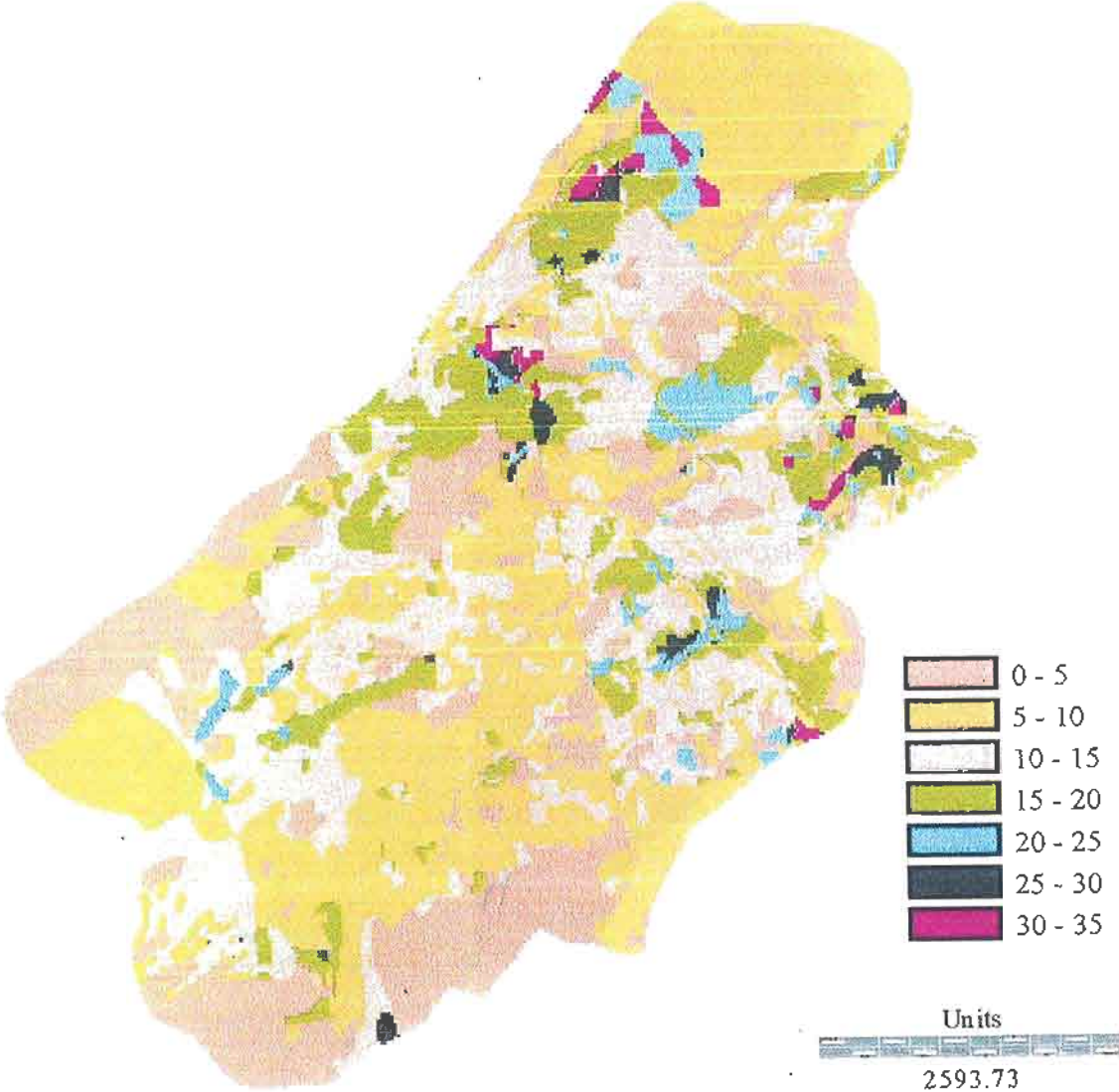


Fig. 4.20. Surface Runoff (mm) of E7 for Ebbanad Watershed

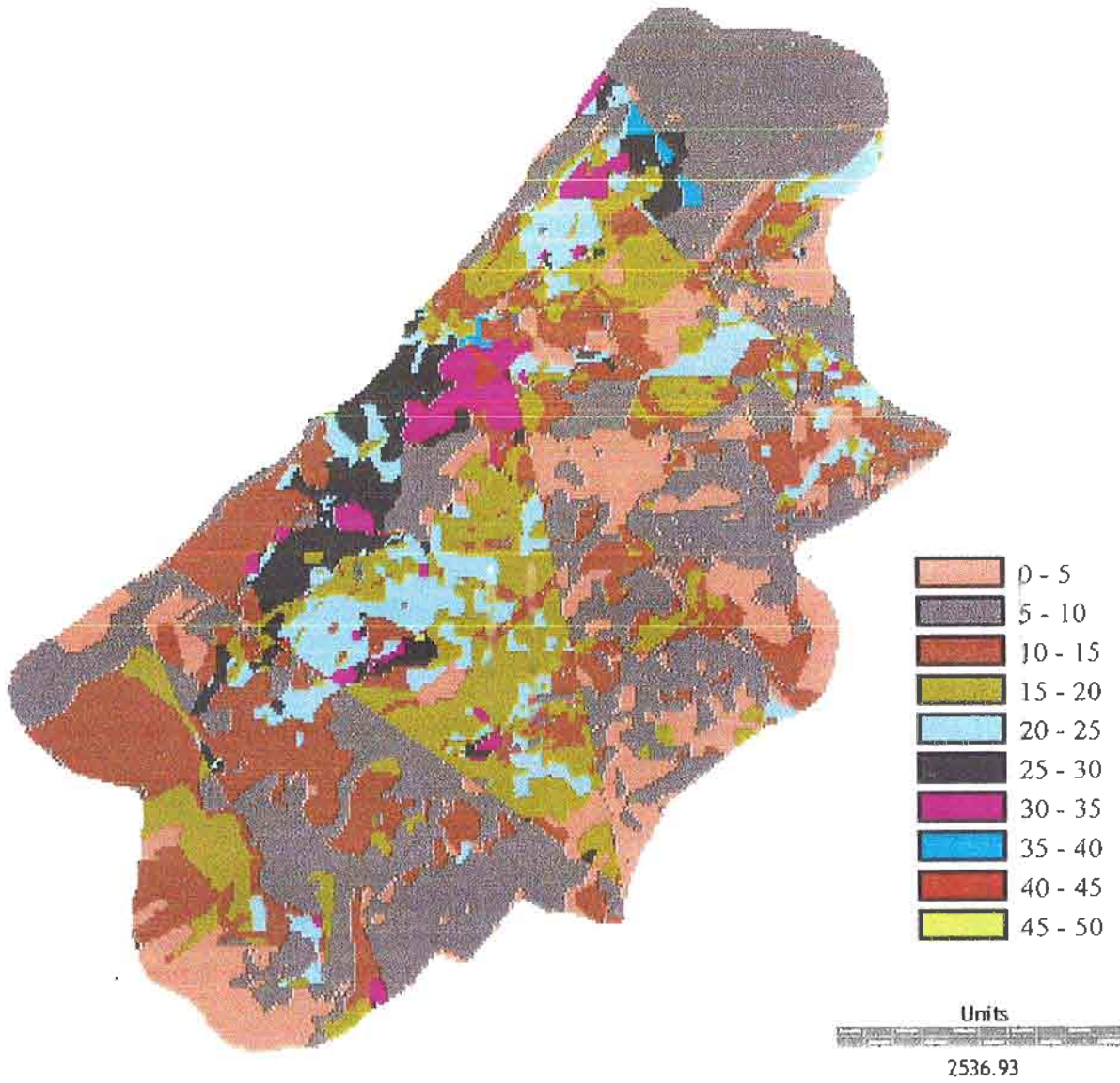


Fig. 4.19. Surface Runoff (mm) of E4 for Ebbanad Watershed

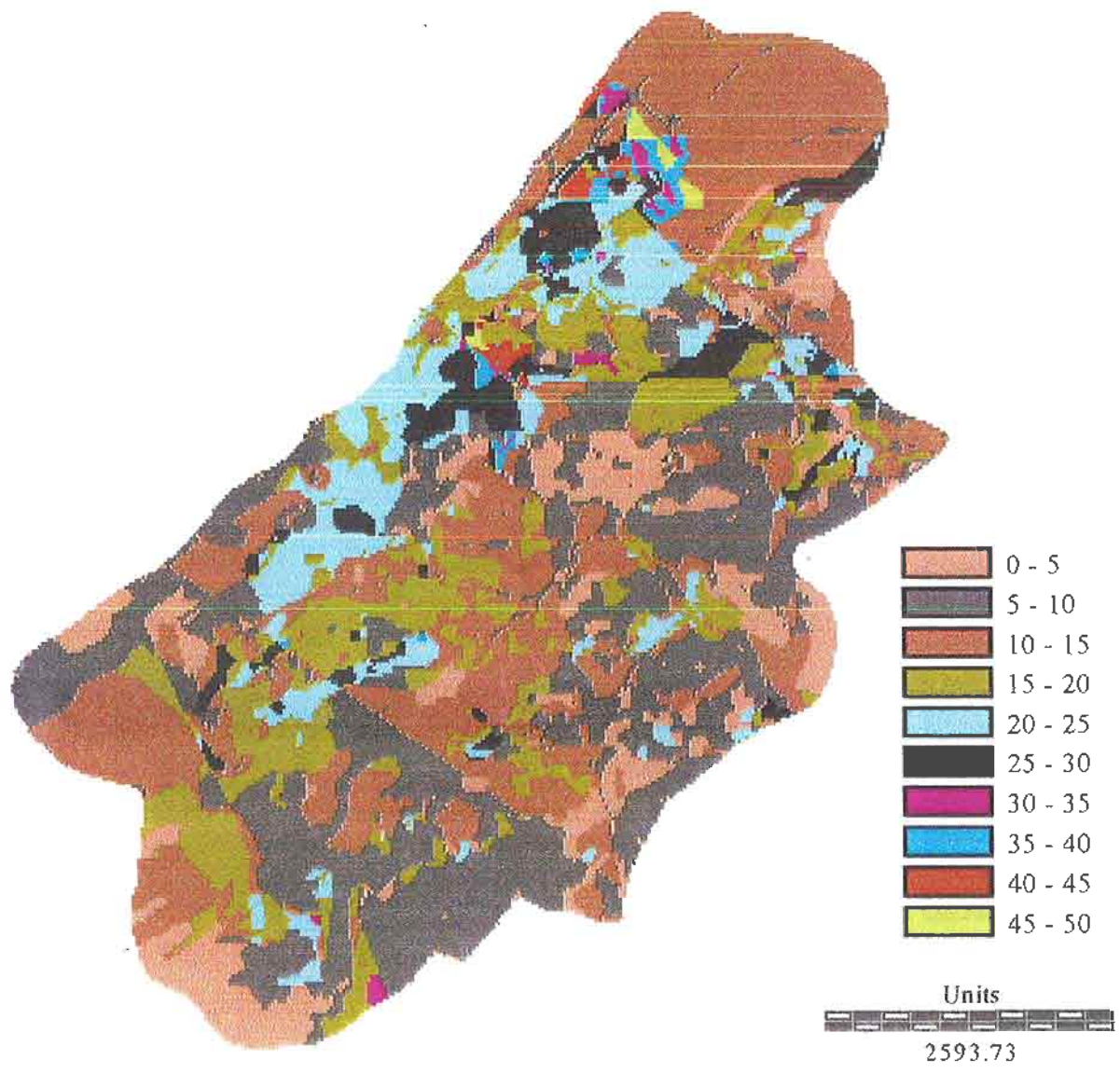


Fig. 4.21. Surface Runoff (mm) of E8 for Ebbanad Watershed

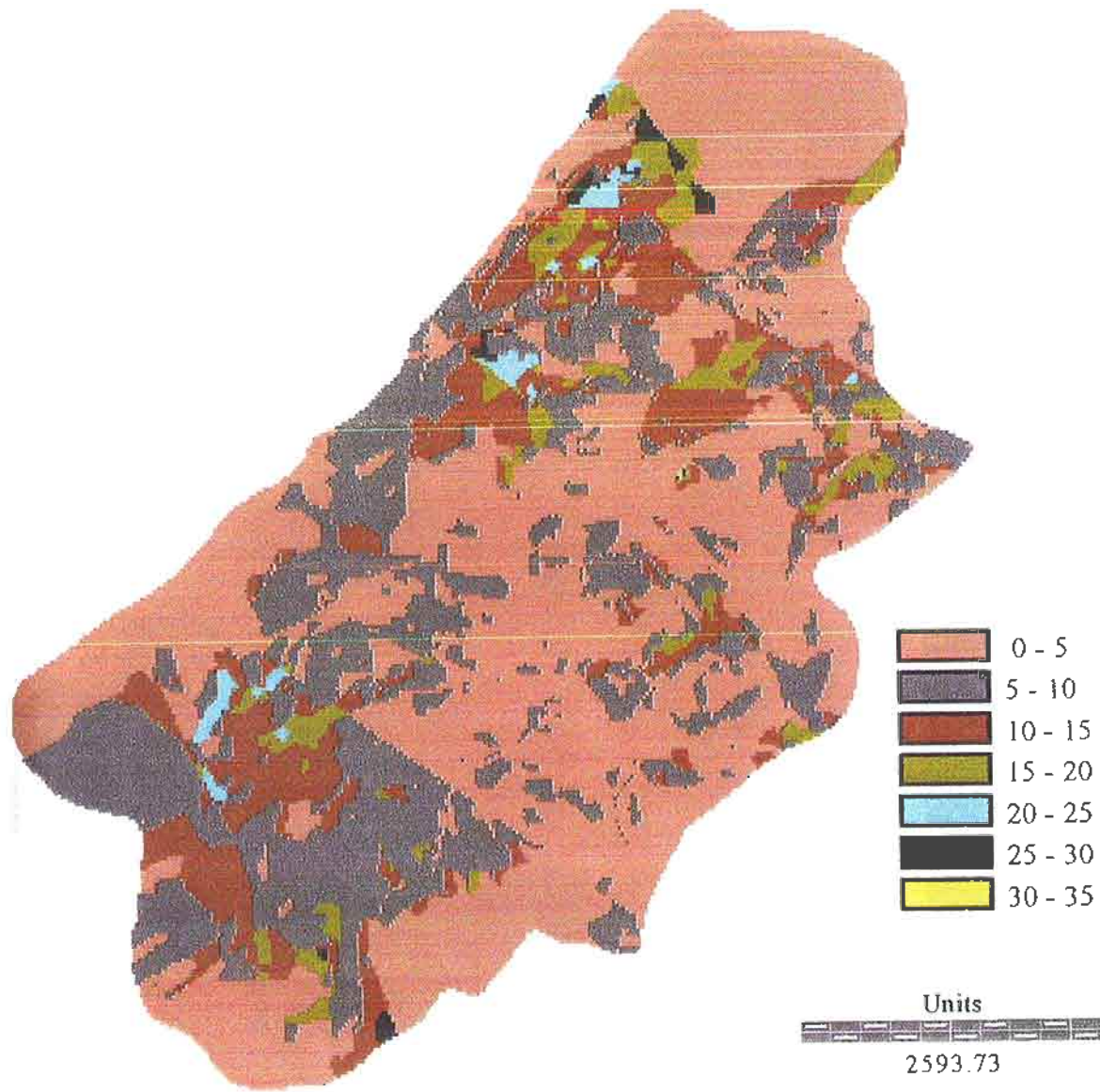
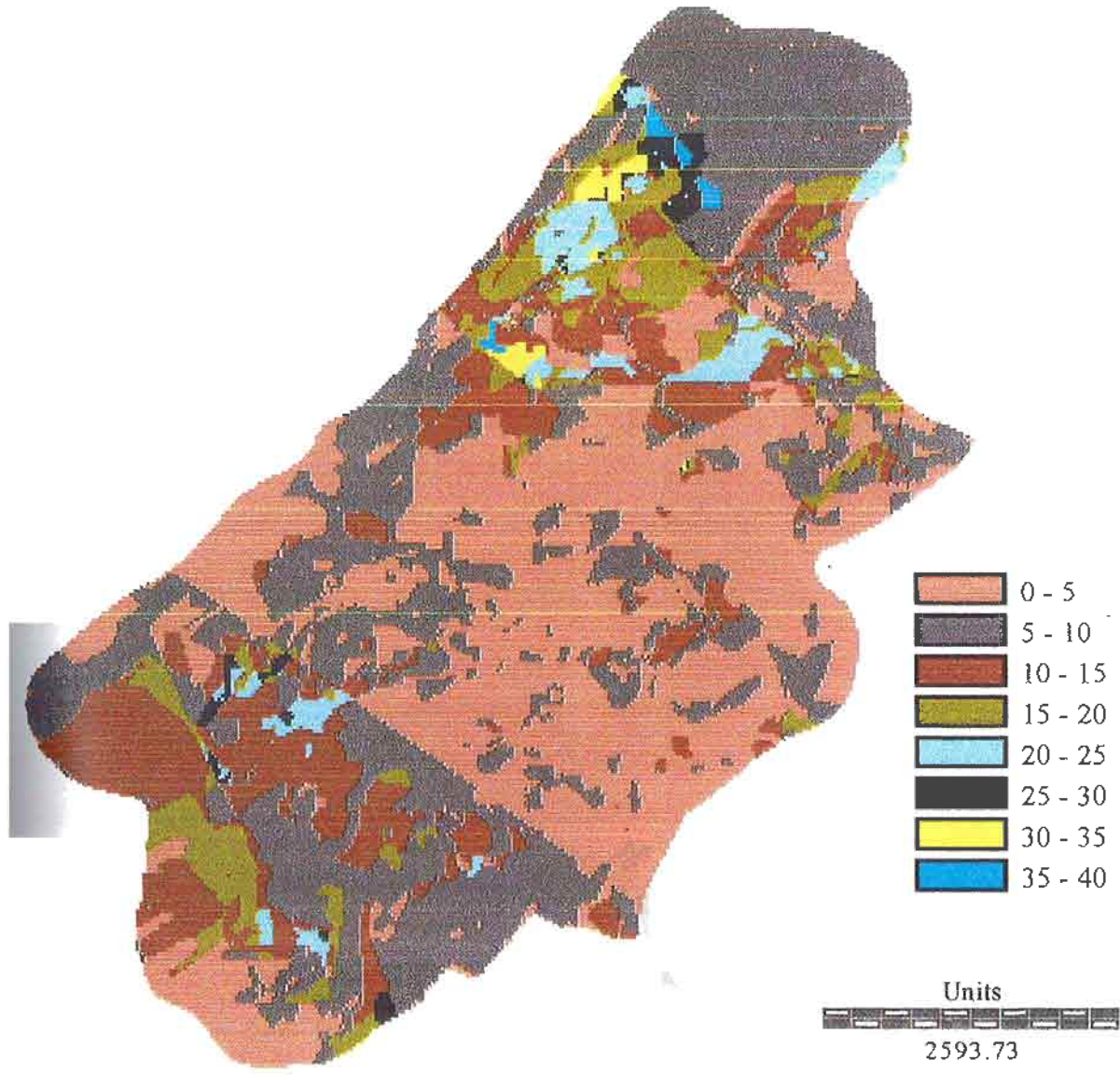


fig. 4.22. Surface Runoff (mm) map of E10 for Ebbanad Watershed



4.1.1.11. Discretisation of the study area

The Ebbanad watershed was discretised into sub-watersheds using DEM of the watershed. The watershed is divided into 45 sub-watersheds (Fig. 4.23.) and the area of the sub-watersheds was extracted in GIS. For each sub-watersheds the peak runoff rate and sediment yield module were being run and the output was routed in sediment routing module.

4.2. Calibration run

The model works on cell basis, which is a uniform square area that divides the watershed. The fixed inputs of the sub-watershed are presented in Table 4.1 and 4.2.

The fixed inputs of sub-watershed derived from GIS for DSYM are:

K-factor

L-factor

S-factor

C-factor

P-factor

Channel length

Area

Surface slope

Surface slope length, and

Channel slope

Surface runoff of the sub-watersheds for all the storm events (E1 to E10) is shown in the Table 4.3. Surface runoff was assumed to be a variable input to DSYM with respect to storm events.

