LAND AND WATER RESOURCES STUDIES OF PENNAR SUBBASIN USING GEOSPATIAL TECHNIQUES

M. Tech. (Agril. Engg.) Thesis

by

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CERTIFICATE-I

This is to certify that the thesis entitled **"Land and water resources studies of Pennar subbasin using geospatial technique"** submitted in partial fulfillment of the requirements for the degree of **"Master of Technology in Agricultural Engineering"** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Sankara Anusha** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigations have been duly acknowledged.

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LIST OF NOTATIONS

Symbol	Description
%	Per cent
ºC	Centigrade
º	Degrees
=	Equal to
+	Plus
-	Minus
×	Multiplication
/	Division
√	Square Root of
∏	Pie
>	Greater than
<	Less than

LIST OF ABBREVIATION

Abbreviation	Meanings
A.P	Andhra Pradesh
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
AMC	Antecedent Moisture Content
cm	Centimeter
cm/hr	Centimeter per hour
DEM	Digital Elevation Model
et al.,	And others
GIS	Geographic Information System
hr	Hour
ha	Hectare
HSG	Hydrologic Soil Group
i.e.	That is
ICAR	Indian Council of Agricultural Research
km	Kilometer
km/km^2	Kilometer per Sq. kilometer
km^2	Square kilometer
km^2/yr	Square kilometer per year
LCC	Land Capability Classification
LULC	Land Use Land Cover
m	Meter
m^3	Cubic meter
m^3/s	Cubic meter per sec
min	Minute
MJ-mm/ha/h/year	Mega Joule millimeter per hectare per hour per year
mm	Millimeter
MPR	Mid Pennar Reservoir
MSL	Mean Sea Level
NBSS & LUP	National Bureau of Soil Survey and Land Use Planning
PABR	Penna Ahobhilam Balacing Reservoir
SCS-CN	Soil Conservation Service Curve Number
sec	Second
SOI	Survey of India
SRTM	Shuttle Radar Topographic Mission
$t\ ha^{-1}\ year^{-1}$	Tons per hectare per year
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
viz.	That is
WCN	Weighted Curve Number
WGS	World Geodetic System

THESIS ABSTRACT

Title of Thesis	Land and Water Resources Studies of Pennar Sub Basin using Geospatial Techniques
Full Name of the Student	Sankara Anusha
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Degree to be awarded	M. Tech in Agricultural Engineering

23/09/2024
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Date: 23/09/2024

Signature of Head of Department

Abstract

Among all the natural hazards, soil erosion is the dangerous hazard which is faced by humans from several decades. In the present research, an attempt has made for prioritization of River Penna sub basin based on land capability class and soil erosion using geospatial techniques in Pennar sub basin of Anantapur district. Using SRTM DEM 30m resolution, boundary of Pennar subbasin has been delineated. Linear, areal and relief parameters of morphometry has been quantified using terrain morphometry tool in ARCGIS 10.1 software. The morphometric analysis revealed that Pennar sub basin has high relief and good infiltration, dendritic in nature with less runoff and less prone to soil erosion.

A change in land use land cover for three different periods viz. 2011, 2015 2020 has been detected using Landsat 5 and Landsat 8 imageries of 30m resolution in Erdas Imagine. The Annual rate of change (ARC) during 2011 to 2020 is in raising trend for agricultural lands, built up, barren lands, forest and water bodies with 9.49 km^2/yr (11.97%), 0.47 km^2/yr (1.63%), 1.09 km^2/yr (7.15%), 1.30 km^2/yr (2.17%) and 0.16 km^2/yr (0.59%) respectively. Furthermore, it was in decreasing trend for reservoir and fallow land 0.07 km^2/yr (0.73%) and 12.47 km^2/yr (6.09%). Class II & Class III lands are suitable for cultivation with better management practices covering 20.82% & 41.07% of the Pennar sub basin. The lands which are not suitable for cultivation, i.e. class VI are covered by barren land with 21% of area and water bodies, settlements covered an area of 17.08% of Pennar sub basin.

Pennar sub basin falls under gentle (1-3^o) and steep slope (35-37^o) with almost flat and undulating topography. The highest rainfall was observed in the year 2005 (665 mm) and the lowest rainfall (214 mm) in the year 1994 & 2003 with runoff 167 to 614 mm for the Pennar sub basin during the period 1990 to 2018. The annual soil loss of Pennar sub basin ranged from 0 (the lower and middle part) to 155 ton/ha/year (the upper sub basin) indicates low to very severe erosion. The major portion (96.49%) of sub basin was under low soil erosion i.e. 0-7 tons/ha/year. Hence the agronomical measures need to be implemented where the erosion is > 7 ton/ha/year. Conservation map has been prepared by using slope, land use land cover and soil map of Pennar sub basin suggesting agronomic and engineering measures for preventing further erosion and better productivity.

शोध सारांश

शोध शीर्षक	भू-स्थानिक तकनीकों का उपयोग करते हुए पेन्नार उप बेसिन का भूमि और जल संसाधन अध्ययन
छात्र का पूरा नाम	शंकर अनुषा
प्रमुख विषय	मृदा और जल अभियांत्रिकी
प्रमुख सलाहकार का नाम और पता	डॉ. एम. पी. त्रिपाठी, प्राध्यापक स्वामी विवेकानंद कृषि अभियांत्रिकी एवं प्रौद्योगिकी महाविद्यालय एवं अनुसंधानकेंद्र, कृषि अभियांत्रिकी संकाय, इं. गा. कृ. वि., रायपुर (छ ग)
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23/09/2024

प्रमुख सलाहकार के हस्ताक्षर

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छात्र का हस्ताक्षर

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विभागाध्यक्ष के हस्ताक्षर

सारांश

सभी प्राकृतिक आपदाओं में मृदा अपरदन एक बहुत बड़ी समस्या है जिसका सामना मनुष्य कई दशकों से कर रहा है वर्तमान शोध में आनंदपुर जिले में पेन्नार उप बेसिन में स्थानिक तकनीकों का उपयोग करते हुए भूमि क्षमता वर्ग और मिट्टी के कटाव के आधार पर पेन्ना नदी बेसिन को प्राथमिकता देने का प्रयास किया गया है SRTM DEM 30 m रिज़ॉल्यूशन का उपयोग करते हुए पेन्नार उप बेसिन की सीमा को चित्रित किया गया है । ARCGIS 10.1 सॉफ्टवेयर में टेरेन मॉर्फोमेट्री टूल का उपयोग करके मॉर्फोमेट्री के लीनियर, एरियल और रिलीफ मापदंडों को निर्धारित किया गया है। मॉर्फोमेट्रिक विश्लेषण से पता चला कि

पेन्नार उप बेसिन में उच्चावच तथा अच्छा संचरण है यह कम अफवाह के साथ द्रुमाकृतिक प्रकार की है तथा इस उप बेसिन में मिट्टी के कटाव की संभावना कम है ।

तीन अलग-अलग अवधियों क्रमशः 2011, 2015 और 2020 के लिए भूमि उपयोग भूमि कवर में परिवर्तन एरडास इमेजिन में लैंडसैट 5 और लैंडसैट 8, 30m रिज़ॉल्यूशन की इमेजरी का उपयोग करके बनाया गया। 2011 से 2020 के दौरान परिवर्तन की वार्षिक दर (एआरसी) 9.49 km^2/yr (11.97%), 0.47 km^2/yr(1.63%), 1.09 km^2/yr (7.15%), 1.30 km^2/yr (2.17%) और 0.16 km^2/yr (0.59%) बढ़ते हुए क्रमशः कृषि भूमि निर्मित क्षेत्र बंजर भूमि और जल निकाय के लिए प्राप्त हुआ । इसके अलावा, यह जलाशय और परती भूमि के लिए घटती हुई प्रवृत्ति में क्रमशः 0.07 km^2/yr (0.73%) और 12.47 km^2/yr (6.09%) थी । पेन्नार उप बेसिन के 20.82% और 41.07% को कवर करने वाले बेहतर प्रबंधन विधियो के साथ वर्ग II और वर्ग III भूमि खेती के लिए उपयुक्त पाया गया। भूमि जो खेती के लिए उपयुक्त नहीं है, अर्थात वर्ग VI 21% क्षेत्र और जल निकायों के साथ बंजर भूमि से आच्छादित है, पेन्नार उप बेसन के 17.08 % क्षेत्र जल निकाय और निर्मित क्षेत्र में आते हैं ।

पेन्नार उप बेसिन हल्की (1-3°) और उबड़ खाबड़ (35-37°) के साथ लगभग सपाट और उबड़ खाबड़ स्थलाकृति में आता है। वर्ष 2005 में सबसे अधिक वर्षा (2157 mm) और वर्ष 1994 और 2003 में सबसे कम वर्षा (657 mm) देखी गई, 1990 से 2018 की अवधि के दौरान पेन्नार उप बेसिन के लिए 167 से 614 मिमी अपवाह था । पेन्नार उप बेसिन 0 (निचले और मध्य भाग) से लेकर 155 टन/हेक्टेयर/वर्ष (ऊपरी उप बेसिन) तक कम से बहुत गंभीर क्षरण को इंगित करता है। उप बेसिन का बड़ा हिस्सा (96.49%) कम मिट्टी के कटाव अर्थात 0-7 टन/हेक्टेयर/वर्ष के अधीन था। इसलिए कृषि संबंधी उपायों को अपनाने की आवश्यकता है जहां कटाव> 7 टन / हेक्टेयर / वर्ष है। संरक्षण नक्शा ढलान, भूमि उपयोग भूमि कवर और पेन्नार उप बेसिन के मिट्टी के नक्शे का उपयोग करके तैयार किया गया है जिसमें आगे क्षरण और बेहतर उत्पादकता को रोकने के लिए कृषि विज्ञान और इंजीनियरिंग उपायों का सुझाव दिया गया है।

CHAPTER I

INTRODUCTION

Watershed management is defined as "Proper utilization of land and water resources for ideal and constant production with fewer hazards to natural resources. It cites to soil and water conservation in the watershed i.e., protecting land against all forms of deterioration, maintaining fertility of soil, effective utilization of land. Watershed management plays a vital role in arid and semi arid regions for conserving the limited water resources, because in maximum places, the surface water resources are rarely available and at some places it is completely unavailable. In these areas, groundwater recharge mainly depends upon rainfall. For better understanding of rainfall recharge mechanism and groundwater recharge estimation in the watershed, first knowledge on the morphometric parameters at the basin level is necessary. Development of a drainage system and the river flowing pattern over spatially and temporally are directed by various parameters viz. structural components, geomorphology, geology, soil and vegetation of the area through which it flows (Hari *et al.* 2018). Watershed management necessitates physiographic information such as location of drainage divide, length of the channel, configuration of channel network, slope of watershed and geomorphologic parameters.