Fig. 4.23. Sub-Watersheds of Ebbanad Watershed

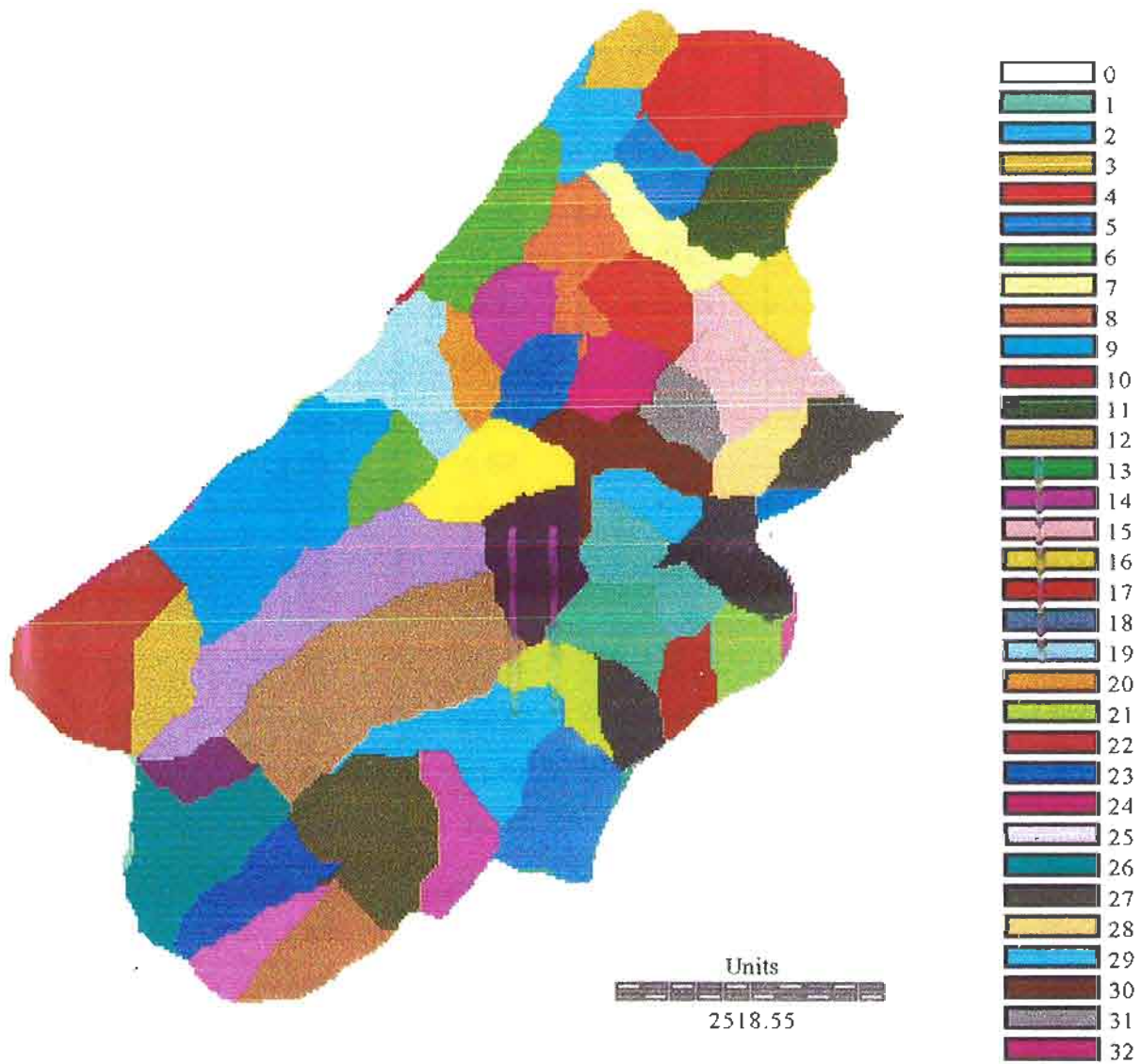


Table. 4.1. Values of Parameters for Peak Runoff Rate Module

Sub-Watershed No.	Channel Length (km)	Area (ha)	Channel Slope (m/m)	Surface Slope Length (m)	Land Surface Slope (m/m)
1	1.27	58.14	0.0073	1750.67	0.2349
2	0.88	43.02	0.0325	1802.35	0.3095
3	2.37	160.74	0.0376	1936.41	0.3734
4	1.09	48.34	0.0266	1850.44	0.3284
5	1.85	97.12	0.0157	1807.05	0.2721
6	1.63	57.69	0.0111	1891.28	0.2224
7	1.71	80.19	0.0077	1840.89	0.2435
8	1.79	109.62	0.0128	2002.11	0.2684
9	1.25	54.72	0.0174	1876.70	0.1540
10	1.47	106.02	0.0051	1945.12	0.1528
11	0.53	47.88	0.0034	1948.02	0.1873
12	1.05	6.69	0.0033	1907.25	0.2460
13	1.19	96.21	0.0124	1926.06	0.2265
14	1.19	38.51	0.0226	1949.44	0.2311
15	0.98	49.23	0.0096	1946.09	0.2662
16	1.08	53.99	0.0112	1929.89	0.2763
17	0.89	57.78	0.0054	1951.54	0.1296
18	1.06	43.02	0.0082	1984.01	0.2026
19	0.84	76.95	0.0085	1963.10	0.1892
20	0.84	43.11	0.0141	1969.46	0.2433
21	2.89	242.91	0.0094	2061.12	0.2860
22	1.02	48.42	0.0222	2024.68	0.2768
23	1.58	87.84	0.0133	1993.26	0.2514
24	1.53	100.08	0.0123	1959.38	0.2054
25	1.74	81.99	0.0059	1954.53	0.2183
26	1.09	38.42	0.0079	1977.25	0.2616
27	1.21	76.59	0.0129	2061.10	0.1824

28	4.26	223.02	0.0196	2152.99	0.2753
29	3.12	283.59	0.0183	2095.18	0.2979
30	0.89	69.12	0.0116	1965.40	0.1941
31	1.79	164.97	0.0274	2322.32	0.3787
32	1.26	63.45	0.0235	2279.89	0.3510
33	0.68	42.75	0.0105	2008.41	0.2474
34	1.31	39.42	0.0254	2044.35	0.2791
35	0.59	48.96	0.0046	2009.32	0.2636
36	0.79	45.89	0.0229	2078.52	0.3804
37	1.77	112.50	0.0185	2082.28	0.2545
38	1.78	108.45	0.0220	2199.39	0.3341
39	1.48	151.74	0.0280	2216.49	0.3545
40	0.79	64.98	0.0299	2275.96	0.3896
41	0.82	36.27	0.0239	2374.33	0.2932
42	1.82	138.78	0.0179	2400.05	0.2378
43	1.80	74.25	0.0374	2363.77	0.2707
44	1.58	49.86	0.0383	2426.59	0.3318
45	1.31	74.07	0.0345	2348.68	0.3296

Table. 4.2. Values of Parameters for Sediment Yield Module

Sub-Watershed No.	K-factor	L-factor	S-factor	C-factor	P-factor
1	0.16	0.99	5.64	0.53	0.81
2	0.13	1.16	8.48	0.18	1
3	0.13	1.28	11.87	0.02	1
4	0.13	1.19	9.92	0.33	0.89
5	0.27	1.08	7.03	0.57	0.5
6	0.23	0.96	5.15	0.36	0.89
7	0.31	1.03	5.63	0.56	0.68
8	0.22	1.06	7.22	0.23	0.76
9	0.29	0.81	2.62	0.51	0.69
10	0.27	0.79	2.76	0.59	0.69
11	0.24	0.89	3.82	0.48	0.87
12	0.34	1.02	5.84	0.49	0.54
13	0.23	0.98	5.01	0.59	0.59
14	0.14	0.99	5.23	0.73	0.74
15	0.31	1.08	6.47	0.58	0.61
16	0.34	1.09	7.09	0.67	0.69
17	0.28	0.74	2.16	0.49	0.64
18	0.26	0.93	4.13	0.46	0.58
19	0.26	0.86	4.00	0.37	0.45
20	0.26	1.02	5.79	0.53	0.69
21	0.22	1.11	7.58	0.56	0.52
22	0.24	1.09	6.94	0.22	0.92
23	0.24	1.04	5.96	0.45	0.49
24	0.25	0.93	4.38	0.44	0.39
25	0.22	0.94	5.07	0.33	0.58
26	0.25	1.05	6.64	0.36	0.49
27	0.28	0.88	3.62	0.36	0.79
28	0.23	1.09	7.23	0.55	0.55
29	0.22	1.13	8.38	0.39	0.55

30	0.22	0.91	4.04	0.52	0.65
31	0.28	1.29	12.22	0.69	0.53
32	0.28	1.24	10.88	0.56	0.93
33	0.25	1.04	5.68	0.28	0.59
34	0.25	1.09	7.53	0.37	0.89
35	0.25	1.05	7.07	0.34	0.67
36	0.25	1.28	12.72	0.45	0.55
37	0.23	1.04	6.67	0.38	0.67
38	0.22	1.19	10.19	0.31	0.75
39	0.22	1.23	11.37	0.31	0.69
40	0.16	1.29	13.53	0.16	0.78
41	0.27	1.14	7.46	0.55	0.65
42	0.27	1.02	5.23	0.39	0.82
43	0.26	1.09	6.61	0.31	0.82
44	0.25	1.21	9.53	0.08	0.97
45	0.23	1.20	9.42	0.19	0.83

Table. 4.3. Surface Runoff (mm) of Ebbanad Sub-Watersheds

Sub-Watershed No.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
1	1.87	16.87	6.79	25.14	1.59	1.74	19.16	12.92	10.79	18.57
2	0.12	7.28	1.36	13.22	0.21	0.16	8.86	4.71	3.44	8.44
3	0.07	7.02	1.21	12.91	0.17	0.11	8.59	4.5	3.24	8.17
4	1.59	15.27	5.89	23.16	1.37	1.48	17.44	11.56	9.57	16.88
5	0.82	13.45	4.51	21.16	0.67	0.74	15.56	9.86	7.95	15.0
6	1.16	10.65	3.53	17.2	1.13	1.15	12.42	7.7	6.17	11.96
7	1.69	13.59	4.47	21.44	0.54	0.61	15.74	9.92	7.98	15.18
8	0.65	9.57	2.7	16.01	0.65	0.65	11.3	6.69	5.22	10.84
9	0.86	12.66	4.19	20.02	0.77	0.81	14.64	9.22	7.42	14.1
10	1.05	14.79	3.98	16.26	3.02	1.66	12.47	8.82	7.24	9.98
11	1.46	6.06	1.76	10.79	1.61	1.52	7.3	4.11	3.17	6.97
12	0.71	10.33	3.08	16.97	0.69	0.7	12.11	7.32	5.77	11.64
13	0.91	13.32	8.60	21.08	3.41	0.71	24.77	7.40	13.95	7.80
14	2.02	20.48	12.45	29.41	5.34	1.70	30.94	13.35	18.85	15.14
15	0.45	14.16	3.27	15.32	2.31	0.92	11.77	7.95	6.55	8.85
16	0.36	15.23	3.47	16.02	2.77	1.12	12.23	8.59	6.95	9.33
17	0.35	15.11	2.87	13.15	3.22	1.16	10.25	7.59	6.13	6.61
18	0.63	15.78	3.41	13.82	3.77	1.60	10.9	8.23	6.75	7.23
19	2.72	7.25	1.73	6.15	1.80	1.67	4.62	3.36	2.74	2.94
20	0.30	13.39	2.16	11.53	2.46	0.74	8.83	6.38	5.05	5.48
21	0.50	9.24	5.27	15.40	1.77	0.60	18.56	4.98	9.51	5.35
22	1.17	6.33	3.81	11.33	1.45	1.34	14.28	2.99	6.95	3.04
23	0.62	7.70	3.15	11.17	1.11	0.46	12.8	3.27	6.24	3.12
24	0.36	9.31	2.68	11.22	1.35	0.39	11.55	4.05	5.75	3.67
25	0.33	13.96	2.39	12.06	2.71	0.88	9.29	6.77	5.4	5.85
26	0.60	9.89	1.09	8.34	1.28	0.30	6.11	4.16	3.14	3.47
27	1.17	8.46	1.04	7.10	1.18	0.56	5.16	3.50	2.64	2.92
28	0.71	10.28	4.66	15.97	1.67	1.23	18.08	7.00	9.11	8.12
29	0.66	8.91	3.71	13.93	1.32	1.14	15.6	6.24	7.58	7.41
30	0.32	13.98	2.41	12.10	2.72	0.89	9.34	6.79	5.43	5.86
31	0.39	6.43	0.93	9.13	0.44	0.93	8.44	6.21	3.29	8.30
32	1.02	8.84	1.90	11.98	1.11	1.90	11.17	8.58	5.05	11.0
33	1.06	13.15	2.73	11.43	3.01	1.43	8.91	6.63	5.40	5.80
34	0.88	9.80	1.30	8.29	1.49	0.56	6.14	4.26	3.28	3.59
35	0.62	8.09	1.63	8.83	0.99	0.45	8.44	3.29	3.99	2.87
36	0.74	9.77	1.17	8.24	1.36	0.42	6.07	4.16	3.17	3.49
37	0.24	7.12	3.17	12.08	0.84	0.47	14.2	4.17	6.59	4.9
38	0.82	5.67	1.44	7.81	0.73	0.81	8.09	3.27	3.45	3.78
39	0.36	6.26	0.87	8.92	0.41	0.87	8.24	6.04	3.17	8.09
40	0.21	4.99	0.51	7.36	0.23	0.51	6.75	4.80	2.33	6.62
41	1.15	10.61	2.35	14.16	1.28	2.35	13.26	10.31	6.19	13.07
42	1.08	8.19	1.84	11.12	1.16	1.84	10.37	7.95	4.69	10.21
43	1.42	7.07	1.94	9.57	1.47	1.94	8.93	6.87	4.16	8.79
44	1.30	3.15	1.12	4.63	1.26	1.12	4.24	3.04	1.70	4.16
45	1.56	6.69	1.99	9.04	1.59	1.99	8.44	6.51	3.99	8.31

The exponent “m” of runoff factor in MUSLE and the α (parameter express the portion of total rainfall that occurs during time of concentration) are the tuning parameters of DSYM. For the first few runs, both the parameters were simultaneously adjusted and the Per cent Error (PE) of sediment routing module was examined. The α - value was adjusted within the range of 0.06 to 1. Thus the increasing or decreasing direction of PE was viewed. By adjusting m – value in smaller increments on either direction, the PE was examined. The “m” value at minimum PE level was fixed to optimise the α parameter. The value of α was then changed with the fixed m value to get further reduction in PE values. By repeated runs suitable values for the parameters within the range was finalized for the events under calibration of Ebbanad watershed. The storm events were splitted into smaller and larger storm events for calibration.

The outputs of peak runoff rate module are presented in Table 4.4 and 4.5. The maximum travel time for channel flow and surface flow of the sub-watersheds of study area were 1.56 and 2.21 hr respectively. The time of concentration is the sum of both channel and surface flow travel time. The time of concentration of sub-watersheds of study area was ranged from 1.93 to 3.36 hr (Table 4.4). The values of peak runoff rate obtained for each storm event under calibration is summarised in Table 4.5.

The output of sediment yield module for all the storm events is presented in Table 4.6. The map depicting the areas under different categories of sediment yield of Ebbanad watershed for storm events E1, E2, E5, E8 and E9 are presented in Fig. 4.24 to 4.28. The sediment yield was observed to be minimum in the range of 0 – 2 tons on Reserve forest and Perennial crop areas for all the storm events. The maximum of 40 to 60 ton was from annual crop areas for E2 and on an average between 4 to 20 tons for all other storms. The model output of sediment yield indicated that the sub-watershed No. 31 contributed higher sediment yield for all storm events, even though the surface runoff of

Table 4.4. Output parameters of Peak Runoff Rate Module for Ebbanad Watershed

Sub-Watershed No.	Channel flow time of concentration (hr)	Surface flow time of concentration (hr)	Time of concentration (hr)
1	0.80021	1.66433	2.46455
2	0.32700	1.55915	1.88615
3	0.71210	1.53861	2.25072
4	0.43635	1.55606	1.99241
5	0.82169	1.62310	2.44479
6	0.88016	1.77213	2.65229
7	1.01155	1.69687	2.70842
8	0.84830	1.73316	2.58147
9	0.57069	1.96953	2.54022
10	0.98157	2.01703	2.99861
11	0.45396	1.89922	2.35319
12	1.16422	1.72801	2.89223
13	0.57719	1.78182	2.35901
14	0.51889	1.78397	2.30286
15	0.56718	1.70811	2.27530
16	0.58172	1.68069	2.26241
17	0.62697	2.12337	2.75035
18	0.66644	1.87550	2.54194
19	0.48270	1.90226	2.38497
20	0.42771	1.76745	2.19517
21	1.38949	1.73035	3.11984
22	0.43416	1.72880	2.16296
23	0.75598	1.76283	2.51881
24	0.74118	1.85384	2.59503
25	1.13951	1.81757	2.95708
26	0.69897	1.73351	2.43249
27	0.59301	1.95426	2.54727
28	1.56668	1.79666	3.36334
29	1.14178	1.72621	2.86798
30	0.46284	1.88909	2.35190
31	0.60254	1.70862	2.31117
32	0.50534	1.72877	2.23412
33	0.38851	1.77940	2.16791
34	0.54080	1.73455	2.27536
35	0.45776	1.74633	2.20410
36	0.33606	1.59647	1.93254
37	0.72542	1.80301	2.52843
38	0.68406	1.71712	2.40118
39	0.50030	1.69471	2.19502
40	0.28930	1.67377	1.96308
41	0.35044	1.86964	2.22008
42	0.73439	2.00378	2.073818
43	0.59709	1.90985	2.50694
44	0.54644	1.82523	2.37167
45	0.44592	1.79341	2.23934