In many parts of the world, with the help of conventional methods various surface drainage parameters of basins and sub basins have been studied earlier. Analysis of morphometric parameters necessitates analyzes the drainage parameters, viz. cross sectional area of basin, basin perimeter, drainage channel length, stream frequency, circulatory ratio, bifurcation ratio, drainage density, elongation ratio, stream ordering and form factor etc. Quantitative representation of basin morphometry involves slope of the channel network, computation of areal and linear parameters and providing basin slopes. This kind of examination plays massive help in better

perception of basin morphometry and its effective utilization of landforms and their characteristics will be useful for the execution of soil and water conservation measures and prioritization of sub watersheds.

Watershed prioritization plays an important aspect in planning for development and implementation of management programs. In this regard, geospatial tools can be widely used in several characteristics of unified watershed management involves land capability and land use planning, land resource inventory, terrain analysis, estimation of soil loss, watershed prioritization and identify the critical areas for effective designing and execution of watershed plans. The development of watershed management plan is considered as essential for the better management of land resources and the improvement of upland inhabitants' living conditions.

The analysis of morphometric parameters of landscape helps to estimate and evaluate erosion risk, watershed characterization, ground water potential and to develop soil and water conservation strategies. The analysis of satellite data in combination with basin morphometry provides a suitable platform for characterization of geological and landform units and also assists in identification of drainage channels, which are changed by human activities or natural forces by environment.

The change detection of land use transformation can be studied by remote sensing data with better accuracy, at low cost in less time. GIS provides better platform for data understand, evaluate, renovate and retrieval (Chilar, 2000). GIS has massive potential in estimation of actual and potential soil erosion using USLE parameters. For the prioritization of sub watershed, the quantitative assessment of USLE parameters using RS and GIS has a crucial role. Depending on the spatial overlay of various parameters of USLE, the soil erosion units can be delineated and identifying the spots to suggest mechanical and agronomical measures. Hence, Pennar sub basin in Anantapur district has been selected for management of natural resources using Geospatial analysis.

River Pennar has a semi arid catchment with extensive variations in the annual flows due to erratic rainfall and bad quality of water. It has its origination near Chikkabalapur in Karnataka state. River Pennar contains high silt loads in monsoon seasons resulting severe drinking problem for the people living in rural areas. In the state, Andhra Pradesh ground water will be available in semi confined and unconfined aquifers. Rainfall is the main source of groundwater recharge, while the other way is percolation of river water in high flow periods and seepage of irrigation water. In summer (low flow) period ground water contributes to base flow. Annual average rainfall in Pennar sub basin is 550 mm. The total culturable area is around 55% while the net sown area is around 36% of the total basin area. Double crops can be grown over very small area, about 1.66%. There is a need to analyze the land and water resources of Pennar sub basin for sustainable development using Geospatial tools. Pennar sub basin area as computed from the topo sheets is 6650 Sq. km. The catchment area from Penna Ahobhilam Balancing Reservoir (PABR) to Mid Penna Reservoir (MPR) which is about 31 km along river Pennar has been selected for the present study.

Hence, it is proposed to develop Pennar sub basin by preparing thematic maps using RS and GIS for the management of land and water resources with the following objectives.

Objectives

1. To prepare various thematic maps namely, drainage map, land use/land cover map, soil map, land capability of the sub basin.
2. To study the quantitative morphometric analysis and its influence on hydrological parameters of the sub basin Pennar.
3. To estimate soil erosion using RS & GIS and to suggest conservation measures in the sub basin.

CHAPTER II
REVIEW OF LITERATURE

This chapter deals with the brief review of research work done on different characteristics of morphometric analysis using GIS, generation of thematic maps, changes of land use land cover in a watershed, runoff estimation using Arc GIS software and effect of soil erosion on crop productivity in a watershed.

2.1 Morphometric analysis using GIS

Pal *et al.* (2012) analyzed six morphological parameters such as absolute topography, relative topography, average slope, intensity index, drainage density, extraction index to comprehend hydrological processes in the basin area. For analysis of morphometric parameters, Landsat ETM topographic and satellite imageries were used. In the ArcGIS software environment, a point level is generated and the elevation of the points is recorded with reference to latitude and longitude values. Contour curves which developed from Arc overlays had used for development of 3D elevations in the Erdas Imagine software. Using krigging interpolation tool of ArcGIS software, all point data was interpolated (Matheron, 1970). In combination with interpolation and the surface outputs, a digital elevation model (DEM) for the Watut watershed and an absolute topographical map were generated. This method can be used in various river basins to design and execute conservation measures.

Kamala *et al.* (2018) carried out a research on morphological analysis of the Amaravathi River basin based on another source, SRTM data downloaded from the GLCF website. The downloaded data has been analyzed with ArcGIS software. A study of the linear, aerial and relief aspects of the drainage basin revealed that the total flow was 16369, among these 12695 are in the first order, 2871 in the second order, 626 in the third order and 142 in the fourth order, 27 in the fifth order, 7 in the sixth

order, 1 in the seventh order. The linear parameters calculated in this study are stream order, stream number, stream length, bifurcation ratio, and length ratio. The areal aspects include basin area, form factor, circulatory ratio, elongation ratio, drainage density, stream frequency, length of overland flow and the relief aspects were analyzed. The study of the drainage map reveals that the Amaravathi River Basin is consequent in nature, whose course is due to the slope of the land surface. The dendritic and sub-dendritic drainage reflects the homogeneous character of the subsurface materials of the Amaravathi River Basin, Tamil Nadu.

Singh *et al.* (2014) applied satellite imagery and DEM data for the extraction of drainage patterns and evaluation of their relative parameters for the Orr watershed, Ashok Nagar district, M.P. Topographical parameters such as land use land cover and hydrological parameters like drainage analysis of the area using SRTM DEM were evaluated and interpreted for the management of watershed by ArcGIS environment. The drainage pattern of the watershed has shown dendritic in nature with stream order of first to sixth order. The bifurcation ratio ranged between 4.74 to 5.00 and the elongation ratio of 0.58 indicating the basin is elongated in shape. The mean R_b of the total watershed is 4.62 which indicated that the drainage pattern is not much affected by geological structures. The drainage density varies from low to medium which reveals that the watershed possesses highly permeable soils and low relief. Land use land cover map of the watershed was prepared using multispectral satellite data and classified into several types, forest, water bodies, agriculture, fallow lands, mining areas and settlements. It is reported that SRTM DEM based hydrological evaluation at watershed scale is more applied and precise compared to other available techniques.

Kannan *et al.* (2018) conducted a study on morphometric analysis at Nagavati watershed in Dharmapuri district. Geospatial tools, such as remote sensing and GIS, are utilized for the extraction of watershed and its drainage networks. The Shuttle Radar Topographic Mission (SRTM) data have been used for drainage morphometric analysis and evaluated various morphometric parameters. The hydrological parameters

of the watershed had evaluated and assessed by different methods like Horton and Strahler. Micro watersheds have varied elongation ratio of 0.13 to 0.43 indicated that watershed falls under elongated in shape and bifurcation ratio of 0.8 to 43.1. This study would help in effective utilization of the water resources for planning rainwater harvesting measures and watershed management.

The morphometric analysis using GIS would prove a practical method of characterizing the hydrological response of the watershed (Rai *et al.,* 2017). Remote sensing technique found appropriate for the extraction of drainage network and river basin through Aster DEM. Kanhar basin a tributary of River Son has been choosed for detailed morphometric analysis. The entire area of the drainage basin id 5654 km^2 indicates that sub dendritic to dendritic drainage pattern. The drainage area has seventh order stream with drainage density of 1.72 km/km^2. The stream order of the basin is mainly affected by physiographic and lithological conditions. Stream length ratio was increased from lower to higher stream order indicates that the basin has attained a mature geomorphic stage. The elongation ratio of study area is 0.48, higher elongation ratio describes high infiltration rate with low runoff and lower elongation ratio indicate lower infiltration rate with high runoff and high erosion. The Kanhar have drainage density values less than five describe that there is coarse drainage with permeable subsurface area.

Javed *et al.* (2016) conducted a study on Govindsagar catchment. By adopting the methods proposed by Horton and Strahler, the drainage network, stream ordering and morphological parameters such as linear, areal and relief aspects were computed. The designation of stream order is based on a hierarchic ranking of streams, and is a useful indicator of stream size, discharge and drainage area. Consequently, the stream length ratio has an important relation with the surface flow discharge and erosional of the basin. The bifurcation ratio of the catchment area varied from 2.00 to 5.23, revealing less structural control on the drainage. Drainage refers to closeness of spacing of stream segments. The Govindsagar catchment has high drainage density of

4.87/km with impermeable sub surface. The shape of the basin is 2.54 indicates peak flow discharge and carrying high sediment load. The drainage texture value is 4.53 reveals it has moderate texture. Form factor of 0.39 describe the catchment is elongated in shape with smaller peak flows for longer duration. Circular ratio of 0.19, the basin is less circular with low to moderate relief.

RS and GIS techniques have been successively utilized in advance tools for determination of basin geometry i.e., morphometric analysis and quantitative description (Biswas *et al.*, 1999). For the present study, the nine sub watershed's of the major Nayagram block which is situated in the Midnapore District has been taken. The results reveal that the ratio between mean stream length and stream order is constant throughout the successive basin orders. The bifurcation ratio and drainage density indicates the area is under dense vegetation and the drainage system is structurally controlled. Form factor values tells about the basin possess high peak flow for shorter duration. The sub watershed 8 has got highest priority as it has high erosion rate.

2.2 Generation of thematic maps

Gojiya *et al.* (2018) developed various thematic maps for a restricted forest Machhundri watershed, Gir Sanctuary of Saurashtra region, Gujarat, India. aspect map, land us eland cover map, slope map, contour map, elevation map, drainage map and soil map were developed in ArcGIS and remote sensing using landsat satellite images. Landsat Satellite imageries and Arc GIS software were used in the process. In the upstream side of the catchment, steeper slopes with heavy contour lines were observed while in the downstream, flat area with moderately spaced contours were discovered. Around 96 % contains loamy soils and 98 % covered by forest which is main reason for low runoff. The study area was sixth stream order, the steeper slopes are observed in first stream order. These thematic maps will be valuable assets in many land and watershed management studies as fundamental inputs.

Yadav *et al.* (2020) considered the importance of advanced technologies, GIS and RS which plays a crucial role in determining canal water distribution, its management, cropping pattern and geomorphology characterization of basin area. False color composite of LISS IV IRS-P6 geocoded data and SOI toposheet on 1:50000 scale were examined in combination to extract the information of command area. Based on the land use land cover, relief, aspect, slope and physiography for characterization and soil texture map was developed using the data collected and with farmers interaction. Depending on preparation and overlaying of several thematic maps along with hydrological, geomorphological and agro meteorological analysis, four farming conditions as per the local names of soil type i.e., Bhata, Matasi, Dorsa and Kanhar were identified and mapped based on soil sampling analysis. 98% of the command area was cultivated by paddy and there are two main streams passing, Sakti Nala and Shangari Nala.

Suryawanshi *et al.* (2010) generated various thematic maps for Malegaon watershed of Nasik District, Maharastra. Using the SOI toposheets, the base maps like watershed boundary map, drainage network map were prepared. For preparing various thematic maps such as land use land cover, soil map, hydro geomorphology and slope map, the satellite imagery of LISS –II IRS-1B of 11th November 1993, 30th Jan 1994 and 8th May 1994 were downloaded. The land use land cover map results that 35.07 % was Kharif cultivated land and 4.32% was double crop land, and hydro geomorphology map revealed that 77.18% area has appropriate ground water potential and soil map has eleven soil series and most of them are cultivated lands. About 50% of the land with less than 5% slope is available for cultivation.

Land cover classification is one of the major uses of distance interest identification of features such as land use, usually using multispectral satellite images. Using multi-temporal data as input, it has been reported to help improve classification accuracy, especially with regard to different kinds vegetation. However, the use of multi-temporal data can also cause problems while using traditional automated classification algorithms. The major problem is to get cloudless images of certain

places in specific years. Therefore, land cover map generated from Landsat images are usually taken at 5 or 10 year intervals.

If the magnitude of the error in the classified land cover map is much greater than the magnitude of changes to common classification methods, then there will be an error recognizing the actual changes. The accuracy of the land cover classification process depends on several factors: the classification scheme, the images used, the selection of training patterns, the pre-processing methods, the classification algorithms, the post-processing techniques and the validation data collection and validation methods. Most of the controlled algorithms performed reasonably well and were able to develop land cover maps with high classification accuracy if the parameters were set accurately and sufficiently representative training samples were used. Several algorithms such as Maximum Likelihood Classifier (MLC), Logistic Model Tree (LMT) and Logistic Regression (LR) are more intuitive and can be easily performed with relative performance stability.

2.2.1 Analysis of change in land use land cover

Pande *et al.* (2014) conducted a research to determine and identify changes in land use/ land cover of Patur taluka in Akola district. The study was carried out using Remote Sensing data and GIS approach using SOI toposheets, Landsat imagery of 2013 and IRS-1D-LISS-III 2007. The classification of land use land cover scheme has performed depending on the SOI toposheets and satellite imageries. The ArcGIS 10.1 software has used for the generation of land use land cover images and ground truth data are carried out for the accuracy validation of classification scheme. The study area was classified into five categories on the basis of field study, geographical conditions, and remote sensing data. The comparison of LULC in 2007 and 2013 derived from satellite imagery interpretation indicates that there is a significant increase in built-up area, open forest, water body, waste land and other lands whereas, the agricultural land decreased in 2013 as compared to 2007. Though there are some changes detected in land use/land cover analysis of the period 2007-2013, it does not indicate any significant environmental impact on the study area.

Butt *et al.* (2015) evaluated that, development and management of watersheds necessitate accurate measurement over past decades, land cover land use parameters as changes observed in these parameters determine the hydrological and ecological processes taking place in a watershed. In the present research, maximum likelihood of supervised classification using ERDAS Imagine to detect the land use land cover variation in Simly watershed, Pakistan using multispectral satellite data of Landsat 5 and SPOT 5 during the 1992 and 2012. The land use land cover of watershed has classified into five major classes i.e., Water, Vegetation, Agriculture, Waste lands, Settlements. LULC maps and surface maps developed in ArcGIS 10 indicates significant changes in vegetation and water to agriculture, waste lands and settlements reducing 38.2% and 74.3% respectively. These changes in land use caused a severe threat to watershed resources. Therefore, proper management of the watershed is required.

Balakrishnan *et al*. (2017) reported that land use and land cover of a watershed has great effect on water quality and stream strength. The land cover has a great impact on stream hydrology due to the amount of storm water runoff. Land use land cover maps of Walayar watershed for the two time periods of 2006 and 2011 were developed using GIS and Remote sensing approach. This information at watershed level has a cope for monitoring, planning, selection and management of water resources.

The knowledge of both land use and land cover within the watershed area is more important for monitoring and improving ecosystems, hydrology, land management activities, land planning, ecological studies and landscape for sustainable planning (Rao *et al.,* 1996). The remote sensing data made feasible for the study of land use land cover variations at low cost, with better accuracy and in less time (Kacchwala, 1985) and also GIS provided a suitable platform for the data understand, evaluate, renovate and retrieval (Chillar, 2000). Several methodology had used for detection of LULC changes using RS as green vegetation index differencing, image

differencing, univariate image differencing, particular principal component analysis, direct multi-date classification, image rationing, change vector analysis and post classification (Mas, 1999).

2.3 Estimation of Runoff using Arc GIS environment

The surface runoff estimation is essential for the design of hydraulic structure and to establish flood control analysis. The surface runoff volume was computed by SCS CN model in ArcGIS and remote sensing data. The study was conducted in Cuddalore micro watershed with an area of 58.54 km^2 in Tamilnadu state. The LULC map and soil map were prepared in ArcGIS environment and used to calculate CN values. The estimated surface runoff in the present study is 4260 mm (Eshantini *et al.*, 2018).

Raju *et al.* (2018) computed the surface runoff in the semi-arid crystalline rock terrain of Mandavi basin using Remote Sensing (RS) and Geographical Information System (GIS) techniques. The study area experiences strict groundwater scarcity despite having high rainfall-runoff. The Weighted Curve Number (AMC II) was assessed by the soil group information and LULC classification of each class and area occupied by the individual class in LULC map. Then CN II was converted to CN I and CN III viz. dry and wet conditions the results declared 52.29 (CN II), 31.50 (CN I) and 71.58 (CN III). The Mandavi basin has exhibits annual average rainfall, runoff volume, runoff coefficient and runoff for 20 year time period as 688.82 mm, 699.75m^3, 0.69 and 478.09 mm respectively with an increase in rainfall- runoff since 1995 to 2014.

Rainfall and runoff constitutes the sources of ground water recharge in the watershed. The surface water resources are existed in the form of excess rainfall (runoff) generated from the streams, canals, rivers and water bodies. The study area of Pappiredipatti catchment, Vaniyar sub basin with total area of 179.4 km^2 has taken into account for the runoff estimation and soil loss estimation and planning the

artificial recharge structures, reservoirs and soil erosion control measures. Runoff is majorly influenced by geomorphological parameters especially, land use changes affected the runoff volume significantly. The proposed construction of artificial recharge structures was the main aim of this research. This result is useful for the watershed development, management and planning of water resources effectively (Kumar *et al.*, 2017).