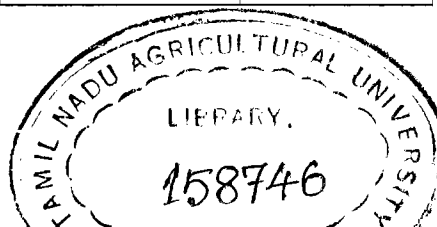


Table 4.5. Peak Runoff Rate (m³/s) of Ebbanad Watershed

Ws_id	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
1	0.03931	0.3095	0.0623	0.3295	0.0406	0.0285	0.4393	0.1016	0.1838	0.4257
2	0.00253	0.1291	0.012	0.1675	0.0052	0.0025	0.1964	0.0358	0.0566	0.1872
3	0.00469	0.3899	0.0336	0.5121	0.013	0.0056	0.5961	0.107	0.1672	0.5675
4	0.03433	0.2882	0.0556	0.3121	0.036	0.025	0.4114	0.0934	0.1676	0.398
5	0.02881	0.4153	0.0696	0.467	0.0289	0.0205	0.6008	0.1305	0.2281	0.5795
6	0.0225	0.1802	0.0298	0.2078	0.0268	0.0173	0.2626	0.0558	0.0971	0.2529
7	0.01804	0.313	0.0514	0.3527	0.0172	0.0126	0.4531	0.098	0.1707	0.4369
8	0.02446	0.3157	0.0447	0.3776	0.0301	0.019	0.4664	0.0947	0.1601	0.4476
9	0.01652	0.2119	0.0351	0.2396	0.018	0.0122	0.3067	0.0662	0.1155	0.2954
10	0.03312	0.4067	0.0547	0.3193	0.1155	0.0408	0.4288	0.1039	0.185	0.3431
11	0.02631	0.0959	0.0139	0.122	0.0354	0.0215	0.1443	0.0279	0.0466	0.1379
12	0.00146	0.0186	0.0028	0.0218	0.0017	0.0011	0.0272	0.0056	0.0096	0.0262
13	0.03309	0.4222	0.1365	0.4776	0.1508	0.0201	0.9823	0.1007	0.4108	0.3094
14	0.03009	0.2664	0.081	0.2733	0.0967	0.0197	0.5031	0.0744	0.2278	0.2461
15	0.00855	0.2381	0.0276	0.1842	0.0542	0.0138	0.2476	0.0574	0.1024	0.1863
16	0.00756	0.2827	0.0322	0.2124	0.0715	0.0186	0.2837	0.0683	0.1198	0.2165
17	0.00658	0.2469	0.0235	0.1535	0.0734	0.0169	0.2093	0.0532	0.0931	0.135
18	0.00951	0.2077	0.0224	0.1299	0.0692	0.0189	0.1794	0.0464	0.0825	0.119
19	0.07815	0.1819	0.0217	0.1102	0.0631	0.0374	0.1448	0.0361	0.064	0.0921
20	0.00529	0.2044	0.0165	0.1258	0.0524	0.0101	0.1685	0.0417	0.0716	0.1046
21	0.03467	0.5589	0.1595	0.6659	0.1495	0.0323	1.4049	0.1293	0.5347	0.4027
22	0.02321	0.1102	0.0332	0.1409	0.0352	0.0208	0.3108	0.0223	0.1123	0.0662
23	0.01907	0.209	0.0427	0.2165	0.042	0.011	0.4338	0.038	0.1571	0.1059
24	0.01237	0.2792	0.0402	0.2403	0.0563	0.0105	0.4332	0.0521	0.1602	0.1378
25	0.00807	0.301	0.0258	0.1858	0.0814	0.017	0.2505	0.0626	0.1082	0.1576
26	0.00843	0.1215	0.0067	0.0732	0.022	0.0033	0.0939	0.0219	0.0358	0.0533
27	0.03134	0.1978	0.0121	0.1185	0.0385	0.0116	0.1508	0.0351	0.0576	0.0854
28	0.04207	0.5297	0.12	0.5883	0.12	0.0567	1.1654	0.1548	0.4361	0.5232
29	0.05752	0.6852	0.1425	0.7655	0.141	0.0782	1.5001	0.2058	0.5412	0.7125
30	0.00834	0.3193	0.0275	0.1975	0.0867	0.0181	0.2668	0.0665	0.1153	0.1675
31	0.02511	0.357	0.0259	0.362	0.0342	0.0461	0.5855	0.1478	0.1749	0.5753
32	0.0268	0.1952	0.021	0.1889	0.034	0.0375	0.3085	0.0812	0.1035	0.3038
33	0.0186	0.2017	0.0209	0.1252	0.0642	0.0196	0.1707	0.0436	0.0769	0.1112
34	0.01355	0.1319	0.0088	0.0798	0.028	0.0068	0.1034	0.0246	0.041	0.0605
35	0.01218	0.1396	0.0141	0.109	0.0237	0.0069	0.1824	0.0244	0.0641	0.0619
36	0.01555	0.1804	0.0108	0.1088	0.0351	0.0069	0.14	0.0329	0.0543	0.0805
37	0.00958	0.2461	0.0549	0.2987	0.0403	0.0146	0.6144	0.0618	0.212	0.2119
38	0.03288	0.1992	0.0253	0.1959	0.0355	0.0253	0.3551	0.0493	0.1125	0.166
39	0.02238	0.3366	0.0235	0.3427	0.0305	0.0419	0.5537	0.1393	0.1585	0.5441
40	0.00612	0.1282	0.0066	0.1354	0.0081	0.0117	0.2171	0.053	0.0556	0.2129
41	0.01672	0.1347	0.0149	0.1285	0.0227	0.0266	0.2106	0.0561	0.0731	0.2076
42	0.04586	0.3229	0.0363	0.3131	0.0635	0.0649	0.5106	0.1343	0.1715	0.5033
43	0.03738	0.1629	0.0223	0.1574	0.047	0.0398	0.257	0.0678	0.0889	0.2531
44	0.02433	0.0515	0.0092	0.0541	0.0288	0.0164	0.0866	0.0213	0.0258	0.0849
45	0.04581	0.1721	0.0256	0.1662	0.0571	0.0458	0.2714	0.0717	0.0954	0.2673

Ws_id – Sub-Watershed No.

Table 4.6. Sediment Yield (tons) of Ebbanad Watershed

Ws_id	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
1	2.053	8.247	3.476	11.831	1.667	2.275	9.542	4.734	5.589	10.282
2	0.249	2.499	0.853	3.7139	0.236	0.466	3.148	1.544	1.400	3.092
3	0.004	0.066	0.019	0.109	0.005	0.008	0.081	0.036	0.035	0.084
4	2.248	9.212	3.874	13.233	1.810	2.545	10.740	5.341	6.169	11.468
5	2.232	12.814	4.853	19.489	1.656	2.650	15.012	7.122	8.185	16.200
6	1.466	5.376	2.299	7.613	1.234	1.792	6.473	3.300	3.459	6.617
7	2.207	13.732	5.315	20.427	1.523	2.723	16.186	7.826	8.775	17.229
8	1.007	5.102	1.897	7.792	0.842	1.282	6.146	2.936	3.110	6.418
9	0.726	3.623	1.489	5.185	0.553	0.909	4.308	2.159	2.334	4.476
10	1.050	5.536	1.845	6.004	1.909	1.549	5.124	2.709	3.070	4.596
11	1.510	3.115	1.431	4.351	1.418	1.846	3.933	2.075	1.902	3.774
12	0.861	3.283	1.750	3.844	0.596	1.317	4.158	2.507	2.151	3.783
13	1.639	8.775	4.733	13.433	3.562	1.789	14.616	4.153	8.555	6.460
14	1.998	8.636	4.522	12.006	3.550	2.148	12.328	4.494	7.655	7.716
15	1.698	13.586	4.473	13.788	4.105	3.297	12.591	6.806	7.311	10.402
16	2.500	24.325	7.717	24.542	7.842	5.987	21.857	11.921	12.889	18.436
17	0.278	2.679	0.783	2.224	0.971	0.687	2.130	1.2450	1.305	1.523
18	0.677	4.696	1.495	3.876	1.855	1.393	3.796	2.259	2.385	2.765
19	1.077	1.861	0.697	1.372	0.783	0.924	1.442	0.915	0.879	0.961
20	1.012	9.585	2.662	7.668	3.174	2.245	7.513	4.455	4.452	5.107
21	1.857	11.288	5.750	18.017	3.754	2.543	19.932	5.294	10.886	8.190
22	1.443	3.535	2.357	5.043	1.442	1.885	7.076	1.875	3.7199	2.069
23	1.032	4.468	2.185	5.616	1.275	1.178	7.010	2.049	3.690	2.326
24	0.428	2.956	1.130	3.247	0.829	0.619	3.703	1.311	1.979	1.525
25	0.424	4.114	1.122	3.430	1.391	0.949	3.219	1.852	1.931	2.264
26	0.753	3.711	0.924	2.699	0.994	0.770	2.817	1.744	1.543	1.694
27	1.095	3.453	0.876	2.574	0.960	0.949	2.579	1.553	1.412	1.571
28	2.203	11.668	5.214	17.496	3.449	3.415	18.655	6.234	6.372	11.027
29	2.370	12.295	5.175	18.733	3.380	3.630	19.536	6.597	10.255	12.174
30	0.459	4.544	1.233	3.816	1.535	1.040	3.561	2.034	2.136	2.509
31	8.555	44.598	11.942	56.701	7.466	16.425	58.359	31.796	26.351	61.958
32	5.173	18.005	6.179	21.325	4.638	8.289	23.053	13.245	11.469	24.086
33	1.327	6.000	1.917	4.824	2.316	1.901	4.799	2.891	2.969	3.399
34	1.599	6.319	1.731	4.646	1.890	1.708	4.843	3.003	2.726	3.001
35	0.950	4.070	1.418	3.775	1.046	1.109	4.564	1.886	2.349	1.871
36	3.816	17.214	4.297	12.975	4.780	3.890	13.021	7.839	7.212	8.068
37	0.821	5.872	2.982	8.657	1.448	1.607	10.542	3.219	5.354	4.779
38	2.482	7.345	2.899	8.508	1.952	3.030	10.368	4.168	4.944	5.741
39	1.830	9.771	2.589	12.377	1.578	3.591	12.837	7.023	5.677	13.574
40	0.577	3.320	0.858	3.908	0.436	1.303	4.5612	2.684	1.858	4.550
41	2.918	10.432	3.716	11.986	2.640	5.019	13.303	7.828	6.786	13.762
42	2.177	7.525	2.514	9.282	2.054	3.286	9.562	5.305	4.759	10.210
43	2.092	5.124	2.103	5.848	1.910	2.811	6.609	3.927	3.362	6.765
44	0.966	1.281	0.766	1.326	0.819	1.100	1.800	1.189	0.820	1.675
45	2.147	4.829	2.072	5.502	1.983	2.746	6.221	3.701	3.202	6.368

Ws_id – Sub-Watershed No.