Pal *et al.* (2011) estimated surface runoff based on different parameters using SCS model. The parameters namely, the land use land cover, hydrological soil characteristics, rainfall data (P), Potential Maximum Retention (S), Antecedent Moisture Condition (AMC), Weighted Curve Number (CN), that are the mandatory inputs to SCS model, have been either derived from remote sensing data or from conventional data collection systems. These parameters are obtained from monthly and annual rainfall data, soil map of the region, Remote Sensing (RS) techniques (with use of Normalized Difference Vegetation Index) and land use land cover map, respectively. The pixel wise runoff CN estimated by GIS software used as input to the SCS model to estimate surface runoff. This study is carried out in the Kaliaghai river basin, Purbo and Paschim Medinipur district of West Bengal. The result shown that the sub-basins are indicating high CN which is more than 80 indicated high runoff in the Kaliaghai river basin. On an average, 722.7 mm the surface runoff was generated in the monsoon season during 2010 compared to the other seasons.

Pathan *et al.* (2019) assessed runoff in Karjan reservoir basin. From the 5 rain gauge stations, the daily rainfall for the study area was collected and used for computing daily runoff using SCS-CN method and ArcGIS. A linear regression model is developed for the confirmation of runoff obtained from SCS- CN method. The deviations are observed in the results obtained from the runoff indicated and observed runoff. The simulated annual runoff using Linear regression coincided with the observed annual runoff in comparison to the simulated annual runoff using SCS-CN

model. Coefficient of determination (R^2) for SCS-CN model is 0.65 while for linear regression model is 0.83.

2.4 Estimation of soil erosion using Arc GIS and RS

Soil loss, a chief concern in land surface management and conservation planning (FAO 1985). In development of spatial data layers and their integration for the estimation of soil erosion by adopting appropriate methods like Universal Soil Loss Equation (USLE), geospatial techniques plays a very significant role. GIS integrated with Database Management System (DBMS) and Image Analysis System (IAS) is an important technique for the preparation of spatial data layer and their combination to soil erosion estimation for a specific area. These techniques have been extensively used in quantitative analysis of USLE parameters. Various components of USLE such as rainfall erosivity factor (R), soil erodibility factor (K), Slope length steepness factor (LS), Crop cover factor (C), Support Practice factor (P) are calculated by using rainfall data, soil information, slope generated from contours, land use land cover map and field data using remote sensed data and GIS. GIS has massive potential in estimation of actual and potential soil loss using USLE. Depending on the spatial overlay of various parameters of USLE, the soil erosion units can be delineated and identifying the spots to suggest mechanical and agronomical measures.

Djoukbala (2018) informed the soil loss estimation using experimental models former a propitious study in recent decades. However, their application over wide areas poses a problem due to the availability and superiority of the data required. The three models of Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Loss Equation (MUSLE) and Universal Soil Loss Equation (USLE) were used for the determination and comparison of water erosion in the catchment of Wadi Gazouana, North-Western Algeria. The results obtained using three models is 11.33, 9.90 and 9.65 ton/ha/year of MUSLE, RUSLE and USLE methods, correspondingly. From the results, it can be concluded soil erosion produced from three different methods produced similar, although the MUSLE method produced higher spatial

resolution of erosion risk than the other two methods, the rainfall erosivity is more effective which determine its higher erosion rate.

Zhang *et al.* (2010) studied the integrated Modified Universal Soil Loss Equation (MUSLE) in a Geographic Information System (GIS) framework in the form of a tool called Arc MUSLE, an extension of ArcGIS software, to assist soil and water conservation agencies in soil erosion risk assessment and prioritization of critical areas for soil erosion control practices. With widely available spatial data, this tool can be applied to determine curve numbers, to estimate runoff, peak flow, and soil loss for a rainfall event within a Black Hawk County watershed, Iowa, USA. Lands with hydrologic group D soil have the highest curve number values and highest runoff depth. Peak flow is derived from six parameters viz. runoff depth, land cover, 2- year 24-hour rainfall, flow length, drainage area, and slope. The high LS factor values are observed, having shallow runoff depth as it contains soil group B and grass as the land cover. After field verification, corresponding Best Management Practices (BMPs) such as contour farming filter strips, or conservation tillage are suggested to those areas. The application of suitable BMPs to these areas will upgrade the efficiency of soil and water conservation projects.

Iaach *et al.* (2016) computed the soil erodibility factor as soil erodibility is an input factor in assessment of soil erosion. The present work studies the soil erodibility using three mapping approach. (a) the CORINE approach, used for Europe by the JRC (b) the UNEP/FAO approach developed by United Nations Environmental Program, for the Mediterranean area (c) the Universal Soil Loss Equation (USLE) K factor. The study area is the province of Tangiers, North-West Morocco. The thematic maps were integrated to estimate soil erodibility factor map for three approaches using GIS. Later, it was checked by three statistical indicators, namely, Kappa factor, Omission/Commisson errors and Overall accuracy in the field, pointing on highly eroded surfaces, by opposing the estimated soil erodibility and the erosion risk as resulted in the field. The UNEP/FAO approach is the most adopted for the study zone,

followed by CORINE approach and the USLE factor used for estimation of soil erodibility, particularly for highly eroded areas.

Kumar (2016) had carried out research on soil erodibility, the main factor used in spatial soil erosion probability. Basically, soil maps at minute range are utilized in determining soil erodibility map that widespread spatial variability. The present research made an attempt for the development of K factor using terrain characteristics delineated from Digital Terrain Model and data of soil samples. The CartoDEM with resolution of 30 m was downloaded to determine terrain index such as stream power index (SPI), sediment transport index (STI), terrain wetness index (TWI) and slope characteristics. Totally, 95 samples were collected for the calculation of K (soil erodibility) values with results varied from 0.23 to 0.81 t/ha/R in the watershed. A multiple linear regression model was adopted from the determination of k factor using terrain characteristics. The coefficient of determination (r^2) and RMSE were computed to be 0.76 and 0.07 t $ha^{-1}R^{-1}$ respectively. The proposed methodology is quite useful in generating soil erodibility factor map using digital elevation model (DEM) for any hilly terrain areas. The developed model was used for the preparation of spatial soil erodibility factor (*K*) map of the watershed in the lower Himalayan range.

Soil loss due to soil erosion can be determined using predictive models such as USLE and RUSLE. The accuracy of these models depends on parameters that are used in equations. One of the most important parameters in equations used in both of models is C factor that represents effects of vegetation and other land covers. The C factor values for Buyukcekmece watershed were predicted using NDVI determined from Landsat 5 TM Image of 2007. Using spatial analyst tool of ArcGIS 9.3, the final C factor map was developed based on the regression equation. Approximately, 60% of study area has the C factor values ranges from 0.2 to 0.4 and higher C factor values are observed in the northern part of the watershed (Karaburun, 2010).

Srinivas *et al.* (2002) estimated the soil erosion using USLE model in GIS to designate the tahsils for conservation of soil and executing conservation practices in Nagpur, Maharastra. The results indicate that, very slight to slight soil erosion takes place in north western valleys, north and the mountainous of middle and eastern areas of the Nagpur district. Moderate to moderately severe erosion identified in the southeastern and few middle parts. High to extremely very high erosion accounted in the western, northern, southern and southwestern parts of Nagpur district. The average soil erosion is accounted as 15.5 tons/ha/year and 23.1 tons/ha/year under actual and potential conditions correspondingly. 41% of the entire area covered under slight to extremely severe potential erosion. Very low erosion effected by the land cover leads to a depletion of 7421.2 ton of potential soil loss. Using overlay analysis of the soil erosion parameters, land cover, soil depth, slope and surface texture has resulted in defining nice conservation units. Suitable mechanical and agronomic measures are suggested for the places with high risk of erosion hazard.

Kiriwongwattana and Aggarwal (2012) applied the Natural Resource Conservation Service Curve Number (NRCS-CN) method for runoff estimation and Modified Morgan Finney (MMF) model to assessment of soil erosion rate. Depending on the estimated runoff and soil loss rate, the conservation measures are suggested. In this approach, LULC prepared from the Landsat TM 2010 data, soil map procured from NBSS & LUP and slope map delineated from ASTER GDEM . With the help of LULC, HSG map, CN map has been prepared. Finally the runoff depth has been calculated. The results indicate that out of 2173 mm rainfall 816.34 mm runoff was produced. The average annual soil loss of 68 ton/ha/year has been registered. Twenty two sites were identified for check dam construction and soil conservation measure as agronomical measure i.e., contour bunding and bench terrace.

Based on the review of literature cited above, the methodology has been selected for the estimation and to meet the requirements of the objectives which discussed in CHAPTER III.

CHAPETR III

MATERIALS AND METHODOLOGY

This chapter deals with the details of the study area, materials used and methodology adopted to achieve the set of objectives. The present study mainly focused on the runoff estimation by using SCS-CN method and soil erosion in the Pennar sub basin using Modified Universal Soil Loss Equation. The details of the materials and methods adopted are given in this chapter.

3.1 Description of the Study Area

The Pennar river basin is an important tributary of River Penna. The entire geographical area of Pennar basin is 55213 km^2. It passes through the states of Karnataka and Andhra Pradesh with area of 6937km^2 and 48276 km^2 respectively. River Pennar has its orientation near Nandidurg hills, Chikkabalapur, Karnataka state. The basin lies between East longitudes of 77º 04’ and 80º 10’and North latitudes of 13º 16’ and 15º 52’. It is surrounded by Erramala range in the north, Nallamala in the east and Velikonda range in the Eastern Ghats, Nandidurg hills in the south and Vedavati valley of the Krishna basin in the west.

The principal tributaries of the River Pennar are the Kunderu, the Jayamangali, the Sagileru from the left and the Chitravathi, Cheyyeru from the right and the Papagni. The major reservoirs are Sathanur and Somasila reservoir. The majority soils found in the Pennar basin are sandy soils, black soils, red soils and mixed soils. The culturable area is 3.54 Mha which is around 1.8% of the total culturable area of the basin. Under the major land uses of Pennar basin, forest accounts 21% of the area, 12% of the waste land. The culturable area is about 55% whereas; the net sown area is 36% of the total basin area.

The climate of the Pennar basin is characterized by the mean maximum temperature of 40.3ºC observed at Kadapa district to 34.7^0 C observed at Arogyavaram and mean minimum temperature of 20ºC observed at Nellore district to 15.3 ºC observed at Arogyavaram. Relative humidity ranged in between 21-84%. The Pennar basin receives well distributed rainfall in the monsoon seasons while in non monsoon season the rainfall is insignificant. The south-west monsoon receives predominant rainfall while the north-east monsoon receives very less precipitation. Post monsoon cyclonic activity in the Bay of Bengal over September and October produces an increased rainfall in coastal areas. The average annual rainfall in the Pennar drainage basin is about 550 mm at Anantapur district.

The present research was carried out in one of the sub basin of Pennar located in Anantapur district of Andhra Pradesh. It comprises three mandals of Anantapur district, namely, Uravakonda, Vajrakarur and Kuderu having an area of 424 km² i.e., the region between Penna Ahobhilam Balacing Reservoir (PABR), Korrakodu village, Kuderu mandal and Mid Pennar Reservoir (MPR), Penakacharla village, Garladinne mandal and covers 26 villages. Pedda chinnapyapili, Venkatampalli, Uravakonda, Lathavaram, Shaiksanipalli, Mopidi, Shivaram peta, Jalli palli, Udiripi konda, Cholasamudram, Indravati, Pedda mustur, Chinna mustur, Racharla, Jayapuram, Mylarampalle, Korrakodu, Raketla, Pennahobilam, Racharla, Marutla, Konapuram, Jarutla Ramapuram, Kalagalla, Budigumma, Peddakowkuntla are the villages in PABR basin. The study area situated in between 77 º 14’ 52” E, 14º 42’ 29”N & 77 º 26’ 38” E, 14º 58’ 57” N. The culturable area is about 55% whereas; the net sown area is 36% of the total basin area. Majorly grown crops are paddy, groundnut, jowar, cotton, sunflower and rabi crops. The MPR is at 338 m MSL and while the PABR is at 349 m above MSL. The annual temperatures are 36.1º C in summer and 31.7 º C in winter. The study area location map is shown in Fig. 3.1.

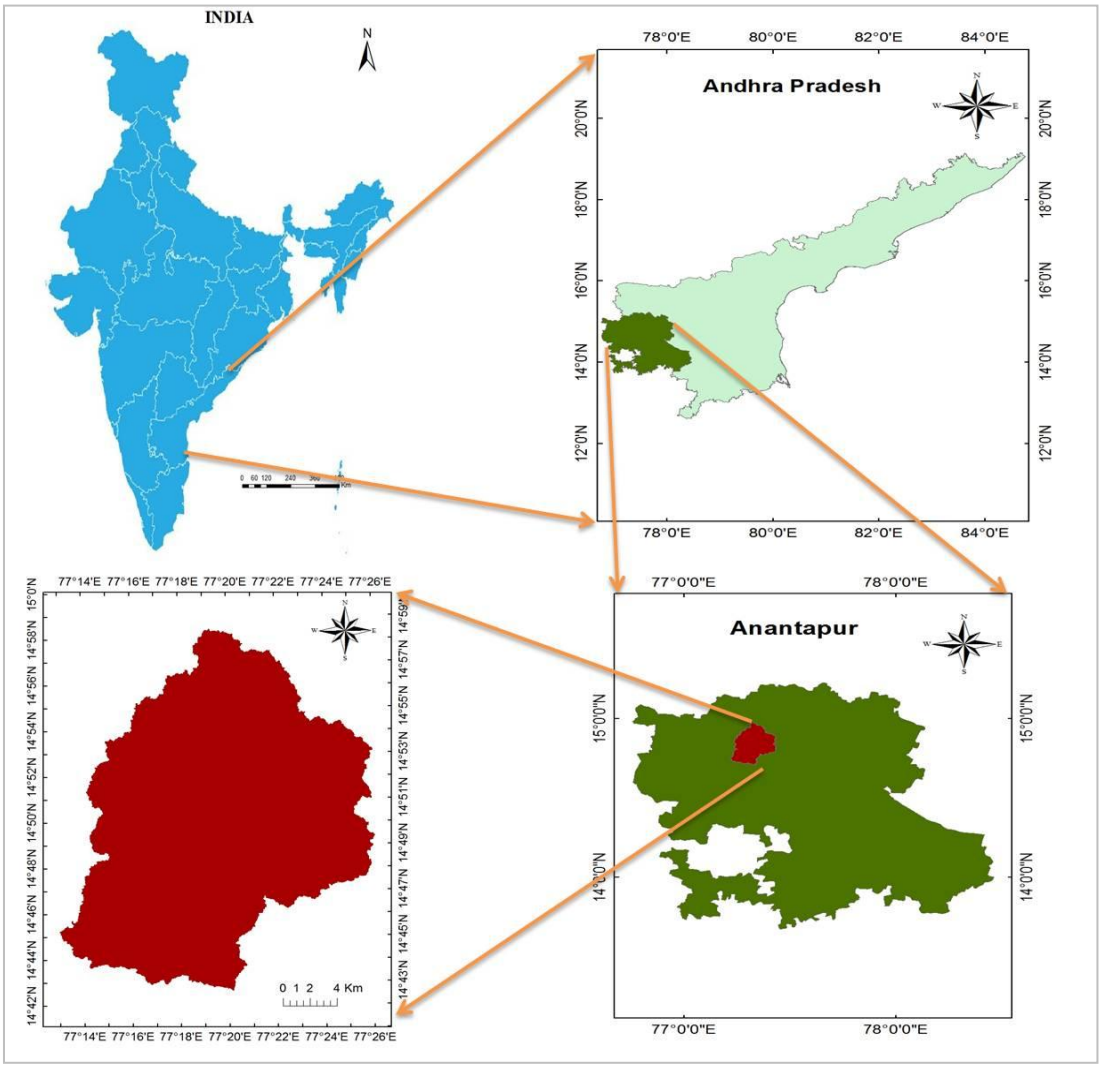


Fig. 3.1 Location map of the study area

3.2 Data used

The Digital elevation Model data (DEM) was downloaded from USGS (United States Geological Survey) earth explorer for the delineation of the Pennar sub basin boundary, extraction of drainage map and morphometric analysis. The satellite data of LANDSAT 8 and LANDSAT 5 of path number 144 and row number 50 covering Anantapur district were downloaded for three different years viz. October 2011, October 2015 and November 2020 from the United States Geological Survey (USGS)

earth explorer for estimating the changes of land use and land cover over a period of time. The soil survey data was used for the preparation of soil map.

3.3 Softwares used

Softwares which have been used for preparation of various thematic maps and drainage maps are Arc GIS 10.1 and Erdas Imagine 2015. The land use land cover images are prepared in Erdas Imagine software and ArcGIS 10 software has been used for the preparation of various boundary maps and drainage maps.

3.4 Preparation of Thematic maps

Thematic maps include drainage map, land use land cover map, land capability map and soil map and of the Pennar sub basin have been prepared. The change detection of land use land cover maps are estimated for 2011, 2015 and 2020.

3.4.1 Preparation of drainage map

Extraction of drainage network and adopting the stream order from a published Survey of India (SOI) topographic map and from the geo-referenced satellite data for a large area is time taking tiresome exercise. In order to overcome this problem, automatic extraction process have been used for basin i.e., extraction of basin boundary and extraction of stream network for the Pennar sub basin using SRTM DEM data. The extracted boundary of the basin and stream networks is then projected to projection co-ordinate system (WGS 1984, UTM zone 43 N).

3.4.1.1 Extraction of Pennar sub basin boundary

The Pennar sub basin is automatically extracted from SRTM DEM data with the resolution of 30m using geo-referenced SOI toposheets. Pennar sub basin area was extracted with the aid of several geo processing techniques in ArcGIS- 10.1 software. The pour point data and the DEM data are the two input parameters essential for the extraction of Pennar sub basin boundary. A pour point is defined as the lowest point on the boundary through which the river or stream flows out, will be given manually

to the cells of high accumulation. The methodical process for the extraction of Pennar sub basin is shown in Fig. 3.2. And the final result of this methodology will delineates a watershed boundary from the flow direction raster data.

3.4.1.2 Extraction of Drainage network map

The drainage/stream network of the Pennar sub basin is extracted geoprocessing tools in ArcGIS environment (Fig. 3.3). The result of this method is a basis for creating a stream/drainage network with stream order based on Strahler 1964. In Strahler system of stream order classifies, a segment with no tributaries or streams area classified as first order stream, the two first order streams combines to generate second order stream, the two streams of second order combines to form third order stream and so on. Fourth order stream is identified as the highest stream order in the Pennar sub basin. This process requires two input parameters: DEM and a minimum upstream area, which is the minimum drainage area required to create a stream.