Fig. 4.24. Sediment Yield (tons) map of E1 for Ebbanad Watershed

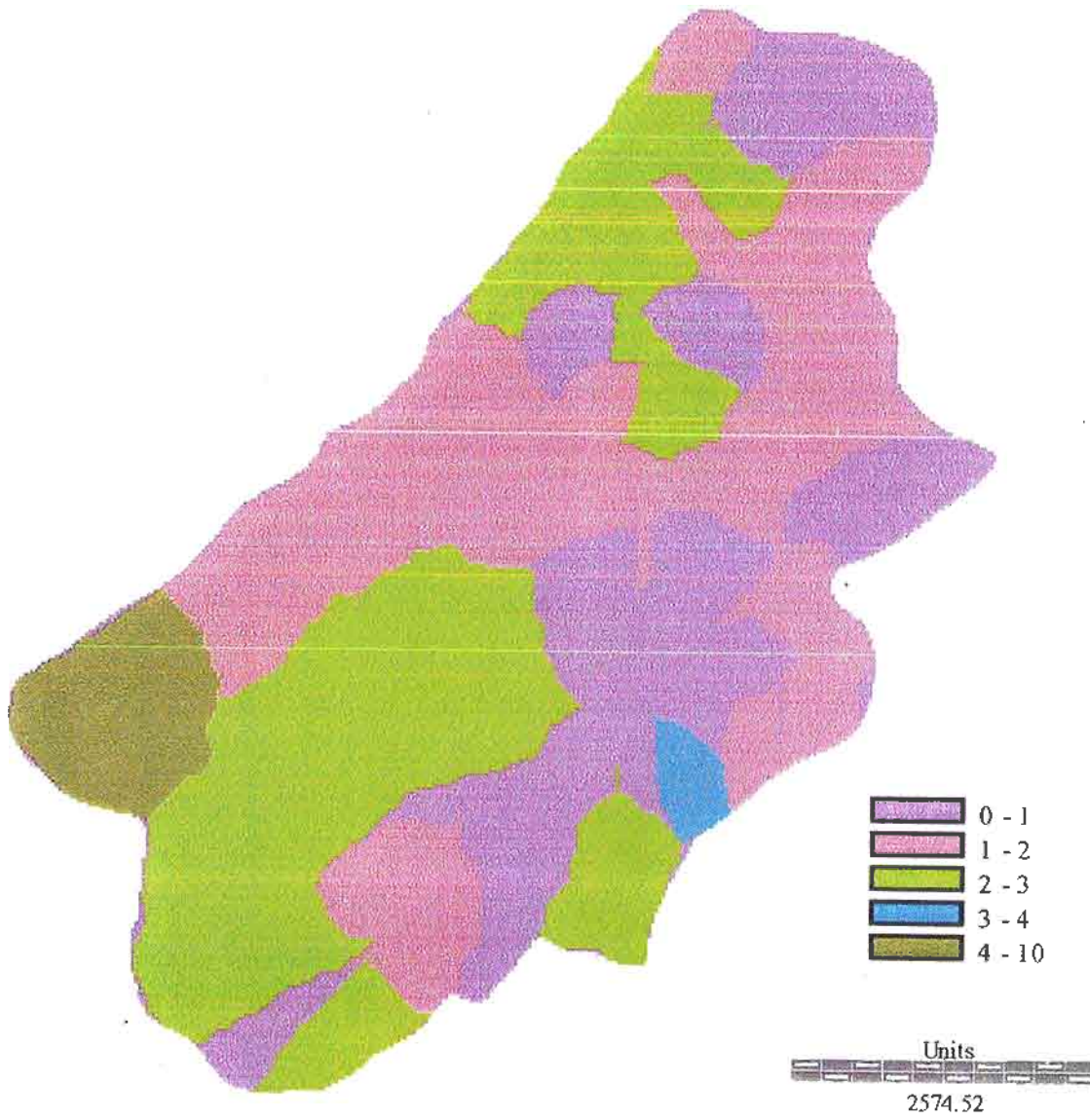


Fig. 4.25. Sediment Yield (tons) of E2 for Ebbanad Watershed

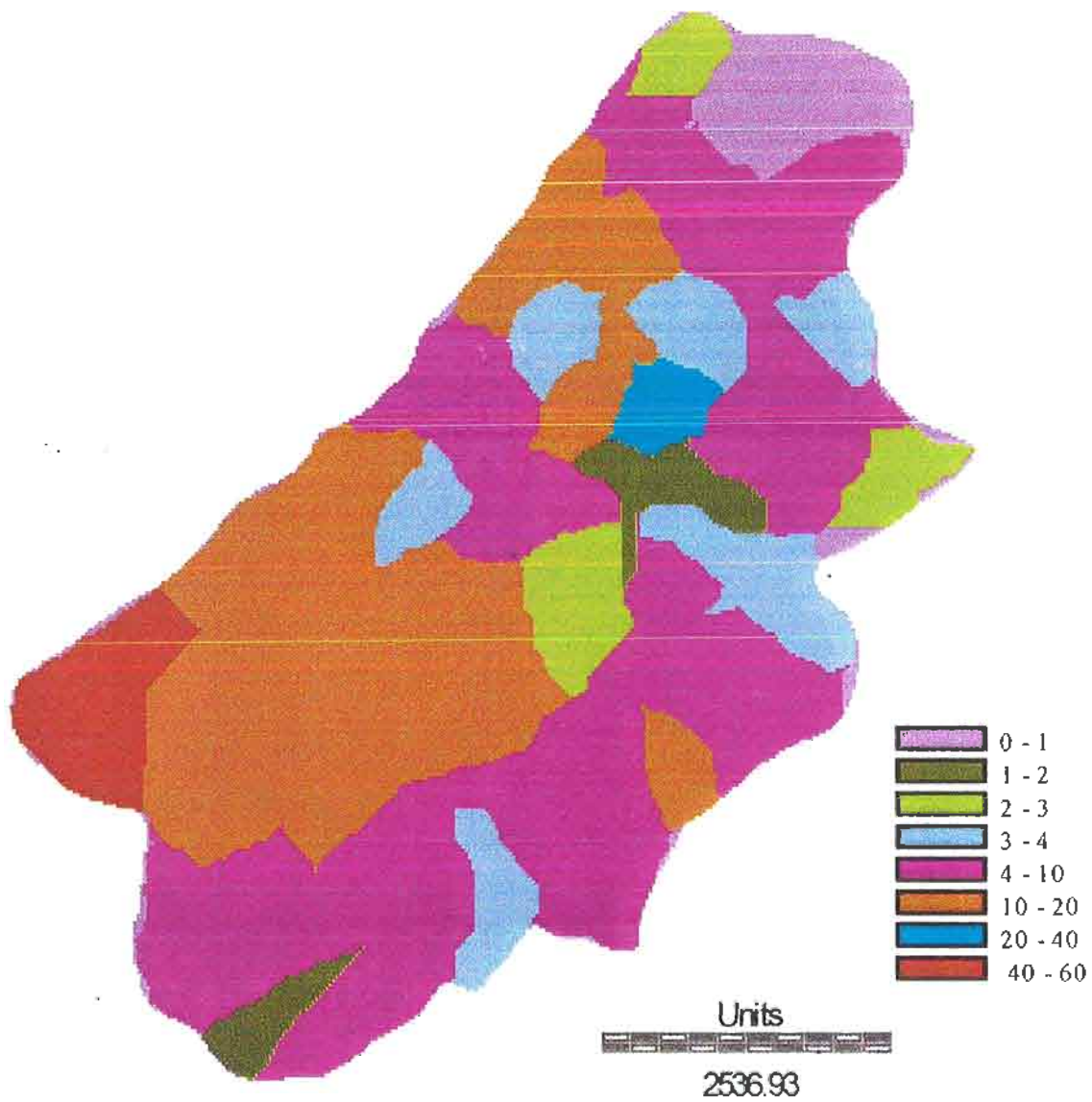


Fig. 4.26. Sediment Yield (tons) map of E5 for Ebbanad Watershed

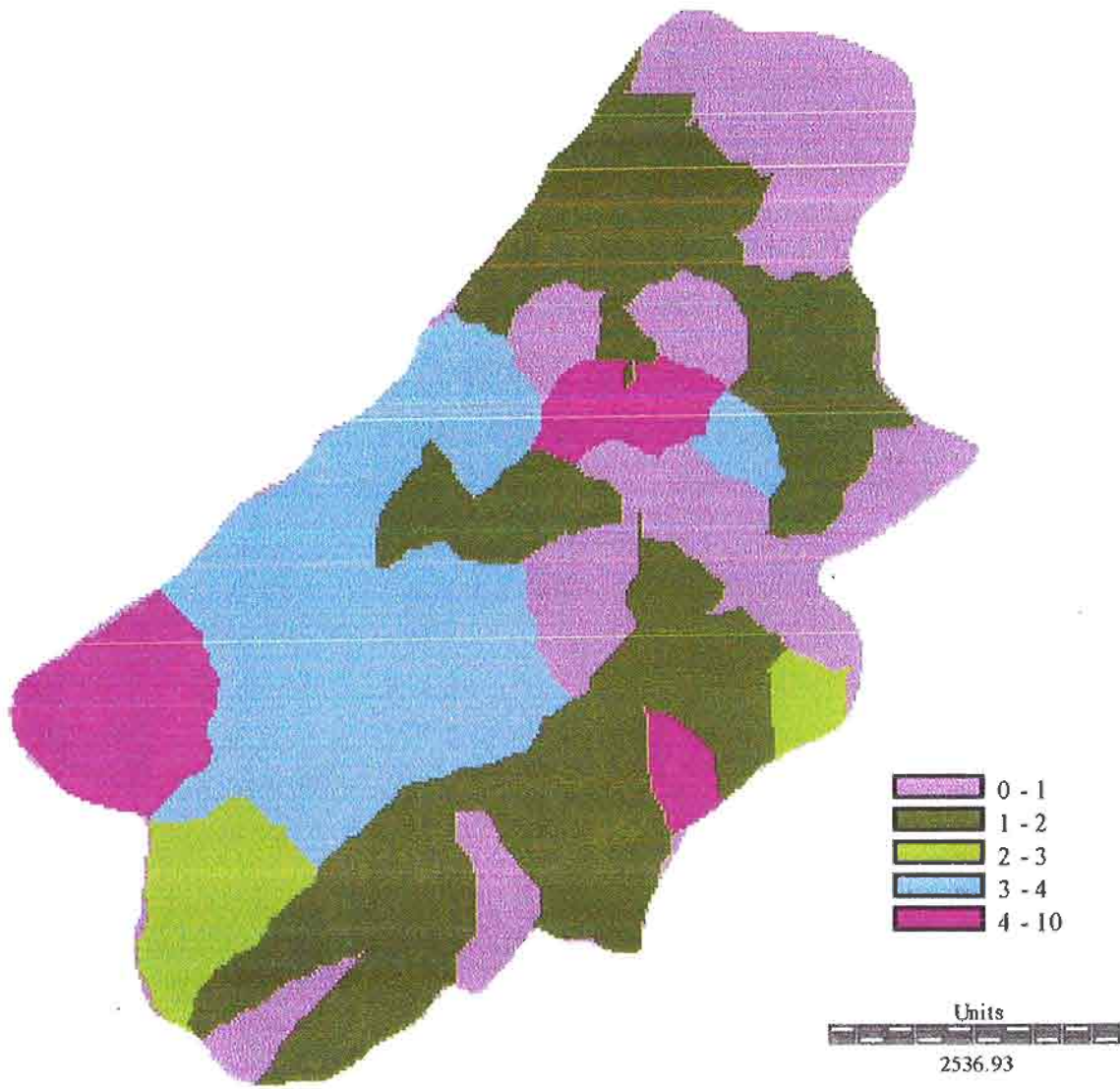


Fig. 4.27. Sediment Yield (tons) map of E8 for Ebbanad Watershed

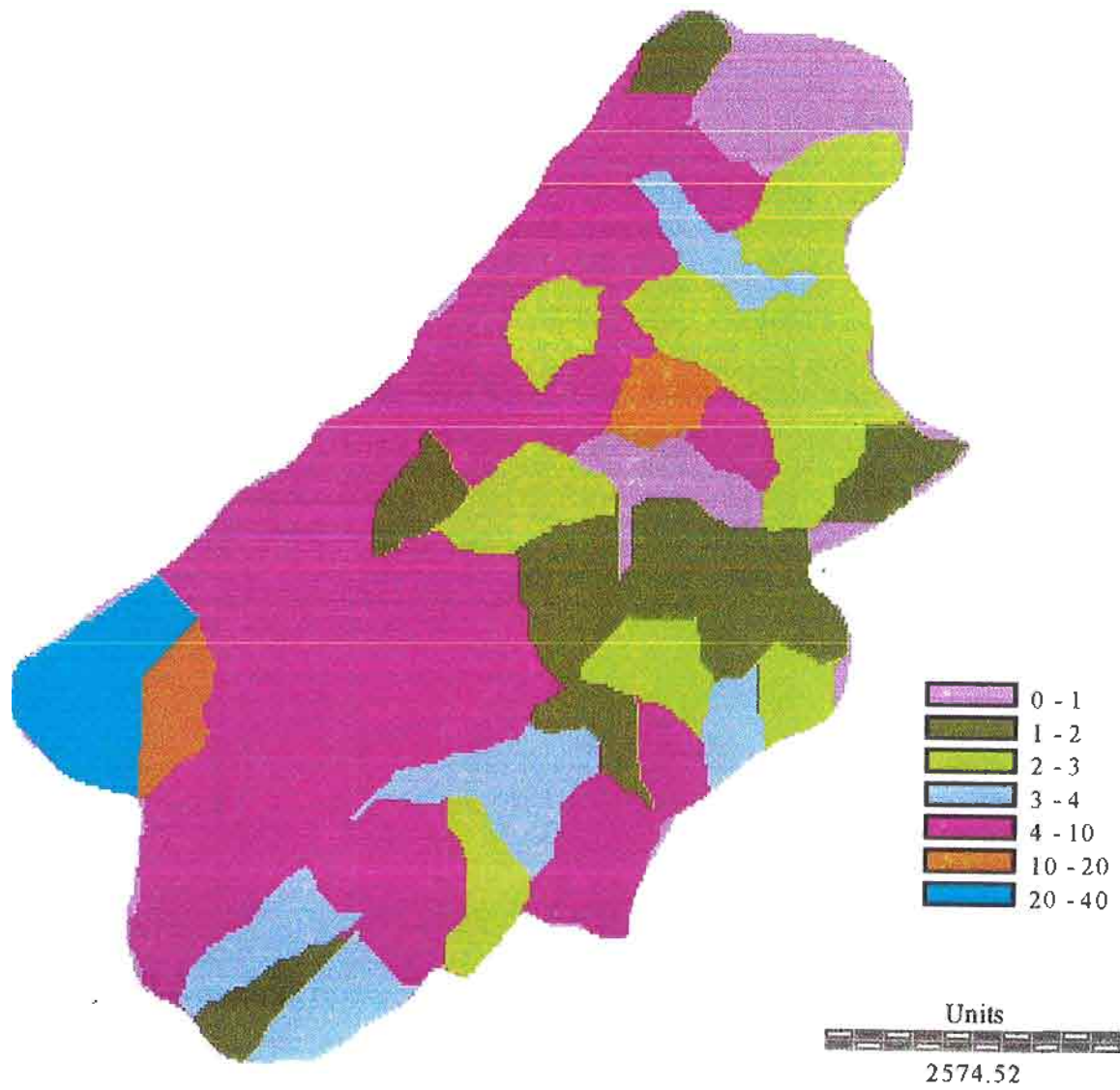
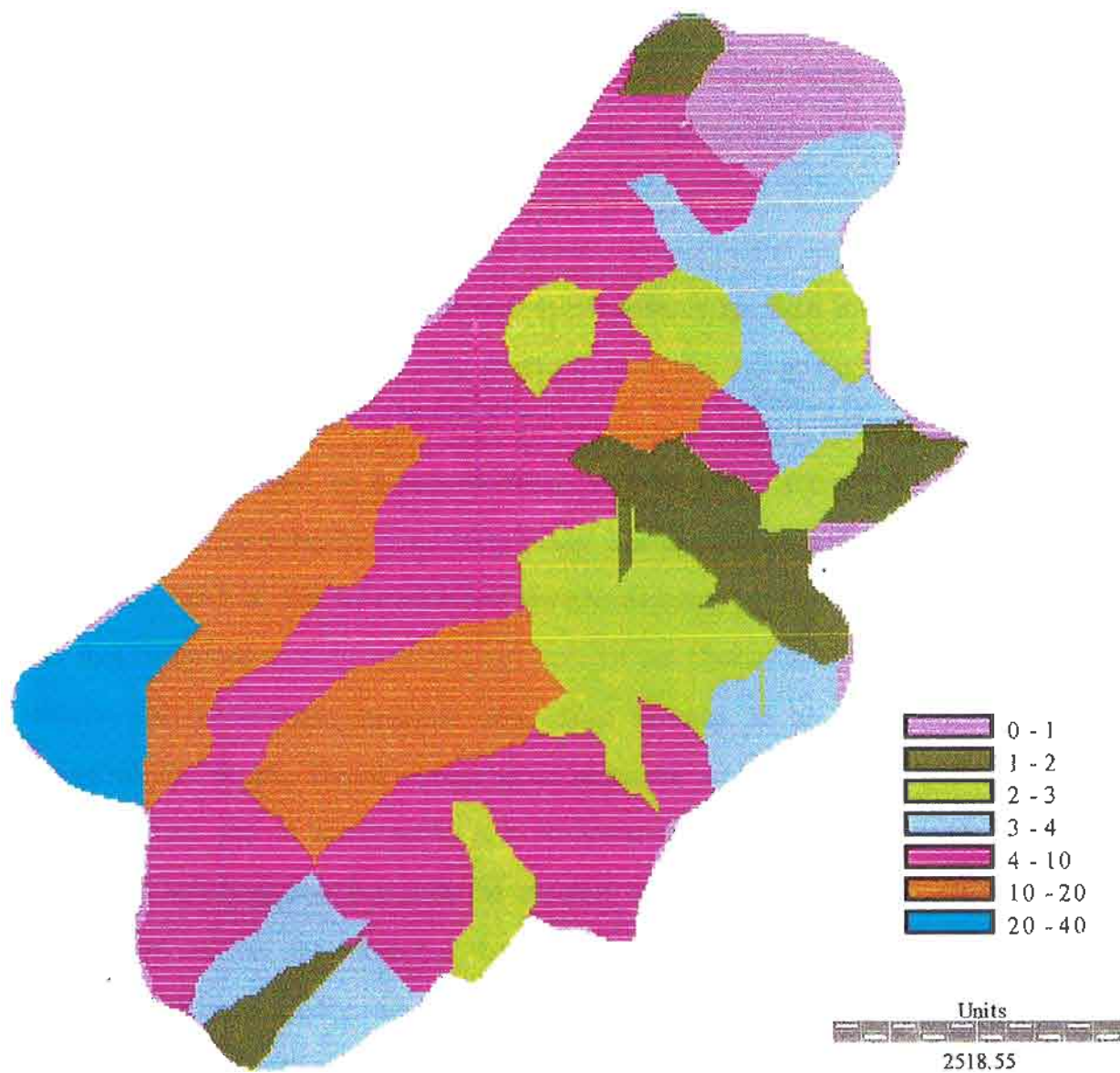


Fig. 4.28. Sediment Yield (tons) of E9 for Ebbanad Watershed



the sub-watershed was not maximum. This may be due to the combination of areas under soil of sandy clay loam, maximum area of up and down cultivation of annual crops and the slope range of greater than 13 per cent. In some Perennial crop areas, the value of sediment yield was found to be higher than 2 tons. Higher sediment yield on the areas of perennial crops may be due to the initial period of tea plantation and absence of any vegetation canopy and suitable conservation measures. Similar result was reported by Chinnamani, (1977) that initial years of tea planting without any conservation measures soil loss ranges from 28 to 40 ton/ha/yr.

In the study area some of the regions of annual crops were switched over to tea plantation after dismantling outwardly sloping terraces due to high remunerative value of tea and high risk of vegetable cultivation. Farmers have an opinion that area available for tea planting is reduced by bench terracing while in reality more cultivable area is available due to terracing by considering bench area and terrace risers which ultimately reduces the soil loss. Similar suggestions were documented by Madhu and Sikka (2000) and they estimated that the soil loss on the new tea plantation on 20 per cent slope without soil conservation measures was varied between 16 to 40 ton/ha/yr in the watershed of Nilgiris. Hence, conservation measures such as contour trenches and mulches alone and in combination are recommended on the initial periods of tea plantation. Mulching also improves the physical condition of the soil in additions of reducing the soil loss and conserving the soil moisture. Utilization of bench terrace risers for raising of tea not only maintains and stabilises the terrace risers but also provides additional yield and income to the farmers.

4.3. Results of calibration

The values of parameters obtained at the end of calibration runs are presented in Table 4.7 and 4.8. For the smaller and larger events the m value was in the range of 0.22 to 0.39 and 0.37 to 0.42 respectively. A statistical analysis of the calculated values of exponent showed that the mean value was 0.29 and 0.41 for smaller and larger storm events respectively. Whereas the α value was varied from 0.1 to 0.39 for smaller events and it was 0.35 for larger events. The optimized α value for DSYM was estimated to be 0.28 for smaller events and 0.35 for larger events. The sediment storage coefficient (K_s) for both the storm events was found to be varied from 1.06 to 2.83 and 1.4 to 2.19 respectively. The estimated sediment yield after routing the sediment yield values from sediment yield module is presented with measured sediment yield and the calculated PE (Table 4.8). The error in the predicted sediment yield as compared to the measured values to be in the range of -6.65 to 13.66 with a correlation coefficient of 0.99. Similar results were reported by Das and Chauhan (1990) for hilly watersheds with a mean exponent value of 0.257 and correlation coefficient of 0.81. The values of Predicted Vs measured sediment yield on 1:1 slope is presented in the Fig. 4.29, which represents the best fit of DSYM.

4.4. Results of simulation

The two parameters, namely m and α of DSYM were estimated for each event by minimizing PE between the observed and predicted sediment yield. Model performance was measured by the coefficient of efficiency CE (Nash & Sutcliffe, 1970), found to be 0.98 and the coefficient of determination R^2 of 0.9826 for DSYM.

Table 4.7. Tuning Parameters of DSYM

Storm Events Code – MM/DD/YY	m	α
E1 - 9/28/1996	0.29	0.32
E2 - 8/18/1996	0.39	0.28
E3 -10/7/1996	0.31	0.1
E5 -11/8/1996	0.35	0.39
E6 -4/19/1997	0.22	0.25
E8 -5/11/1997	0.29	0.12
E9 -10/7/1997	0.37	0.26
E4 -11/5/1993(LSE)	0.42	0.35
E7 -4/27/1995(LSE)	0.37	0.35
E10 -11/21/1995(LSE)	0.42	0.35

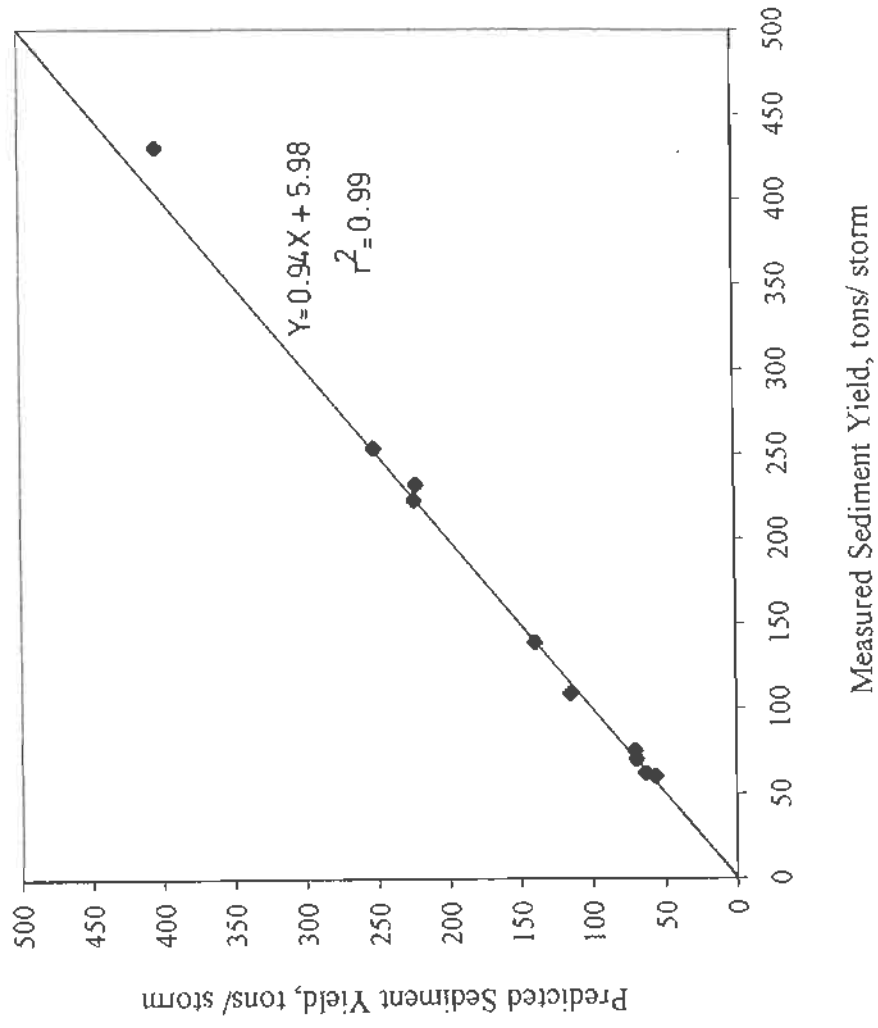
LSE – Large Storm Event

Table 4.8. Observed Vs. Predicted Sediment Yield of Ebbanad Watershed

Storm Events Code – MM/DD/YY	Ks	Observed Sediment Yield (tons)	Predicted Sediment Yield (tons)	Per cent Error
E1 - 9/28/1996	2.21	60	56.85	-5.56
E2 - 8/18/1996	1.37	238.28	223.74	-6.72
E3 -10/7/1996	1.61	60.09	69.6	13.66
E5 -11/8/1996	1.09	75.05	70.76	-6.07
E6 -4/19/1997	1.06	61.99	63.53	2.42
E8 -5/11/1997	2.83	108.91	114.56	4.93
E9 -10/7/1997	1.24	126.91	139.59	9.08
E4 -11/5/1996(LSE)	2.19	430	403.19	-6.65
E7 -4/27/1997(LSE)	1.4	229.26	251.56	8.86
E10 -11/21/1997(LSE)	1.38	245.02	222.14	-10.3

LSE – Large Storm Event

Fig. 4.29. Predicted Vs. Measured Sediment Yield of Ebbanad Watershed



4.5. Validation of DSYM

DSYM was validated with three small storm events (E11, E12 & E13) and one large event (E14) on Ebbanad watershed. The surface runoff as an output of GIS for all the events is tabulated in Table 4.9. The outputs of peak runoff rate and sediment yield module are presented in Table 4.10 and 4.11. The Ks value of smaller storm events was well within the estimated range whereas for the larger storm event it was slightly on higher side (3.06). The PE was found to be varied from – 1.64 to 16.09 (Table 4.12).

DSYM was validated with a real watershed namely Katteri Watershed of Lower Bhavani Catchment, Nilgiris district. The boundary with streamlines of the watershed is shown in Fig. 4.30. The area of the watershed is 2911 ha with the fifth order stream. The outputs from GIS for Katteri watershed are pictorially represented in Fig. 4.31 to 4.41. The landuse map (Fig. 4.31) shows the categories of landuse / landcover in the watershed are: Annual Crops (AC), Perennial Crops (PC), Building (Bldg), Reserve forest (RF), Wasteland (Wl), Trees (Tr), Current Fallow (CF) and WaterBodies (WB). Out of the total 2911 ha, AC and PC cover 863.63 ha (30 per cent) and 1321.01 ha (45 per cent) respectively. The Reserve forest covers the area of 45.36 ha, whereas 76.85 ha of land is left under fallow. Water Bodies occupies an area of 21.06 ha. Major soil type (Fig. 4.32) of the watershed is sandy loam (972.26 ha) and lowest area is under sandy clay loam (467.1 ha). The variability of conservation measures are shown in the Fig. 4.33, and the maximum area (1635.8 ha) is left without any measures. The K, C, and P factors were derived from GIS and shown in the Fig. 4.34 to 4.36.

The Digital Elevation Model for Katteri watershed is presented in the Fig. 4.37. The highest per cent of area (47.26 per cent) was under the slope group of 15 to 33 like Ebbanad Watershed (Fig. 4.38). The L and S – factor was derived from the DEM of the watershed (Fig. 4.39 and 4.40).

The watershed was divided into 38 sub watersheds whose area ranged from 28.08 to 239.85 ha (Fig. 4.41). The sub-watershed wise values of input parameters of DSYM are given in the Table 4.13 and 4.14. The outputs of evaluation of DSYM on Katteri

Table 4.9. Surface runoff (mm) of Ebbanad Watershed - Validation

Ws_id	E11	E12	E13	E14
1	1.04	12.92	2.31	20.02
2	1.64	4.71	0.80	9.47
3	1.65	4.50	0.03	9.19
4	1.13	11.56	1.95	18.27
5	0.93	9.86	1.07	16.36
6	1.98	7.7	1.26	13.1
7	0.80	9.92	0.95	16.56
8	1.69	6.69	0.7	11.96
9	1.16	9.22	1.09	15.42
10	1.92	8.82	2.89	13.47
11	3.34	4.11	1.31	7.78
12	1.57	7.32	0.81	12.81
13	0.96	7.40	1.49	18.12
14	1.55	13.35	3.34	25.4
15	1.10	7.95	2.14	25.4
16	1.36	8.59	2.57	13.31
17	1.25	7.59	2.87	11.38
18	1.70	8.23	3.41	12.04
19	1.65	3.36	1.73	5.19
20	0.81	6.38	2.16	9.88
21	0.64	4.98	0.83	13.72
22	1.14	2.99	1.04	9.42
23	0.38	3.27	0.55	9.29
24	0.35	4.05	0.87	9.38
25	0.95	6.77	2.39	10.37
26	0.33	4.16	1.09	6.97
27	0.57	3.5	1.04	5.9
28	1.39	7.0	1.53	15.97
29	1.26	6.24	1.33	14.35
30	0.96	6.79	2.4	10.4
31	1.14	6.21	1.16	12.47
32	2.21	8.58	2.24	15.76
33	1.49	6.63	2.73	9.89
34	1.59	4.26	1.30	6.97
35	0.38	3.29	0.77	7.29
36	0.45	4.16	1.17	6.91
37	0.47	4.17	0.5	11.66
38	0.75	3.27	0.78	7.94
39	1.04	6.04	1.09	12.23
40	0.65	4.80	0.67	10.36
41	2.74	10.31	2.77	18.4
42	2.11	7.95	2.14	14.68
43	2.14	6.87	2.15	12.66
44	1.12	3.04	1.13	6.63
45	2.17	6.51	2.18	11.97

Table 4.10. Peak runoff rate (m³/s) of Ebbanad Watershed - Validation

Sub-Watershed No.	E11	E12	E13	E14
1	0.01911	0.04231	0.06295	0.45925
2	0.02916	0.00134	0.00331	0.20995
3	0.09187	0.00069	0.00538	0.63830
4	0.02134	0.03668	0.05472	0.43086
5	0.02867	0.03318	0.05703	0.63189
6	0.03347	0.02134	0.02850	0.27702
7	0.01839	0.02183	0.04004	0.47671
8	0.05568	0.02321	0.03424	0.49392
9	0.01946	0.01834	0.02967	0.32289
10	0.05290	0.07944	0.09204	0.46295
11	0.05279	0.02071	0.01887	0.15392
12	0.00282	0.00145	0.00220	0.02879
13	0.03051	0.04739	0.07419	0.71836
14	0.02011	0.04338	0.06308	0.41314
15	0.01852	0.03604	0.04383	0.26591
16	0.02518	0.04779	0.05638	0.30873
17	0.02039	0.04704	0.05267	0.23243
18	0.02236	0.04489	0.04967	0.19817
19	0.04150	0.04346	0.04529	0.16305
20	0.01235	0.03294	0.03759	0.18863
21	0.03905	0.05032	0.09162	1.03864
22	0.01991	0.01815	0.01965	0.20519
23	0.01036	0.01486	0.02066	0.31504
24	0.01061	0.02618	0.03320	0.35170
25	0.02059	0.05156	0.05846	0.27961
26	0.00404	0.01334	0.01577	0.10706
27	0.01321	0.02420	0.02761	0.17255
28	0.07173	0.07880	0.15456	1.02967
29	0.09651	0.10221	0.20618	1.37963
30	0.02196	0.05490	0.06219	0.29726
31	0.06328	0.06440	0.16449	0.86565
32	0.04877	0.04941	0.10229	0.43521
33	0.02286	0.04184	0.04613	0.18955
34	0.00790	0.01757	0.02011	0.11743
35	0.00651	0.01332	0.01553	0.15750
36	0.00821	0.02162	0.02517	0.15945
37	0.01619	0.01747	0.04391	0.50425
38	0.02627	0.02729	0.04401	0.34847
39	0.05774	0.05882	0.15329	0.82216
40	0.01678	0.01714	0.05295	0.33343
41	0.03476	0.03523	0.07246	0.29223
42	0.08337	0.08439	0.16970	0.72346
43	0.04918	0.04961	0.08864	0.36457
44	0.01837	0.01839	0.02578	0.13557
45	0.05569	0.05613	0.09541	0.38496