The above figures (Fig. 3.2) represent extraction of sub basin boundary through the following features:

1. SRTM DEM 30 m resolution
2. Flow direction
3. Flow accumulation
4. Pennar sub basin boundary vector

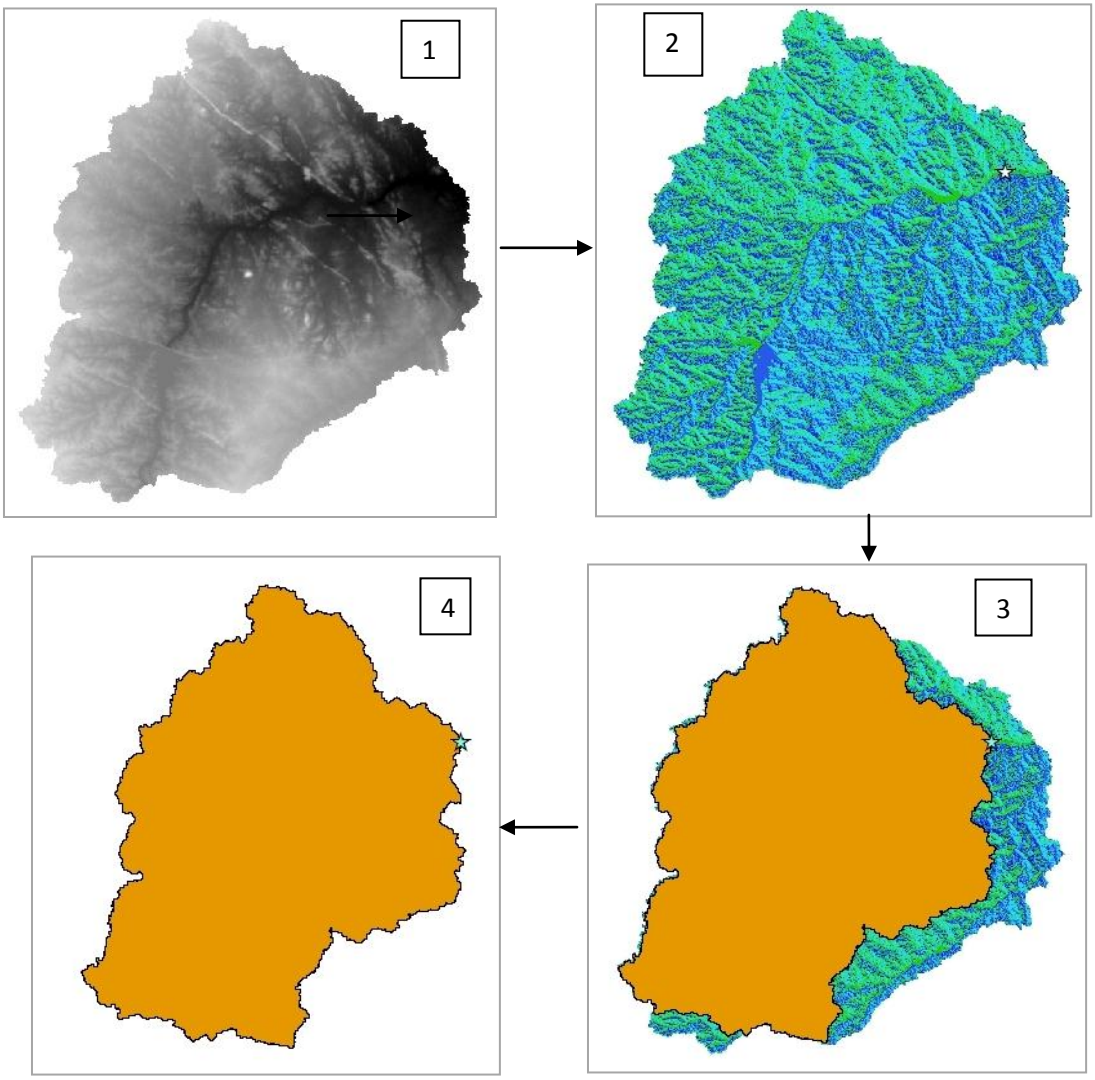


Fig. 3.2 Extraction of Pennar sub basin boundary through SRTM DEM

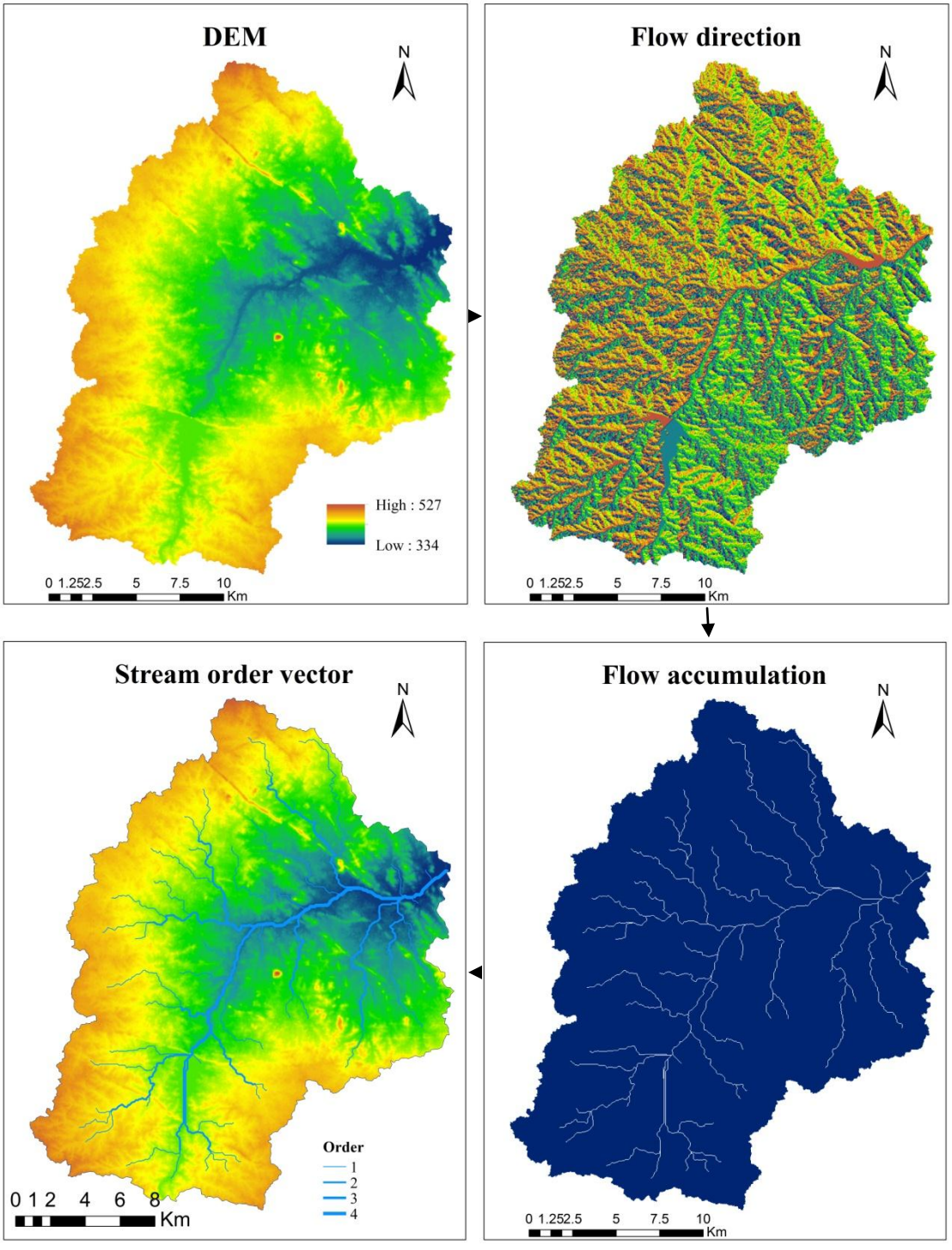


Fig. 3.3 Extraction of drainage map

The extraction of drainage map is shown in Figures 3a to 3d.

3.5. Morphometric Analysis

The hydrological analysis of watershed and their morphometric evaluation of Pennar sub basin, Anantapur district, Andhra Pradesh were carried out for water resource management through the use of SRTM DEM, satellite images and GIS analysis. The main aim of this thesis is to study and define various runoff parameters in order to understand the water geometry for the conservation and management of water resources. The results observed can be used as a scientific database for the detailed hydrological investigations and alternative solutions for the water extraction in the study area by suggesting conservation measures (check dams, recharge shafts, storage tanks) based on the observed calculations

Catchment area of the Pennar sub basin delineated from SRTM DEM. For the delineation of sub basin DEM was extracted from Shuttle Radar Topographic Mission (SRTM) data of 30 m resolution downloaded from the US Geological Survey website. The SRTM DEM data was used to prepare drainage map, topographical and relief map of the Pennar sub basin using Spatial Analyst tool of ArcGIS 10.1

To assess the drainage basin morphometry, various parameters like stream order, stream number, stream length and their ratio, elongation ratio, bifurcation ratio, circulatory ratio, form factor, stream frequency, texture ratio, drainage density and compactness coefficient etc. have been calculated using the standard mathematical formulae as given in Table 3.1. On the other side, the slope and aspect map of the Pennar sub basin were delineated using slope and aspect tool of spatial analyst toolbox in ArcGIS 10.1

Table 3.1 Linear, areal and relief morphometric parameters estimated for Pennar basin

S. No.	Parameters	Formulae	References
1	Stream order (N_u)	Hierarchical rank	Strahler (1964)
2	Stream Length (L_u)	Length of the stream	Horton (1945)
3	Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$	Strahler (1964)

4	Stream length ratio (R_L)	$R_L = L_u /(L_u - 1)$	Horton (1945)
5	Bifurcation ratio (R_b)	$R_b = N_u / N_u +1$	Schumm (1956)
6	Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all order	Strahler (1957)
7	Drainage density (D_d)	($D_d = L_u /A$	Horton (1945)
8	Drainage texture (T)	$T = Dd \times F_s$	Smith (1950)
9	Stream frequency (F_s)	$F_s = N_u /A$	Horton (1945)
10	Elongation ratio (R_e)	$R_e = D/L = 1.128\sqrt{(A/L)}$	Schumm (1956)
11	Circulatory ratio (R_c)	$R_c = 4\prod A/P2$	Strahler (1964)
12	Form factor (F_f)	$F_f = A/L2$	Horton (1945)
13	Relief (R)	R = H - h	Hadley and Schumm (1961)
14	Relief ratio (R_r)	$R_r = R/L$	Schumm (1963)

This morphometric analysis represents the physical characteristics of the Pennar sub basin and to identify the sites for conservation structures to avoid land degradation.

3.6. Preparation of LULC, land capability and soil map

3.6.1. Preparation of LULC map

Change in LULC plays a vital role in policy making with regards to the management of natural resources and monitoring of environmental changes distinguished and studied by factors in spatially and temporally at various magnitudes. The factors comprises of political, cultural, socioeconomically, natural and several other factors.

3.6.1.1 Data used

Satellite data and secondary data were used for examining the historical changes of LULC in the study area for a period of 10 years from 2011 to 2020. Three landsat satellite images i.e., 2011, 2015, and 2020 of Path/Row 144/50 were downloaded from the USGS website (https://earthexploree.usgs./). The following table

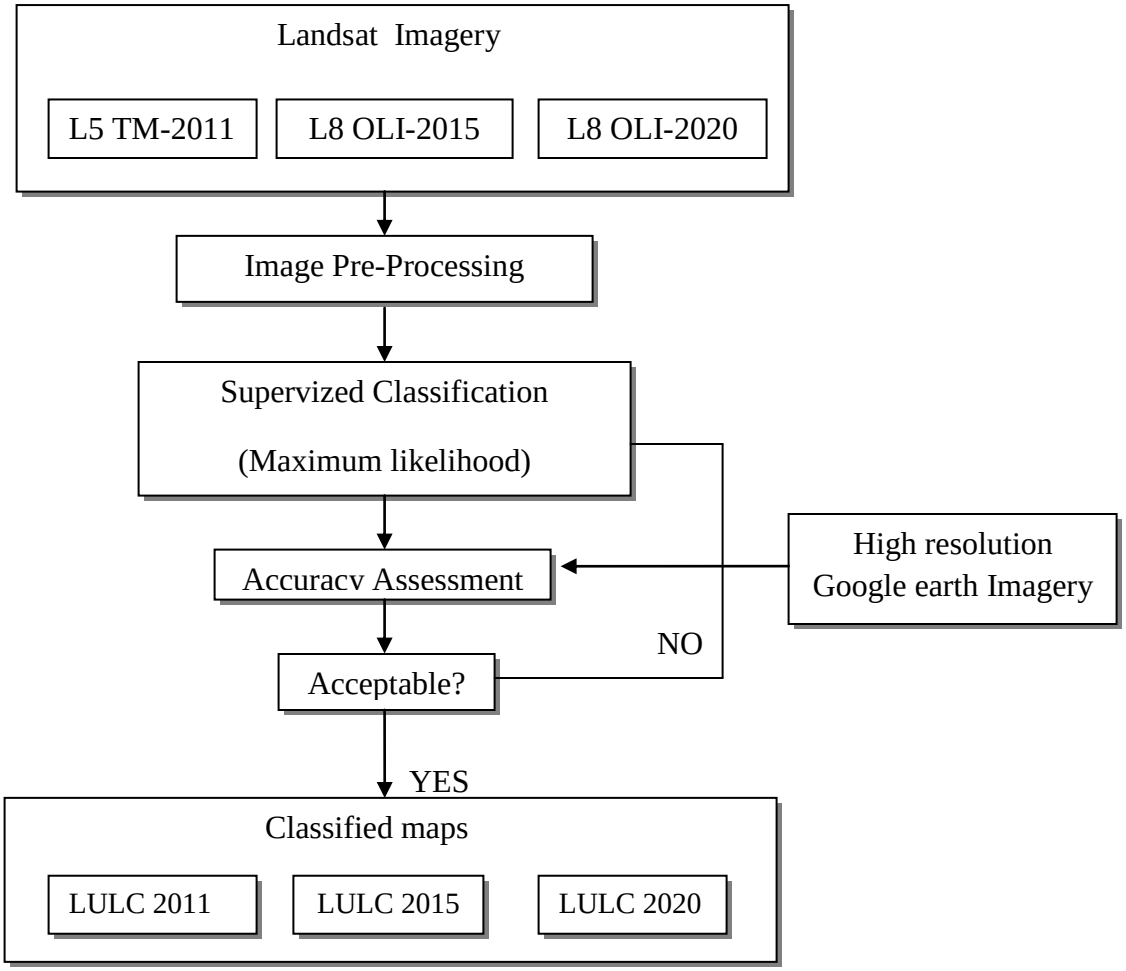
3.2 shows the attributes of landsat satellite images for the present study. In order to satisfy the best change detection, the landsat images of wet season i.e., October and November were used which enabled as a cloud free imagery with best visibility.

Table 3.2. Source and characteristics of satellite imagery

Satellite data	Path/Row	Date	Number of bands	Resolution
L5 TP	144/50	01/10/2011	7	30m
L8 OLI	144/50	28/10/2015	11	30m
L8 OLI	144/50	10/11/2020	11	30m

3.6.1.2 Image Processing and analysis

The downloaded image data was processed in Erdas Imagine 2015 and ArcGIS 10.1 environment. The systematic flow chart is given in Fig. 3.4 and explained as following:



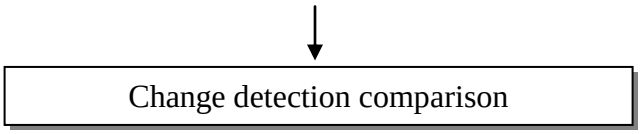


Fig. 3.4 Flow chart of data processing steps

3.6.1.3 Image Preprocessing

This study was followed by a series of data analysis steps using ArcGIS and Erdas 2015. These steps include atmospheric, geometric corrections, radiometric in addition to gap filling, sub-setting, and enhancement. The selection of suitable bands to be used in image classification also includes in Preprocessing. The satellite imageries were then projected to the projected coordinate system, WGS 1984, UTM zone 43 North and corrected for geometric errors from the sources.

Landsat 8 OLI imagery is accelerated to increase the image resolution from 30m to 15m by combining color information in the multispectral bands and high resolution panchromatic bands using layer stack tool to achieve high image valuable color image with high resolution that improves mapping and classification accuracy. However, it was not possible to perform this on the Landsat 5 TM image captured in 2011 since the panchromatic band is not available.

3.6.1.4 Image Classification

Image classification is an important remote sensing technique used to guide all pixels in an image or raw remotely sensed data into a limited number of individual LULC classes to produce beneficial thematic maps and information. The image classification process is normally directed to assign different spectral signature from the dataset to several classes based on reflectance attributes of the diverse types of LULC.

Although there are many ways to classify image data, the commonly used methods are supervised and unsupervised methods. Most scientists prefer to use supervised techniques because they provide more accurate classification than unsupervised methods. There are several classifications based on statistics, the most common being maximum likelihood, minimum distance, parallopiped classification, and mahalanobis classification. During the literature review, it was found that it is

possible to work on a large scale in the maximum likelihood, because it is quick and easy to implement, allows for ambiguous interpretation of results, and provides satisfactory accuracy. Improved visualizations of various characteristics to easily detect LULC layers in images using True and False color composites. The LULC training sets is created by visual interpretation of Landsat images (2011, 2015 and 2020) based on Google Earth images, knowledge of the field of study and field observations. After developing a set of instructions, the maximum likelihood classification is followed to generate a spectral signature, which is then used to classify all pixels in the image.

In this study, mainly 5 classes are classified i.e., Built up lands (rural), Agricultural lands (Crop lands and Follow lands), Barren lands, Shrub forest and Water bodies (Reservoirs and streams, canals, ponds).

3.6.1.5 Classification accuracy assessment

The accuracy assessment in this present study was computes using historical high resolution google earth imagery acquired from Google Earth Pro. The here google earth images captured during October 2011, October 2015 and November 2020 were used to study the accuracy validation for LULC maps of 2011, 2015 and 2020 respectively.

3.6.1.6. Change detection

Change detection is defined as "the process of identifying differences in the state of an object or phenomenon by observing it at various times". Change detection analysis makes LULC study a subject of interest because it not only explore changes that have taken place but also identifies their nature and determines their spatial extent and pattern. There are several methods that have been developed for change detection analysis of remote sensing data, and they have been classified into two major categories: pre-classification and post-classification comparison techniques.

However, the post-classification comparison approach has been chosen to be the most commonly used method for LULC change detection. The post-classification

approach involves the classification of multiple date images separately to generate thematic maps, after which a pixel-based comparison of the corresponding classes is used to produce tables and maps of changes that have occurred. There are several advantages of using post-classification comparison approach, and this involves the following steps:

1. It reduces the possible effects of sensor and atmospheric and environmental differences between images as they are independently classified.
2. It provides more detailed information obtained from a complete matrix of LULC change.
3. It quantifies the change rates and magnitude of change.