Table 4.11. Sediment Yield (tons) of Ebbanad Watershed – Validation

Ws_id	E11	E12	E13	E14
1	1.405	2.228	2.805	10.505
2	1.072	0.180	0.303	3.366
3	0.026	0.001	0.005	0.090
4	1.774	2.428	3.063	11.277
5	2.313	2.517	3.447	16.662
6	1.918	1.477	1.747	6.977
7	2.319	2.564	3.643	17.824
8	1.687	1.015	1.273	6.743
9	0.830	0.802	1.060	4.682
10	1.432	1.813	1.974	5.712
11	2.351	1.366	1.295	4.133
12	1.313	0.893	1.138	4.191
13	1.625	2.098	2.721	12.473
14	1.645	2.570	3.193	11.398
15	2.763	4.066	4.555	13.720
16	5.226	7.577	8.340	24.199
17	0.558	0.906	0.968	2.369
18	1.156	1.733	1.838	4.184
19	0.776	0.797	0.816	1.561
20	1.720	3.038	3.283	8.295
21	2.067	2.394	3.391	17.208
22	1.373	1.301	1.363	5.292
23	0.754	0.929	1.125	5.696
24	0.407	0.688	0.789	3.279
25	0.760	1.294	1.392	3.595
26	0.512	1.022	1.127	3.070
27	0.689	0.980	1.057	2.842
28	3.121	3.296	4.872	18.451
29	3.326	3.438	5.166	20.019
30	0.837	1.424	1.530	3.979
31	15.205	15.355	26.468	83.444
32	7.706	7.765	11.842	31.407
33	1.556	2.208	2.337	5.267
34	1.217	1.932	2.090	5.272
35	0.686	1.039	1.136	4.098
36	2.741	4.804	5.246	14.331
37	1.157	1.209	2.064	9.575
38	2.264	2.314	3.053	10.508
39	3.296	3.331	5.807	18.374
40	1.078	1.091	2.100	6.483
41	4.637	4.673	7.100	17.771
42	3.146	3.169	4.751	13.239
43	2.550	2.563	3.588	8.934
44	0.854	0.854	1.039	2.492
45	2.500	2.511	3.416	8.409

Ws_Id - Sub-Watershed No.

Table 4.12. Measured Vs Predicted Sediment Yield of Ebbanad Watershed -Validation

Storm Events Code – MM/DD/YY	Measured Sediment Yield (tons)	Predicted Sediment Yield (tons)	Per Cent Error	Ks
E11 -5/3/1997	52.00	61.97	16.09	1.37
E12 -5/14/1997	79.56	81.99	2.97	2.04
E13 -8/28/1997	85.93	96.42	10.88	1.39
E14 -10/11/1997(LSE)	402.20	395.68	-1.64	3.06

LSE – Large Storm Event

Fig. 4.30. Drainage map of Katteri Watershed

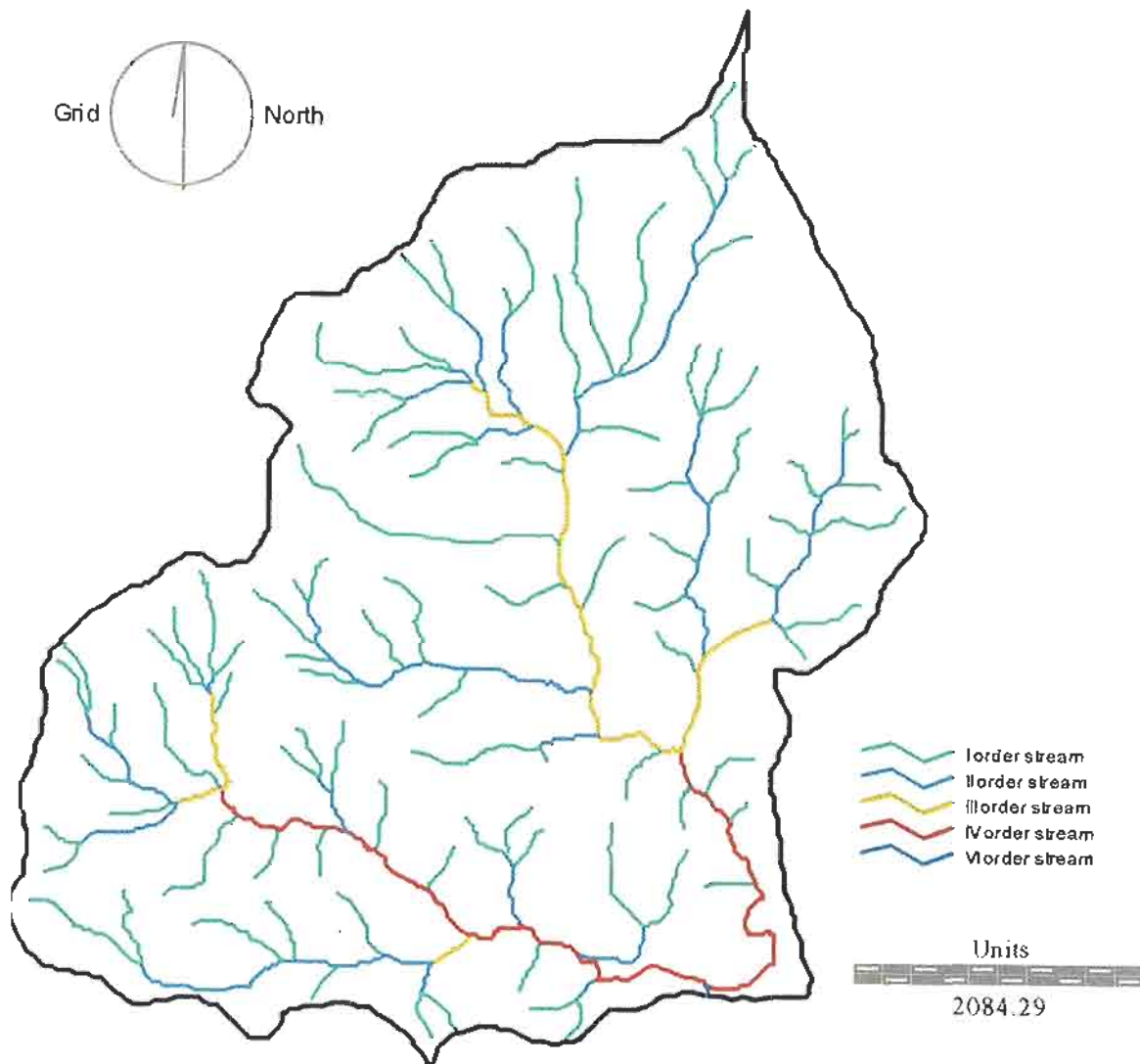


Fig. 4.31. Landuse map of Katteri Watershed

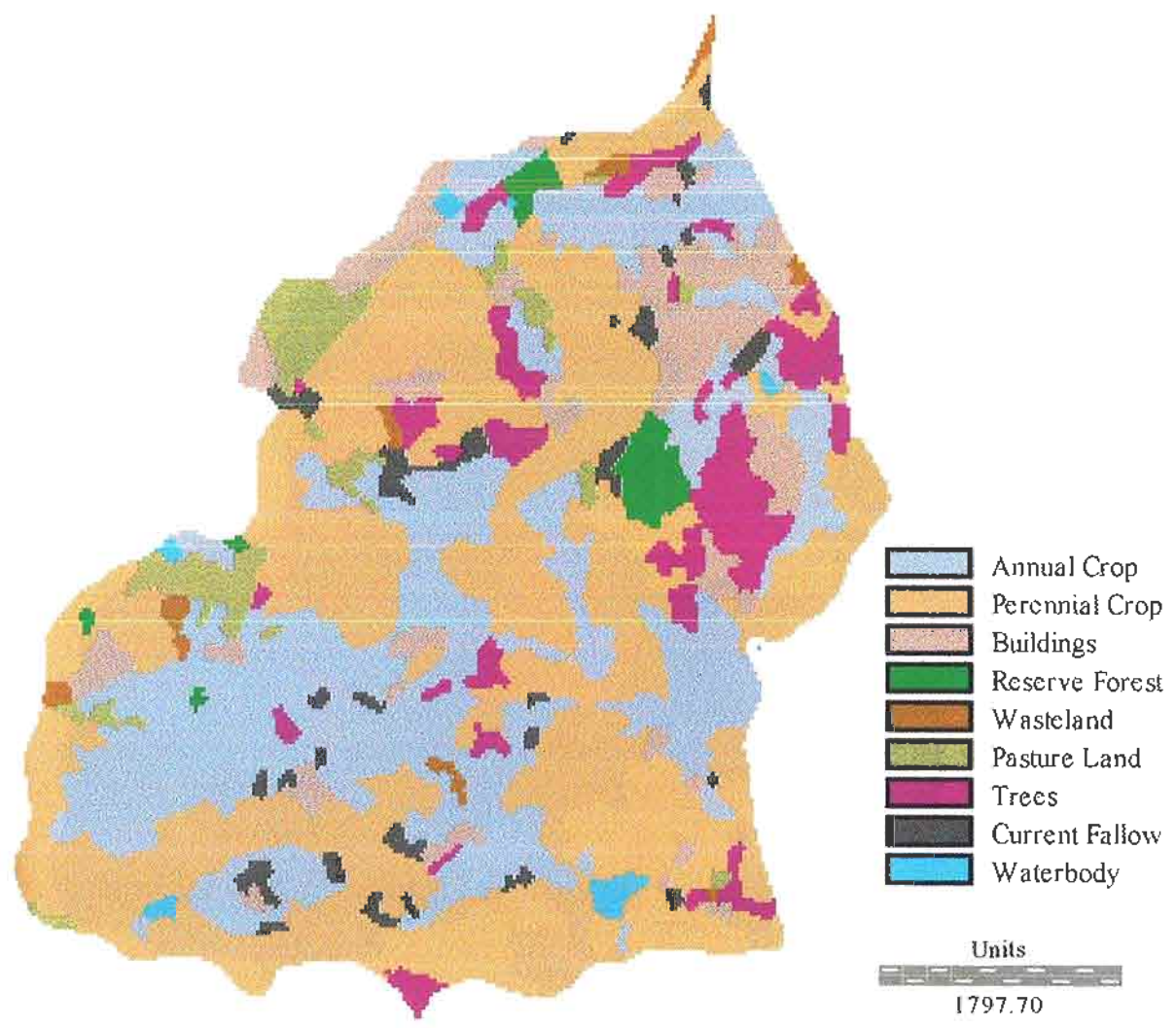


Fig. 4.32. Soil map of Katteri Watershed

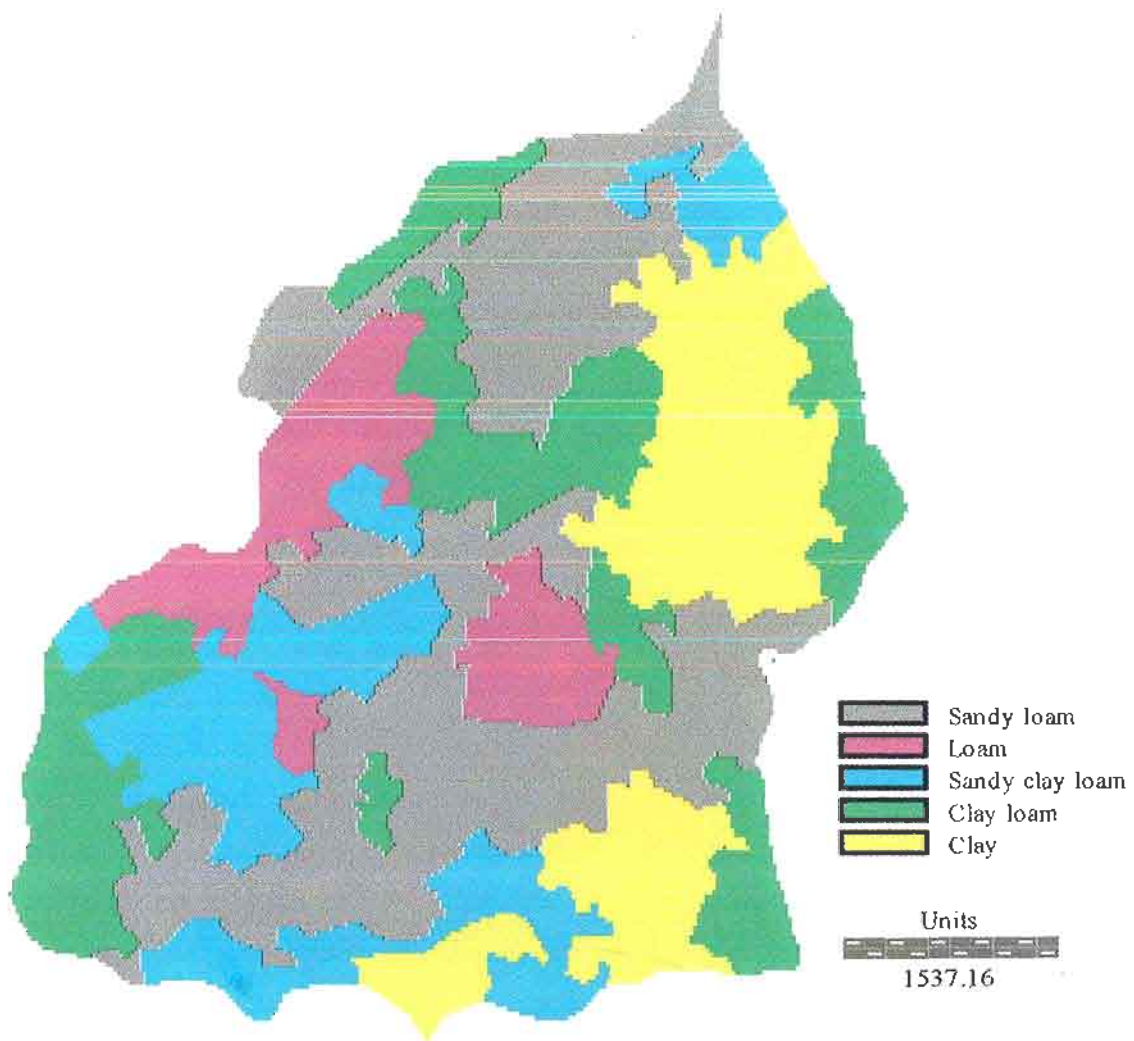


Fig. 4.33. Soil conservation map of Katteri Watershed

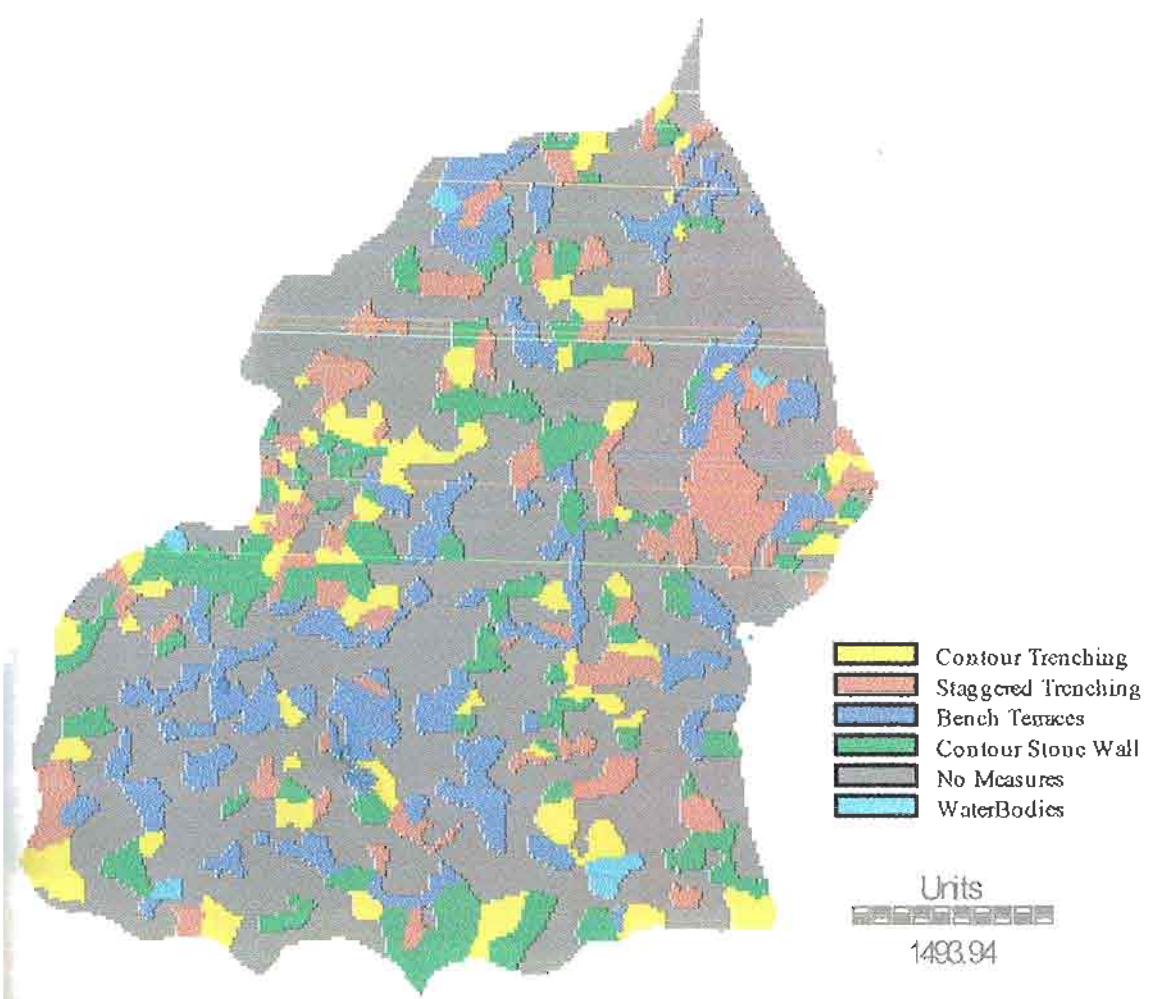


Fig. 4.34. K-factor Map of Katteri Watershed

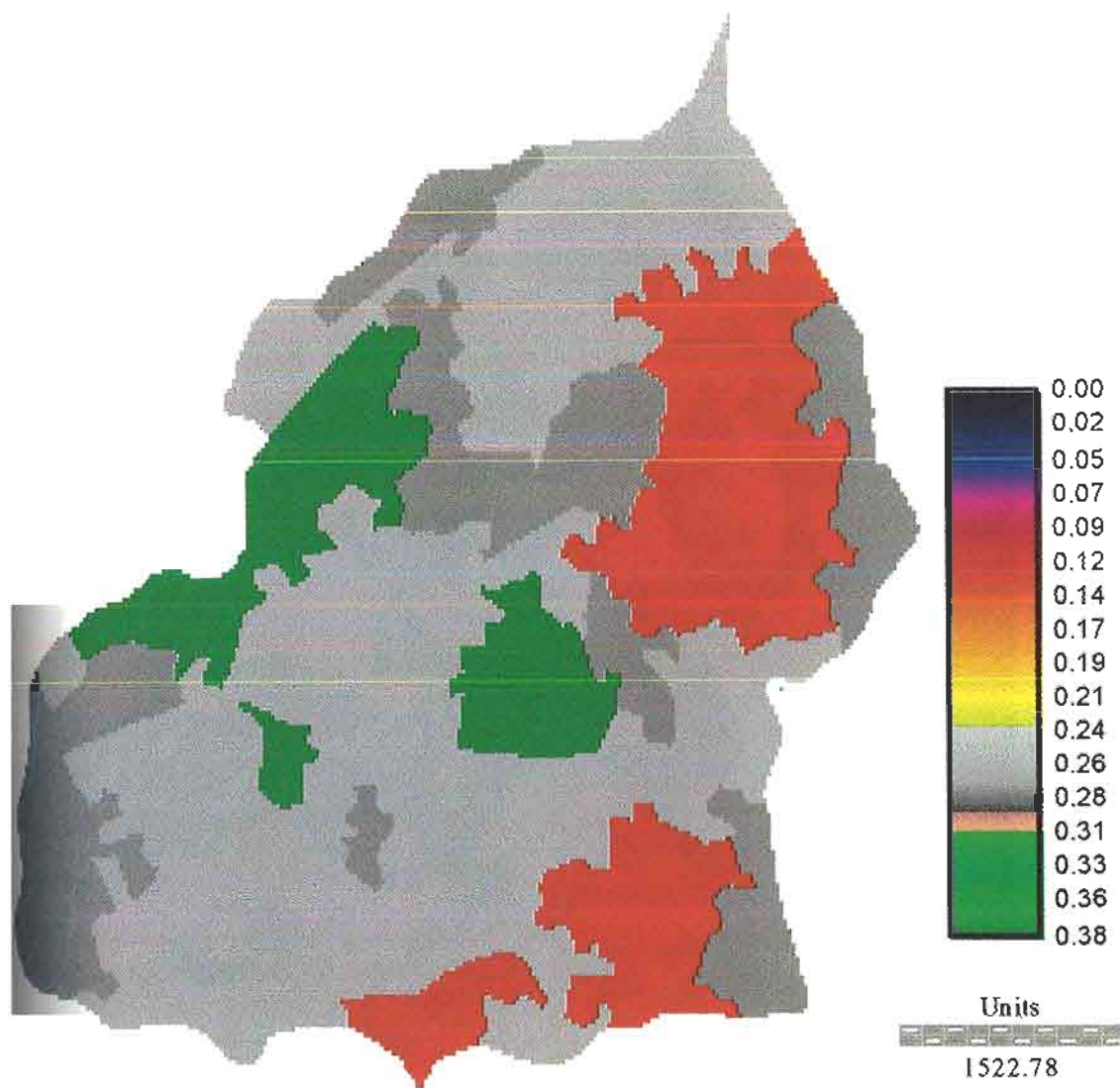


Fig. 4.35. C factor map of Katteri Watershed

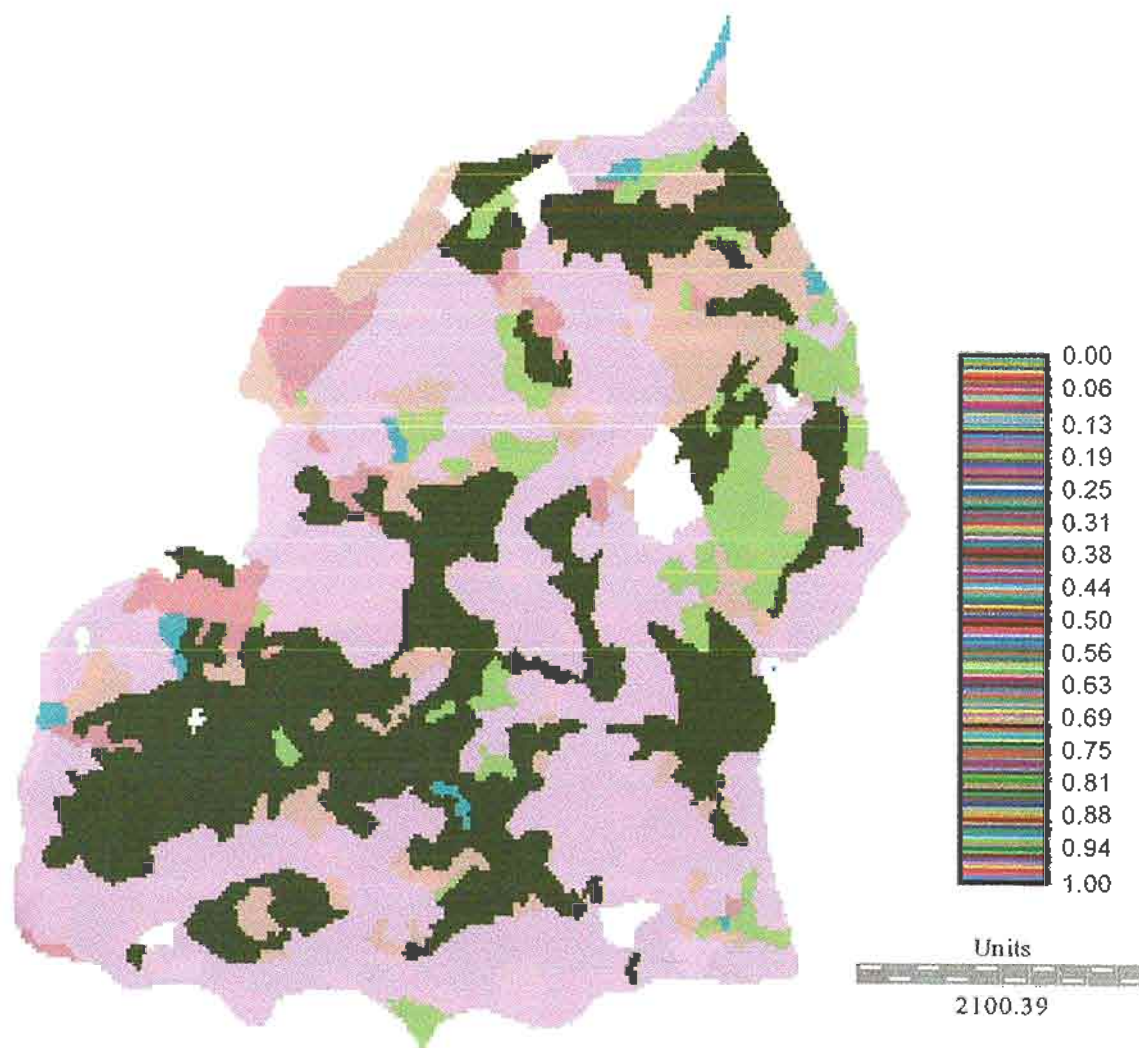


Fig. 4.36. P factor map of Katteir Watershed

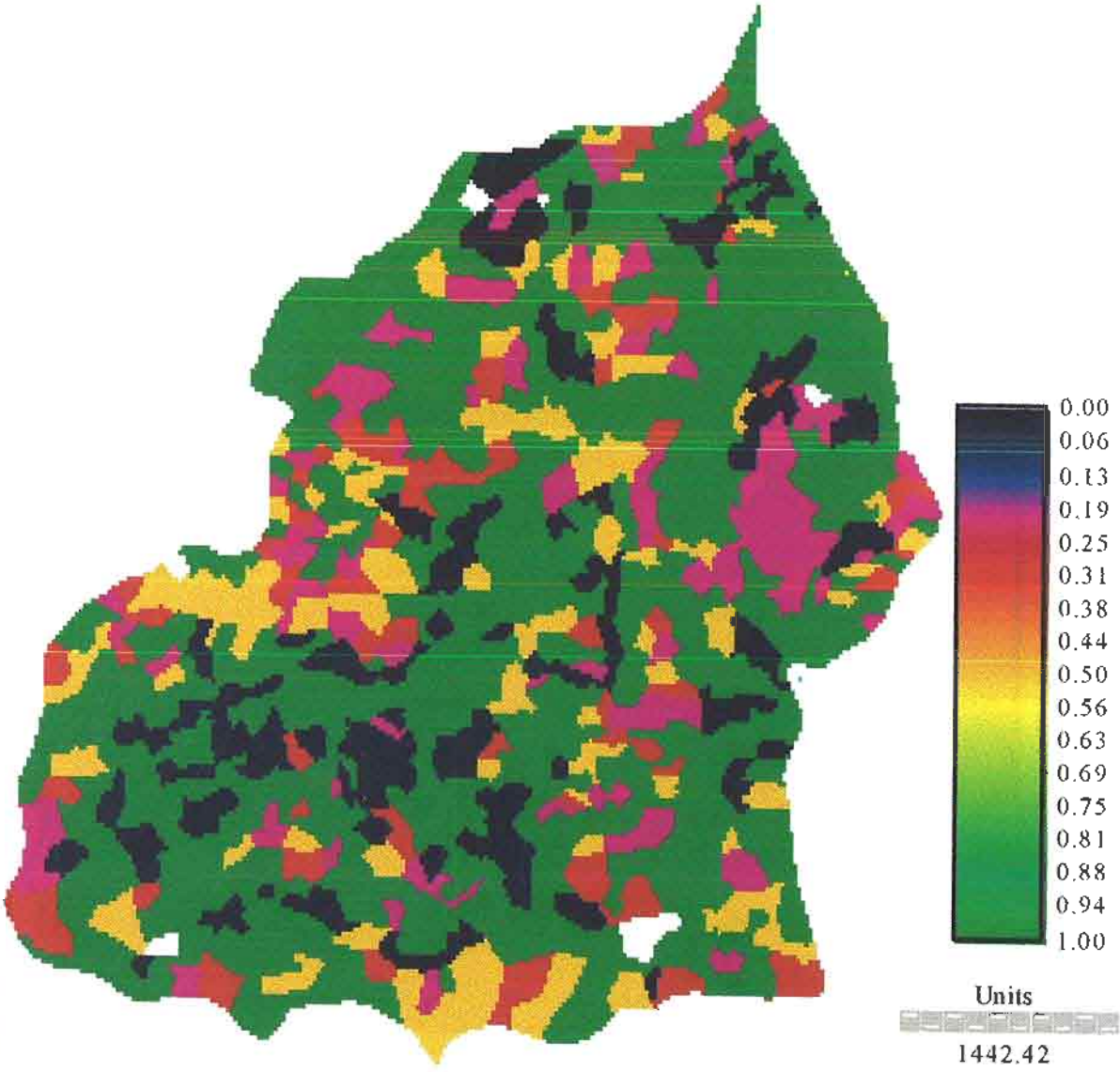


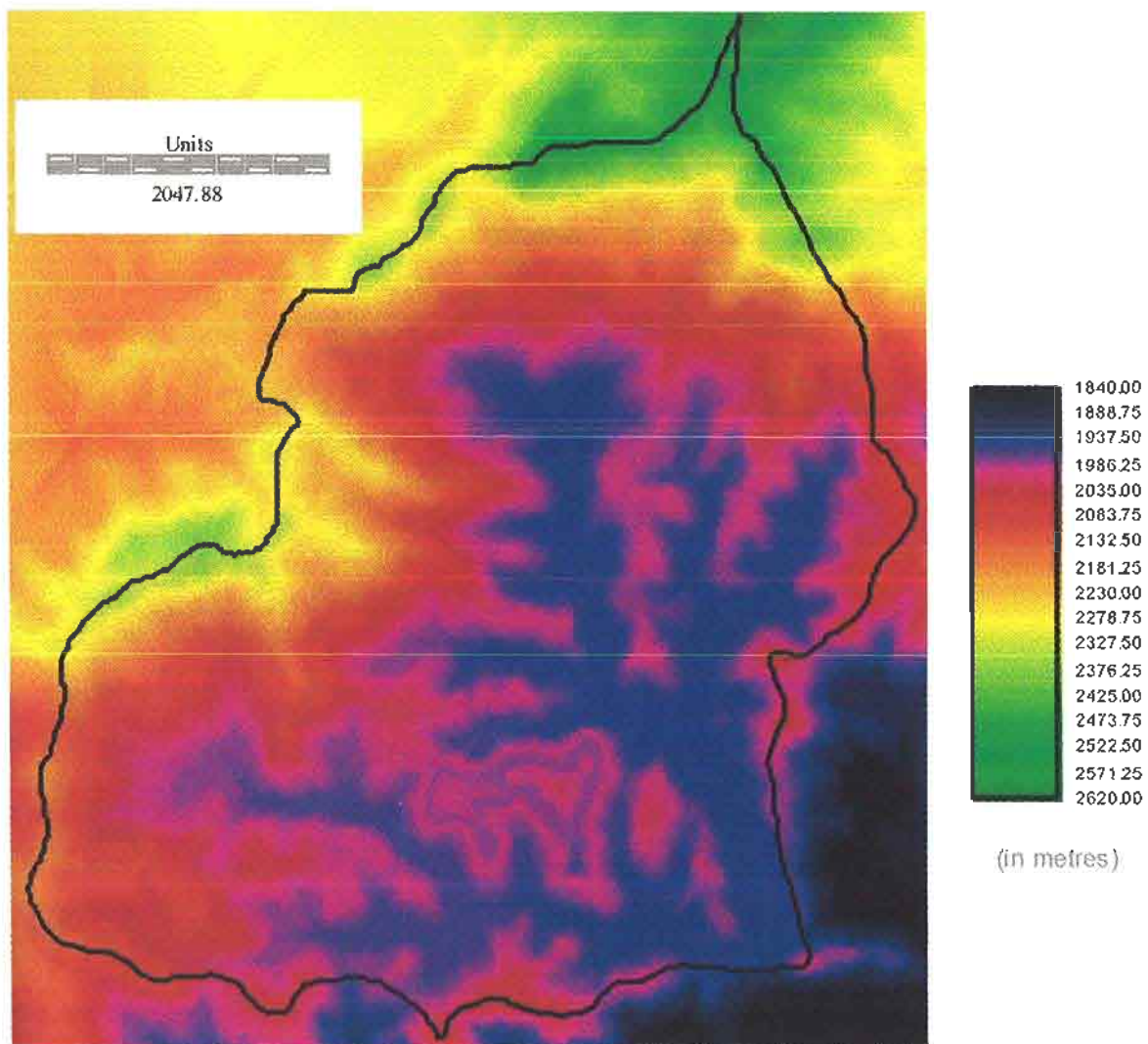
Fig. 4.37. DEM of Katteri Watershed

Fig. 4.38. Slope classification of Katteri Watershed

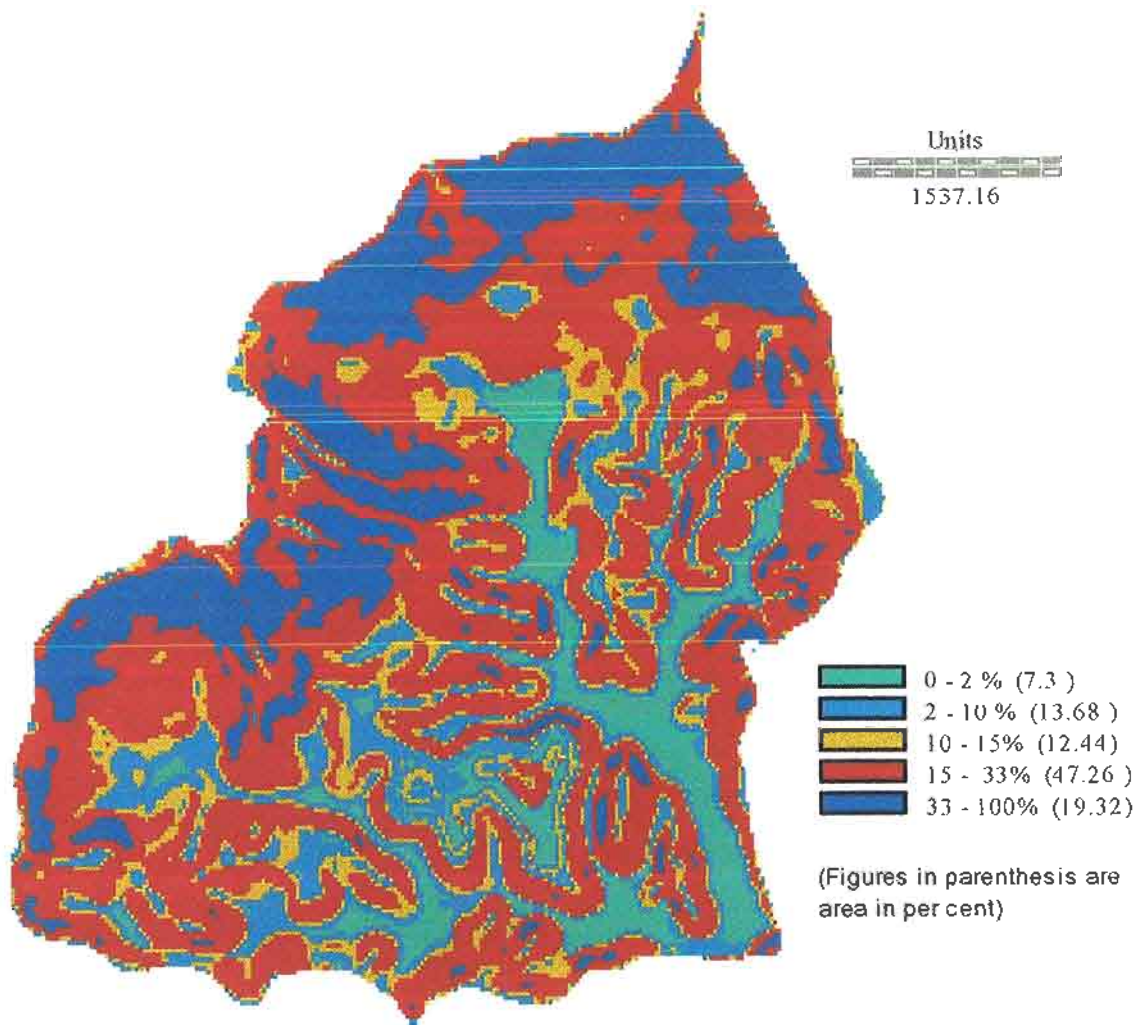


Fig. 4.39. L factor map of Katteri Watershed

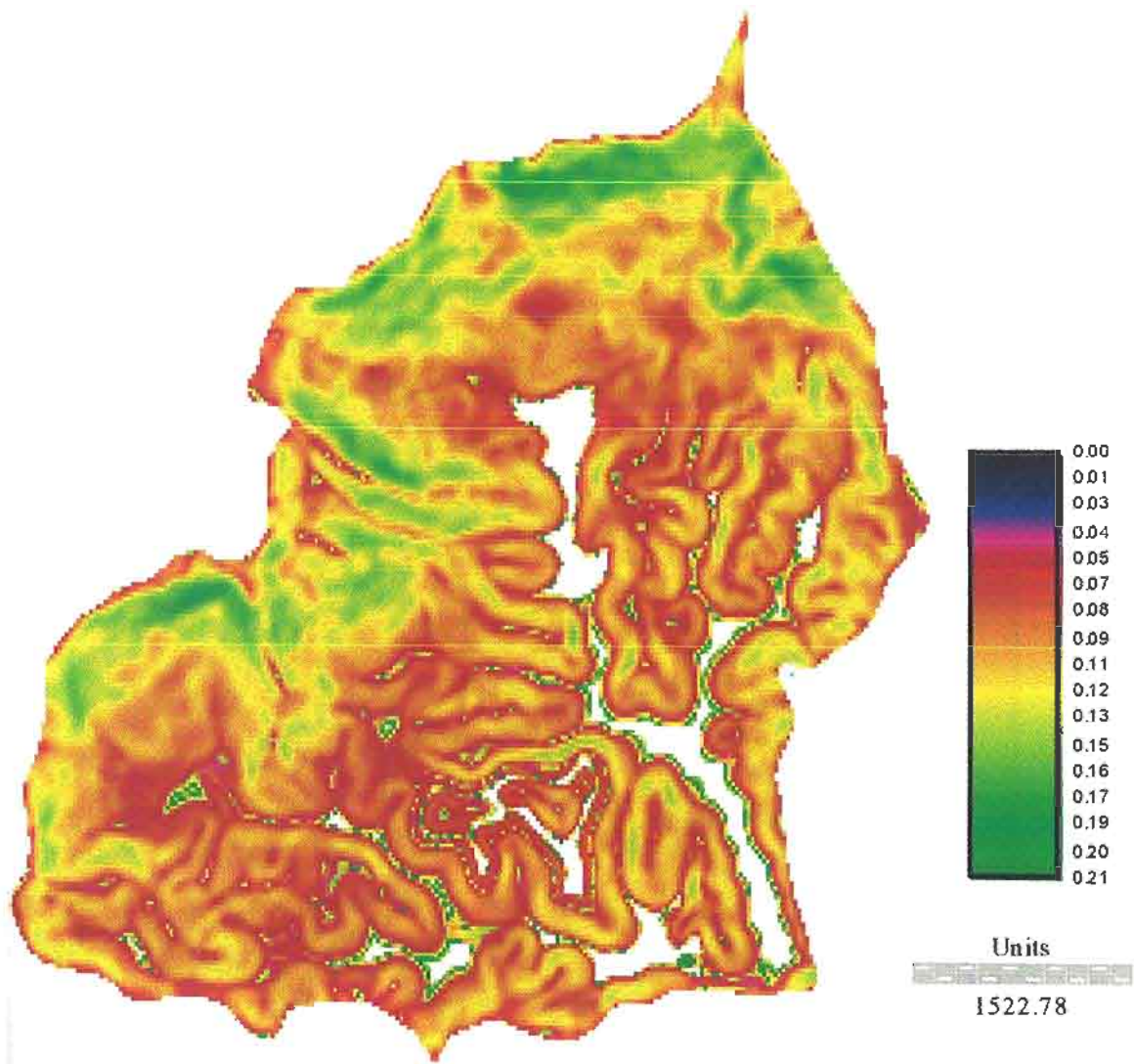


Fig. 4.38. S factor map of Katteri Watershed

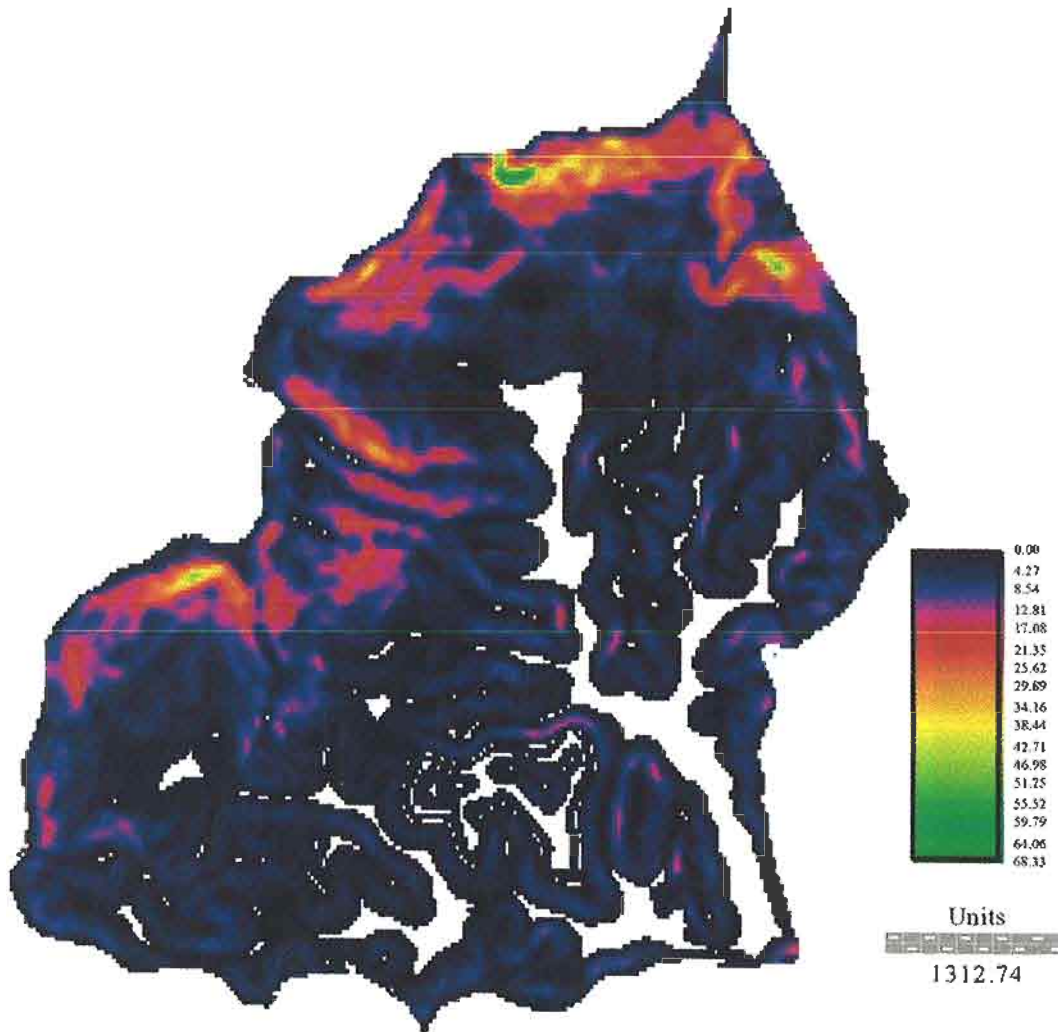


Fig. 4.41. Sub-Watersheds of Katteri Watershed

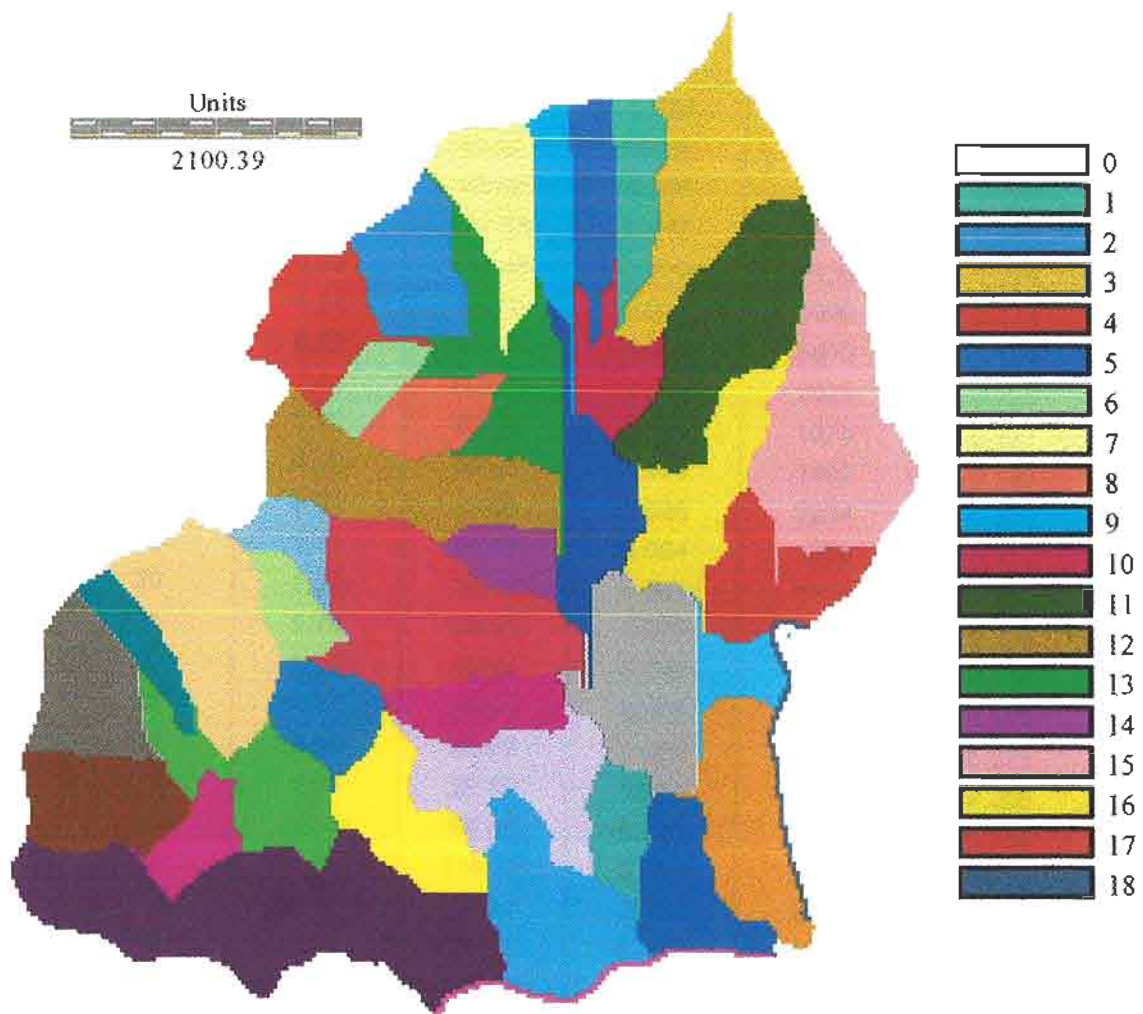


Table 4.13. Input parameters of Katteri Watershed for Peak Runoff Rate Module 131

Sub-Watershed No.	Channel Length (km)	Area (ha)	Channel Slope (m/m)	Surface Slope length (m\m)	Land Surface Slope (m/m)	Surface Runoff (mm)
1	1.35	43.29	0.018	2208	0.359	1.94
2	1.26	64.98	0.031	2141	0.390	2.91
3	2.48	120.05	0.025	2253	0.344	5.10
4	1.43	66.96	0.009	2170	0.311	1.87
5	1.51	43.11	0.013	2191	0.369	1.36
6	0.78	28.08	0.029	2109	0.317	1.54
7	1.54	65.16	0.011	2190	0.347	4.48
8	1.02	40.77	0.025	2057	0.310	4.11
9	0.89	40.32	0.026	2177	0.350	4.36
10	0.79	43.92	0.008	1971	0.129	5.14
11	1.20	127.98	0.008	2065	0.254	10.99
12	2.22	114.48	0.010	2120	0.274	3.62
13	1.31	89.10	0.010	1990	0.171	3.84
14	0.62	31.95	0.005	1979	0.199	1.90
15	1.45	156.60	0.008	2023	0.229	7.10
16	1.82	82.89	0.008	1975	0.177	5.45
17	1.29	69.48	0.009	1967	0.182	4.96
18	0.64	28.08	0.028	2224	0.305	2.43
19	1.74	89.73	0.004	1950	0.112	5.56
20	1.02	30.06	0.044	2126	0.352	4.68
21	1.75	152.82	0.009	2015	0.220	3.79
22	1.25	68.04	0.002	1959	0.133	4.18
23	1.41	48.06	0.009	1977	0.169	3.07
24	0.96	90.09	0.002	1989	0.073	3.43
25	1.03	29.79	0.007	2136	0.288	6.52
26	1.51	69.39	0.025	2107	0.280	8.28
27	1.65	110.43	0.024	2132	0.332	5.81
28	0.74	28.89	0.003	1961	0.162	1.44
29	1.13	70.47	0.012	2052	0.233	7.84
30	1.68	107.99	0.005	1957	0.141	3.56
31	0.86	32.31	0.009	2021	0.169	2.16
32	0.81	46.89	0.013	2013	0.189	4.22
33	1.24	78.03	0.008	1993	0.143	4.92
34	1.34	67.77	0.005	1976	0.131	4.35
35	3.56	239.85	0.0087	2014	0.159	5.28
36	0.81	34.56	0.007	1975	0.197	9.40
37	1.44	98.28	0.009	1972	0.172	6.57
38	1.05	62.73	0.004	1958	0.126	10.53

Table 4.14 Input parameters of Katteri Watershed for Sediment Yield Module

Sub-Watershed No.	K - factor	L - factor	S - factor	C - factor	P - factor
1	0.259	0.124	11.79	0.510	0.777
2	0.299	0.131	12.62	0.488	0.850
3	0.243	0.122	10.52	0.693	0.710
4	0.307	0.116	8.71	0.312	0.852
5	0.270	0.126	12.40	0.495	0.643
6	0.372	0.117	9.40	0.426	0.663
7	0.274	0.121	11.75	0.560	0.399
8	0.319	0.115	9.14	0.386	0.660
9	0.271	0.119	12.08	0.382	0.655
10	0.278	0.077	2.06	0.422	0.730
11	0.146	0.104	7.08	0.738	0.823
12	0.307	0.109	7.11	0.577	0.651
13	0.277	0.082	3.64	0.421	0.681
14	0.328	0.095	4.09	0.371	0.853
15	0.202	0.101	5.23	0.463	0.608
16	0.141	0.092	3.44	0.303	0.571
17	0.205	0.097	3.89	0.496	0.710
18	0.319	0.116	8.02	0.324	0.494
19	0.250	0.075	2.20	0.465	0.694
20	0.275	0.125	10.33	0.586	0.588
21	0.290	0.100	5.16	0.576	0.670
22	0.259	0.075	2.67	0.503	0.591
23	0.295	0.091	3.19	0.664	0.599
24	0.252	0.072	1.01	0.572	0.675
25	0.287	0.112	7.48	0.511	0.742
26	0.276	0.111	7.48	0.577	0.794
27	0.315	0.119	10.35	0.539	0.577
28	0.270	0.097	3.30	0.809	0.671
29	0.278	0.101	5.43	0.675	0.581
30	0.279	0.086	2.87	0.506	0.654
31	0.270	0.088	2.88	0.421	0.877
32	0.312	0.092	3.97	0.785	0.504
33	0.270	0.088	2.42	0.69	0.649
34	0.272	0.089	2.18	0.618	0.617
35	0.249	0.089	2.94	0.469	0.666
36	0.155	0.094	4.12	0.343	0.551
37	0.228	0.088	3.35	0.488	0.679
38	0.154	0.082	2.37	0.355	0.769

Table 4.15. Output parameters from DSYM of Katteri Watershed

Sub-Watershed No.	Channel flow time of concentration (hr)	Surface flow time of concentration (hr)	Total time of concentration (hr)	Peak Runoff Rate (m ³ /s)	Sediment Yield (tons)
1	0.62917	1.68443	2.31360	0.02823	0.74013
2	0.45522	1.61299	2.06821	0.07111	1.48625
3	0.89952	1.72691	2.62644	0.18130	1.71681
4	0.81842	1.74032	2.55874	0.03806	0.43829
5	0.79549	1.66287	2.45837	0.01854	0.52809
6	0.32459	1.70102	2.02561	0.01660	0.45613
7	0.82027	1.69336	2.51364	0.09032	0.76619
8	0.42343	1.68699	2.11043	0.06175	0.65693
9	0.36785	1.68297	2.05083	0.06667	0.77940
10	0.49939	2.13903	2.63842	0.06654	0.11393
11	0.66197	1.79508	2.45705	0.44522	1.18428
12	1.14215	1.78262	2.92476	0.11020	0.78369
13	0.69541	1.97694	2.67236	0.09957	0.20518
14	0.48833	1.88275	2.37109	0.01991	0.18126
15	0.77995	1.82906	2.60902	0.33145	0.44061
16	1.06001	1.94773	3.00774	0.11681	0.07749
17	0.73489	1.92683	2.66172	0.10070	0.25501
18	0.26761	1.77653	2.04414	0.02596	0.24404
19	1.30128	2.21736	3.51864	0.11027	0.13217
20	0.35585	1.65637	2.01222	0.05437	0.94148
21	0.90340	1.84680	2.75021	0.16379	0.57553
22	1.25498	2.11177	3.36675	0.06570	0.12128
23	0.84113	1.97615	2.81728	0.04073	0.21324
24	0.93350	2.55132	3.48483	0.06896	0.05332
25	0.71676	1.76411	2.48087	0.06089	0.79824
26	0.58731	1.76455	2.35186	0.19000	1.37019
27	0.61408	1.68854	2.30263	0.21671	1.47645
28	1.69799	1.99165	3.68964	0.00876	0.15091
29	0.57995	1.83519	2.41515	0.17792	0.75378
30	1.12910	2.07382	3.20292	0.09335	0.18959
31	0.54227	2.00242	2.54469	0.02133	0.11855
32	0.42486	1.93174	2.35661	0.06530	0.35513
33	0.72767	2.08778	2.81546	0.10605	0.24406
34	0.95460	2.13242	3.08702	0.07427	0.15917
35	1.90878	2.03516	3.94394	0.24974	0.25233
36	0.55739	1.88617	2.44357	0.10340	0.12877
37	0.78554	1.96276	2.74831	0.18273	0.26860
38	0.82118	2.14565	2.96683	0.17316	0.11131

Watershed is presented in Table 4.15. The maximum time of concentration of the sub-watersheds was 3.94 hr whereas the minimum value was observed as 2.01 hr. The predicted sediment yield (12.08 tons/storm) from DSYM on the Katteri watershed was close to the measured sediment yield (10.16 tons/storm) for the selected storm with the PE of 15.89 and the sediment storage coefficient was estimated as 1.39.

4.6. Critical Areas of Erosion

Erosion zones of both the watersheds were identified by overlaying the thematic layers of landuse, soil and slope. Each theme had been divided into three categories such as high, medium and low erodable zones (Table 4.16).

Table 4.16. Categories of Erosional areas

Themes	Erosion Categories		
	Low	Medium	High
Slope (degrees)	Less than 2	2-12	Greater than 12
Land use/Land cover	Dense Vegetation	Sparse vegetation	Bare soils
Soils	Loamy	Clay loam	Clayey

The critical area of erosion were categorised as Low, Medium and High and are shown in the Fig. 4.42 and 4.43 for Ebbanad and Katteri watersheds respectively. Out of 3917 ha of area in Ebbanad watershed, 308.16 ha (7.9 per cent) was identified as High Erosion zones, 978.29 ha (25 per cent) was under Medium and 8.28 ha (0.2 per cent) was under Low Erosion zones. High erosion zones were found to be at the areas of annual crop, trees and wasteland whereas Medium erosion zones were at the side and bottom portion of the valleys. In Kattery watershed, the areal extent of Low, Medium and High erosional areas were 46.44 ha (1.6 per cent), 856.61 ha (29.4 per cent) and 196.92 ha (6.8 per cent) respectively. Higher percent of area was under Medium erosion zones that were lying under annual crops, trees, current fallow and some areas of perennial crops. Major portion of High erosion zones of Katteri Watershed where under annual cropping and some where under tree areas.

Fig. 4.42. Erosion Prone Zones of Ebbanad Watershed

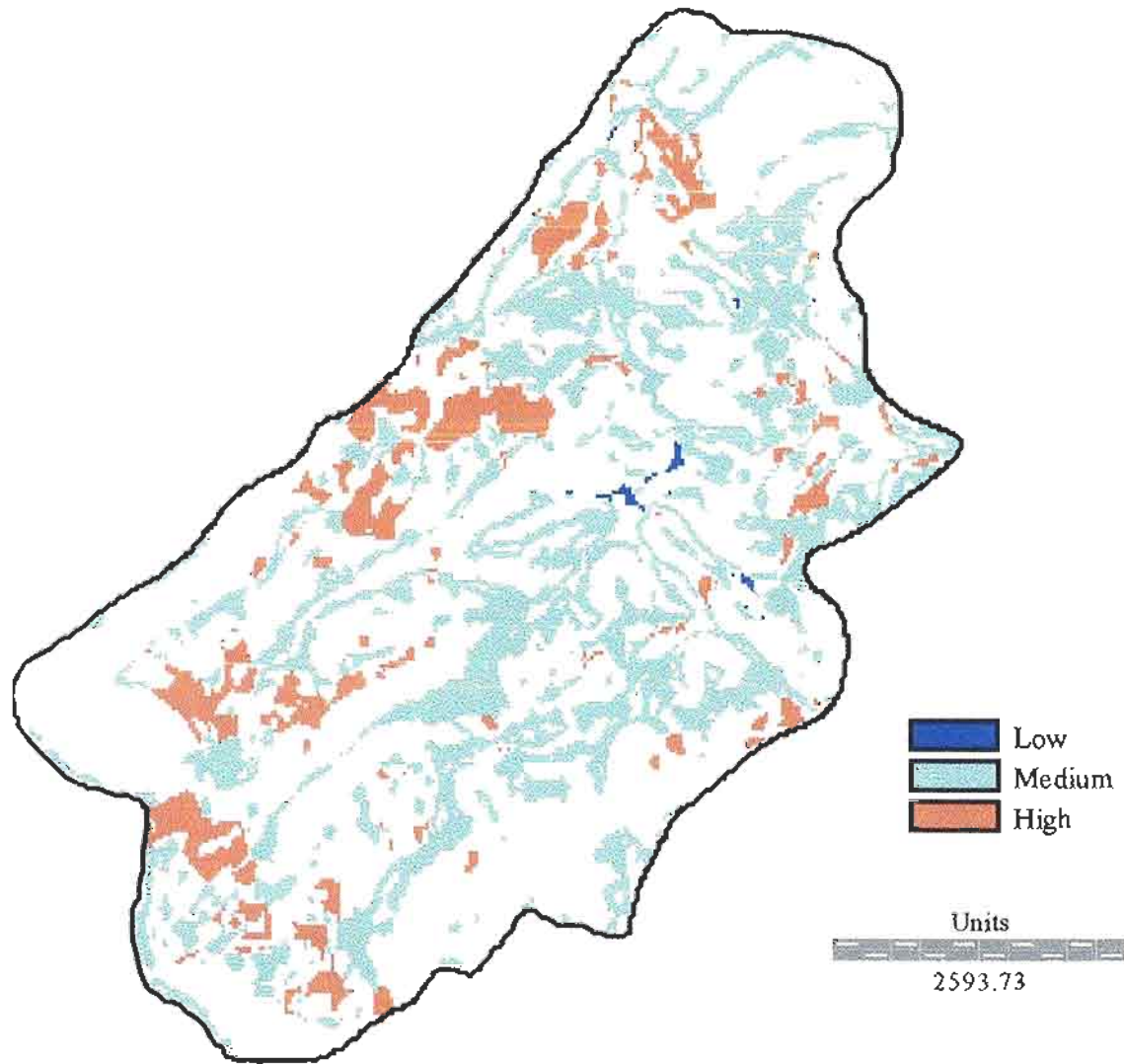
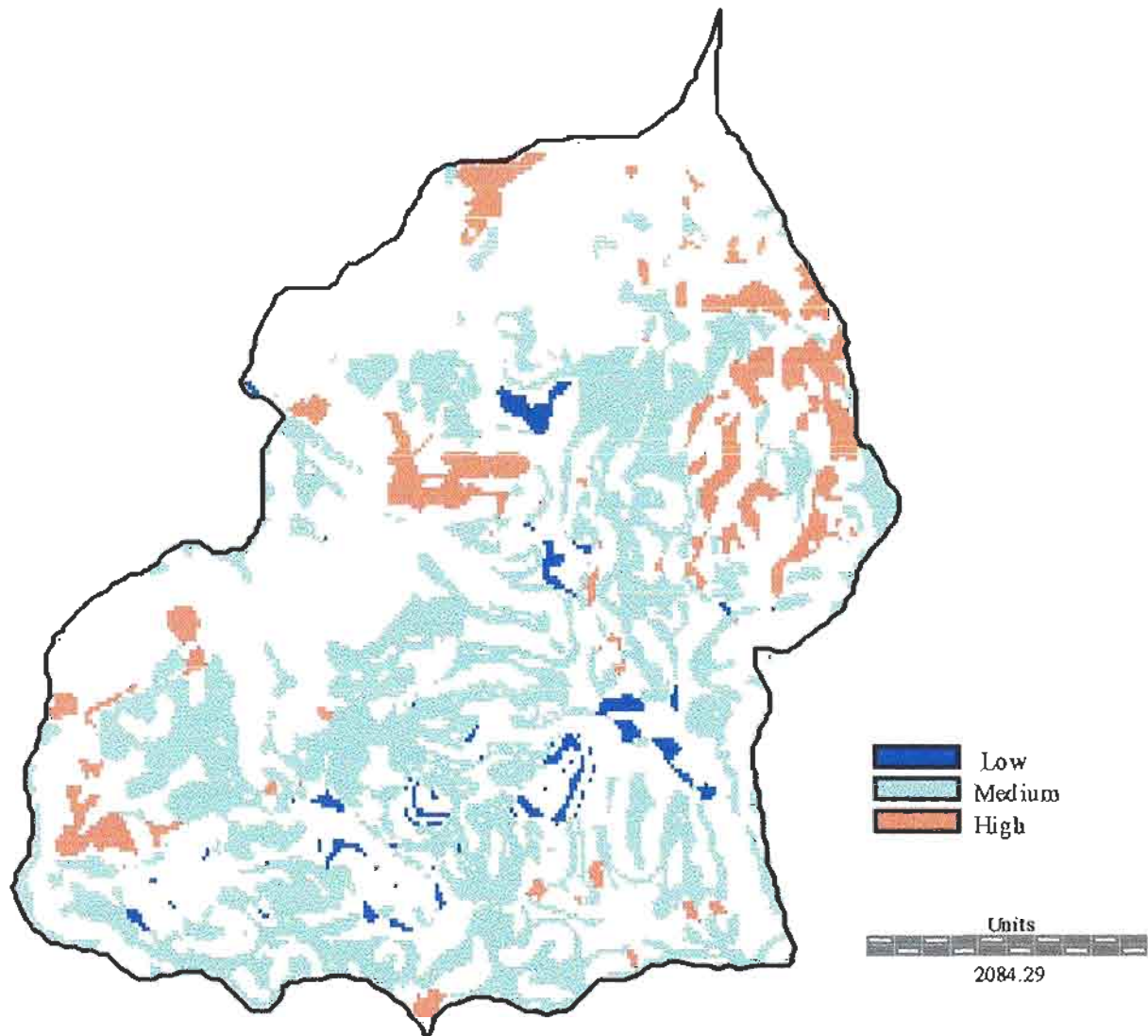


Fig. 4.43. Erosion Prone Zones of Katteri Watershed



4.7. Scenarios for future alternate land management

Sediment yield was estimated on DSYM with different scenarios considering alternate erosion control practices for the different land categories and alternate land use managements. The following two scenarios were presented in Ebbanad watershed.

Scenario I: The watershed was considered to be treated with conservation practices under identified Medium and High erosion zones in annual cropping, tree and perennial land covers.

Scenario II: The annual crop area of the watershed was considered to be shifted to perennial crops with conservation practices.

The results of scenarios from DSYM, were compared with the results of existing conservation measures and landuse for the storm event E2. (Table 4.17.)

Table 4.17. Areas under different conservation practices of Ebbanad Watershed for the two scenarios

Types of Conservation Practices	Area under Existing Conservation Practices (ha)	Area under Scenario I (ha)	Area under Scenario II (ha)
Contour trenching	289.6	361.79	393.29
Staggered trenching	488.2	614.07	766.71
Bench terracing	448.1	875.61	208.44
Contour stone wall	419.2	543.96	549.45
No measures	2271.96	1521.8	1999.44
Sediment yield of the Ebbanad watershed (tons/E2)	223.74	119.12	126.4

In scenario I, out of 2271.96 ha of untreated area, 750 ha was considered to be treated with conservation practices like contour trenching, staggered trenching, bench terracing and Contour stone wall. DSYM predicted the sediment yield of 119.12 tons per E2 over the sediment yield of 223.74 tons under existing conservation practices. It was observed from the Fig. 4.25 and 4.44 that a shift of areas under the category of 40 – 60 tons of sediment yields in E2 to the category of 20 – 40 tons in scenario I. The 50 per cent of annual cropping areas were considered to be converted into perennial crops with suitable conservation practices under scenario II. The sediment yield of scenario II was estimated to be 126.4 tons per E2 which was slightly higher than scenario I and it was only 45.5 per cent of sediment yield under present conditions. The spatial variability of sediment yield under scenario II was shown in Fig. 4.45. It was observed from the Fig.4.44 and 4.45 that a shift in the zones of lower sediment yields under scenario I to higher sediment yield in scenario II. Areas of erosion zones under scenario II and I is presented in the Table 4.18.

Table 4.18. Classification of Sediment Yield of Ebbanad Watershed for the two Scenarios

Category code	Sediment yield categories (tons)	Area under scenario I (ha)	Area under scenario II (ha)
1	0 – 1	220.76	263.79
2	1 – 2	253.71	184.59
3	2 – 3	452.69	288.89
4	3 – 4	715.49	427.68
5	4 – 10	2009.79	2424.06
6	10 – 20	99.89	109.35
7	20 – 40	164.97	218.96

Fig. 4.44. Sediment Yield (tons) map of E2 under scenario I for Ebbanad Watershed

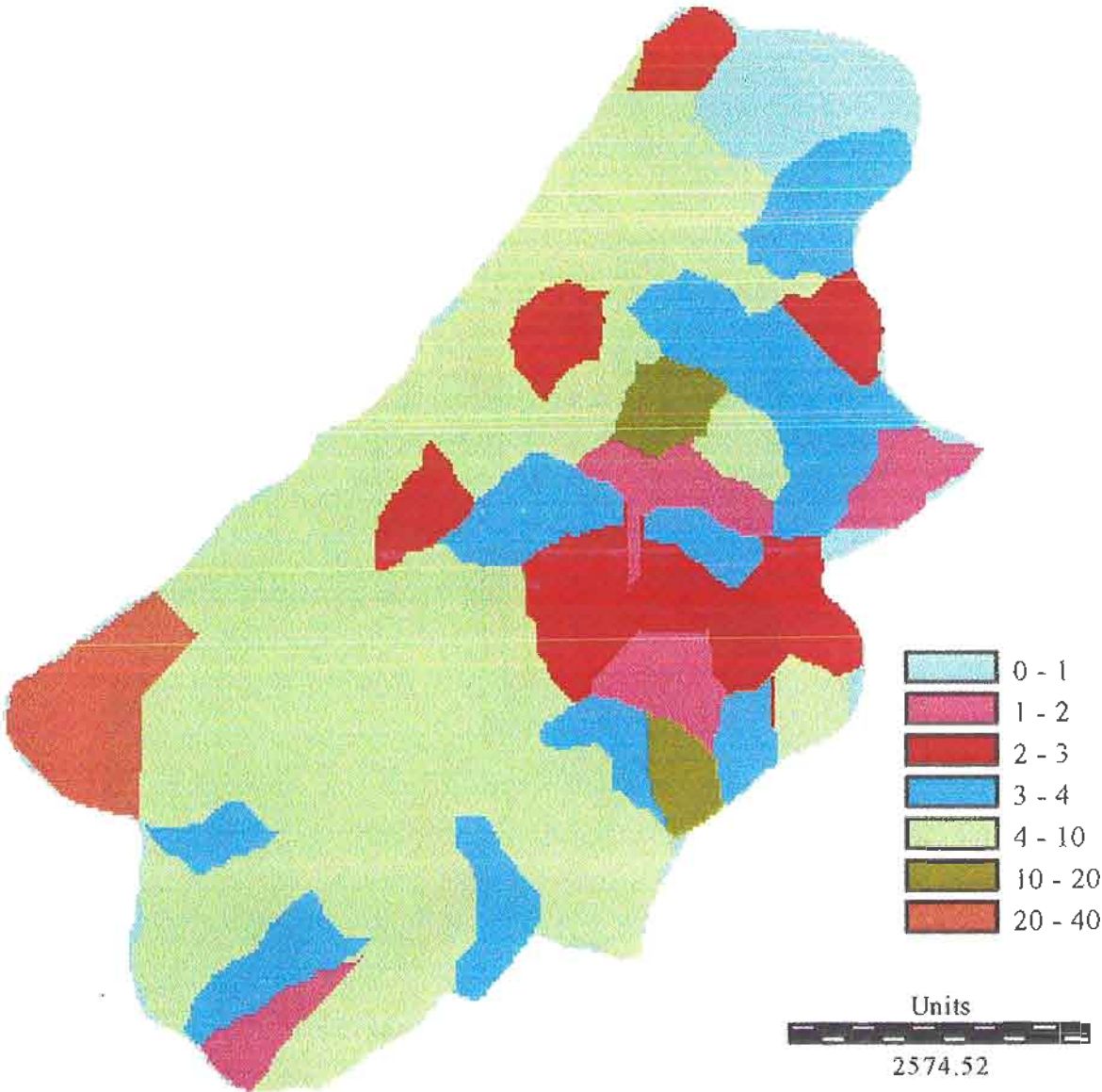
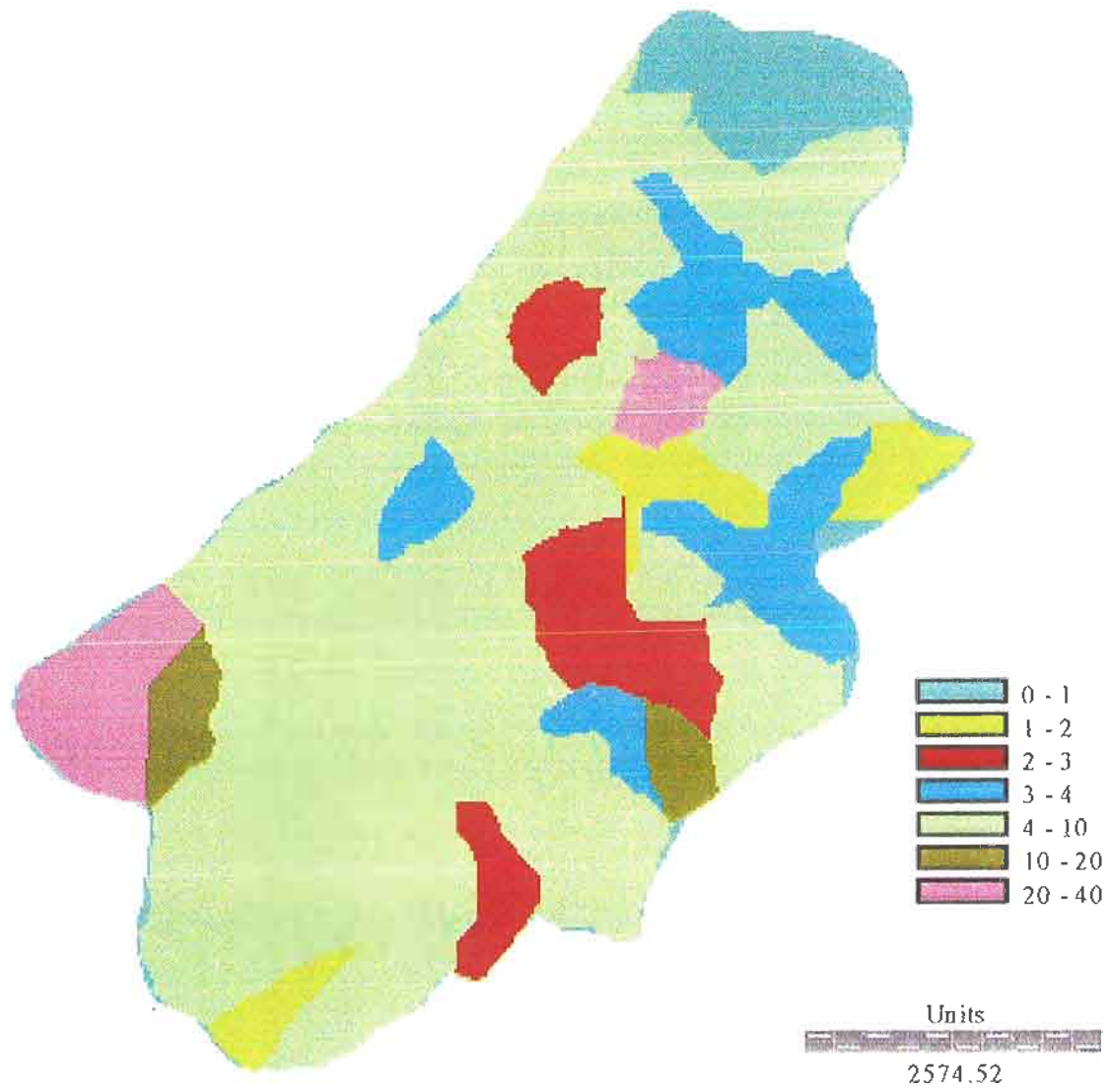


Fig. 4.45. Sediment Yield (tons) map of E2 under scenario II for Ebbanad Watershed



Even though increase in area was found to be under category 1 of scenario II than scenario I, the high sediment yield value categories of 5,6 and 7 of scenario II was also observed with increase in areas than scenario I. Higher sediment yield categories of scenario II were observed with larger areas. Hence, scenario I is considered to be the best when compared with scenario II with respect to total sediment yield and area wise distribution of sediment yield. These scenarios are provided as examples for comparing the impact of watershed treatments.

Summary and Conclusion

CHAPTER – V

SUMMARY AND CONCLUSION

Many watershed models like CREAMS, SWRRB, EPIC, ANSWERS, AGNPS, SWAT, etc. have been developed in foreign countries and are in wide use there. But these models were developed for watersheds considering the availability of data in their countries. The quantity and quality of data available in India restrain the use of such models here. Moreover those models were developed for specific purposes and each was considered to be good in predicting only selected hydrologic and erosional processes. The models developed with specific purposes cannot be blindly extrapolated for Indian conditions. The need for an erosion model, that requires only commonly available data and easily measurable data in hillslope watersheds, is keenly felt.

Hence a distributed parameter model, (DSYM) for predicting sediment yield on event basis in a small watershed of Lower Bhavani Catchment was developed.

Even though, SCS runoff equation is basically an empirical model, it provides a simple, yet robust, means of estimating excess rainfall and various studies (Shrivastava and Bhatia, 1992, Jain et al., 1996 and King et al., 1999) showed that the SCS-CN provided as good or better simulations than physically based models. For accurate prediction of sediment yield contributions from the sub-watersheds of a watershed, a routing procedure for sediment yield estimation on per storm basis was developed by considering the storage effects during the sediment transport process. To formulate the routing model, a sediment yield model for the sub-watersheds was also developed taking runoff as the input. The procedure eliminates the need for consideration of sediment particle diameter and its settling velocity and instead considers the values of sediment storage coefficient.

The DSYM requires 10 fixed input parameters and one variable input. GIS is an tool for the preparation of the input data for the model since large quantities of data can be processed in less time than could be done by the traditional topographic maps. All the inputs of DSYM were derived from GIS, where the DSYM has been split with 3 modules namely, Peak runoff rate module, Sediment Yield module and Sediment routing module. The DSYM gives the outputs in the Output1.dbf and Output2.dbf files, which contains channel, surface and total time of concentrations, peak runoff rate and sediment yield for sub-watersheds and the storage coefficient (K_s), parameters m and α and predicted sediment yield for the watershed respectively.

DSYM was routed with 10 storm events, and estimated results were compared with the measured data. The average value of parameters m and α were estimated as 0.29 and 0.28 for smaller storm event and 0.41 and 0.35 for larger event respectively. The error in prediction of sediment yield was in the range of -6.65 to 13.66 per cent. The simulated sediment yields from DSYM, for the calibrated values of the parameters were compared with the observed sediment yield to assess the model performance. The model performance was evaluated by Coefficient of Efficiency (CE) and Coefficient of Determination (R^2) and were found to be 0.98 and 0.9826 respectively which implies that the model is a better predictor of sediment yield than the mean. The close agreement between the observed and the estimated following this method is encouraging as similar exercises could be carried out for other watershed as a part of watershed planning.

DSYM could not be used on ungauged watershed for determination of the exponent value, because measured hydrologic data were not available. However, if the watershed has similar hydraulic characteristics to the calibrated watershed, the average

value was considered to apply to the watersheds also, which was well validated with the real watershed Katteri of Lower Bhavani Catchment.

From the results it is concluded that spatial databases, GIS and a sediment yield model could be used to aid in watershed planning. How a model describes the variation in a watershed is to determine how well a model can predict the runoff and sediment yield. Too much or too little description of watershed can have detrimental effects on the use of model. If a model requires a user to input long and complicated set of data for a watershed, then the model may not be accepted except by researchers. On the other hand, if a model requires little input by the users, the use of model becomes site specific or produces inaccurate results. The inputs for the DSYM is neither too large nor too less. All the needed inputs can be obtained normally from a watershed and also can be derived easily. Hence, the DSYM can have a practical applicability of identifying the critical areas, which need soil conservation treatment on a priority basis, which would have been difficult if a lumped parametric approach had been followed. It also facilitates the decision of Best Management Practices for planning of conservation programmes in a watershed.

5.1. The Distinct features of DSYM

- The input parameters of the model are spatially distributed even though the processes are not physical in nature
- The inputs are easily collected and derived from the watershed
- The incorporation of the future change in Land Use / Land Cover is easy
- It can identify the Erosion Prone areas of the watershed to go for action plans
- Any types of scenarios can be developed to recommend the Best Management Practices.

5.2. Limitations of the Model

- Rainfall intensity and duration were not considered for estimating surface runoff
- Average values of K, L, S, C, and P factors from GIS were used in this model.

It is suggested that the calibration of the model is to be improved further with many widely distributed storm events to improve the efficiency of the model still more.

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