However, the degree of change detection depends on the accuracy of individual classifications. Many studies have employed post-classification techniques based on maximum likelihood classification for detecting LULC changes in different areas around the world using Landsat imagery data and have attained high accuracy. The capability of the post-classification comparison techniques is not limited to just identifying the size and distributions of areas that have changed, but it goes beyond that to determine the individual participation rate of each LULC class in changing another particular class. Therefore, the post-classification comparison technique was chosen in this study to be employed for change detection. Pairs of the produced classified thematic maps for the three dates (2011, 2015 and 2020) were compared by applying the detection algorithm using Erdas 2015. The magnitude of change (MC), the percentage of change (PC), and the annual rate of change (ARC) for each LULC class during each period of time were computed based on the following equations:

$$MC\ (km^2) = A_i - A_f \quad \ldots (3.1)$$

$$PC\ (\%) = \frac{Ai - Af}{Ai} \times 100 \quad \ldots (3.2)$$

$$ARC\ (km^2/yr) = \frac{Ai - Af}{n} \quad \ldots (3.3)$$

$$\text{ARC (\%)} = \frac{Ai - Af}{Ai \times n} \times 100 \quad \ldots (3.4)$$

Where, Ai is the initial time class area (km^2), Af is the final time class area (km^2) and n is the number of years of the time period.

3.6.2. Land Capability classification

Land capability classification is a scientific assessment of the physical properties of the soil. "The natural capacity of land to manage the general land use function." This is quality of the soil, which is valued by the physical properties of the soil and the characteristics of the landscape

The LCC classified into three major types of soil viz. capability unit, capability sub class and capability class. Land capability unit is combining of soils that have equal responses to agricultural crops and pasture plants, yields are also used as standard in developing the capability units. Land capability sub class is a combination of land. The last category, land capability class is series of soils having the equal level of limitations. The limitations in use of soil steadily increase from class I to class VIII. The LCC classes I to IV are suitable for cultivation and Class V to VIII are unsuitable for cultivation expect these classes are suitable for forestry, grazing and wildlife maintenance and recreation or protection of watershed or catchment (ICAR, 1980).

According to this system of classification, three land capability classes i.e., class II, class III and class VII are observed in the Pennar sub basin. The detailed view of each class of land is explained as follows.

3.6.2.1 Land suitable & unsuitable for cultivation

In the present study, the class II and class III are the lands suitable for cultivation. The entire area covered by these two classes is about 61.9% of the total area of Pennar sub basin. Class VI is the land which is unsuitable for cultivation, occupied an area of 21% among the total area of the basin.

3.6.2.1.1 Land capability class II

The class II lands are suitable for cultivation with moderate limitations. The texture of soil is clay, clay loam and sandy loam with depth greater than 50 cm and slope ranges from 1-3%. The soil color is medium to dark with less drainable capacity. The soil erosion will be less with less gravel content. This class II land has a great productivity and generally observed in the banks of the river.

3.6.2.1.2 Land Capability Class III

The class III lands are quite good with various limitations which cause choice reduction in crops and necessitate specific care in management and handling. Comparatively the limitations of class III lands are more than class II, thereby, extra care should be given for the management.

The soil texture of class III land is sandy clay, sandy loam, clay loam of depth greater than 25 cm with gentle slopes. The drainable capacity of these soils is moderate to well. As in class II lands, there are also no gravels in this class and the soil erosion is moderate to less. This type of class is occupied an area of 41% of the total Pennar sub basin.

3.6.2.1.3 Land Capability Class VI

Class VI lands have critical limitations which causes not suitable for cultivation and widely used for pasture and wood lands. The texture of this class is sandy loam, sandy clay and sandy soils with very shallow depth and moderate slopes and moderate gravel content. The soil erosion in this class is very high and also it is well drained. The class VI lands occupied an area of 21% of the total area of the Pennar sub basin.

3.6.3 Preparation of soil map

The soil map of Pennar sub basin was procured from National Bureau of Soil Survey and Land Use Planning, Andhra Pradesh. The study area was clipped from the

soil map of A.P by using Arc GIS tools. Thus the soil map for the Pennar sub basin was generated.

3.6.3.1 Soil Characteristics

Hydrologic soil group and soil texture plays very important role for estimation of net detachment, transport, and runoff and soil loss. Soil texture is the primary factor influencing soil erodibility factor. Several types of soil found in the Pennar sub basin viz. sandy soil, clay soil, sandy clay, sandy loam and fine sandy loam soil. The HSG indicate the infiltration capacity of the soil after wetting. The SCS model classified all soils into four hydrological groups explained as follows.

Group A soils which possess less runoff potential and high infiltration rate even in highly wetted conditions. They contains deep, well to excessively well drained sands or gravels, whereas sandy loams are sometimes classified to this group where the saturated infiltration rate is more than 0.76 cm/hr when thoroughly wetted.

Group B soils have moderate infiltration rates in wetted conditions and contain moderate well to well drained soils with moderate fine to moderate coarse textures. the saturated infiltration rate of this type of soil i.e., silt loams, loamy soils is 0.38 cm/hr to 0.78 cm/hr.

Group C soils have low infiltration rate in wetted conditions and contains chiefly of soil layer which causes downward movement of water with moderate fine to fine texture of soils i.e., sandy clay loams with saturation infiltration rate of 0.13 to 0.38 cm/hr.

Group D soils have very low infiltration rate and high runoff potential when thoroughly wetted conditions and consists majorly clay soils with high swelling capacity. It contains permanent high water table, clay loams, sandy clays, silty clays or clay, silty clay loams with saturated infiltration rate of 0- 0.13 cm/hr.

There are mainly four soil groups were observed i.e., Sandy soil, Clay soil, Sandy clay and Sandy loam soil. The sandy soil has very low runoff and less erosion

potential while the clay soil has high runoff and high erosion potential, sandy clay has slight erosion and sandy loam has moderate erosion. Thus for the study area there is low to severe erosion loss has been identified.

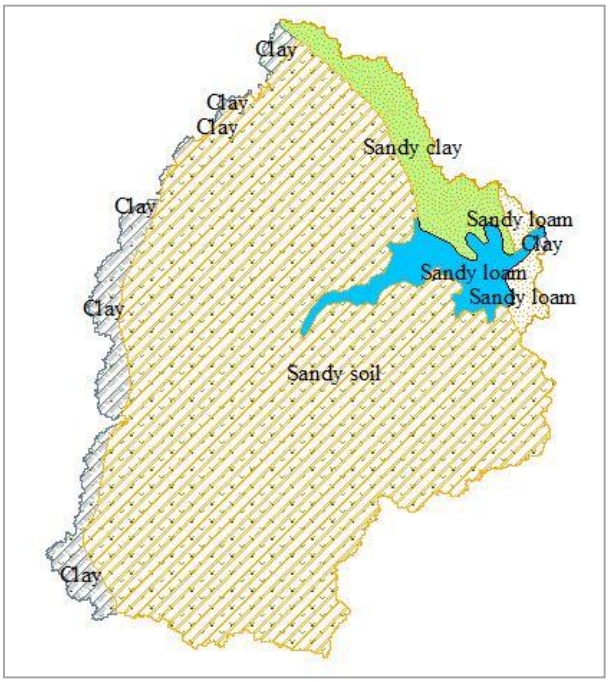


Fig. 3.5 Soil map extraction

3.7. Soil loss estimation using MUSLE

Soil loss is a disperse process that varies with the space and time over a landscape. This occurrence is caused by loosening and transport of soil particles from surface by runoff. The hydrological models and empirical model applied with mathematical and statistical laws and validated with field or laboratory experiments. The most commonly used model is Universal Soil Loss Equation (USLE) which computes the soil loss either by rainfall or runoff conducted by Wischmeir and Smith in 1965. In Modified class of USLE developed by Williams 1975, used for estimation of sediment transport of each storm accounting the runoff volume instead of taking into account of the rainfall erosivity.

Therefore, RS and GIS become an extensive use in collecting, process, examine and overlay of spatial information, describing the watershed environment, since all factors can be mapped in pixel value. This made it achieving the results by determining the values of each factor of soil erosion in spatial unit.

3.7.1 MUSLE model

The MUSLE model was proposed by Williams in 1975, which a modified version of USLE mode. This model is replaced with the instantaneous peak flow and runoff factor instead of rainfall factor of estimating soil erosion. The average soil erosion for a flood is a product of flood runoff volume (Q in m^3), the peak discharge of flood (q_p in m^3/s), soil erodibility factor (K), the slope length steepness factor (LS), the crop cover factor (C) and management factor (P). The following formula gives the expression for soil loss using MUSLE

$$A_{MUSLE} = 11.8\ (Q \times Q_p)^{0.56} \times K \times LS \times C \times P \qquad .....(3.5)$$

3.7.1.1 Rainfall erosivity (R) factor

The rainfall erosivity (R) factor was proposed by Williams and Berndt (1977). It is estimated from the peak flow discharge and runoff volume. Runoff volume, computed by SCS-CN method and peak flow is calculated by using the following formula.

$$R = 11.8\ (Q \times Q_p)^{0.56} \qquad \ldots (3.6)$$

Where, Q is runoff volume (m) & Q_p is peak discharge in (m^3/s).

3.7.1.1.1 Runoff estimation by SCS-CN model

For runoff estimation, there are various runoff models that could be adopted. The NRCS- CN (Natural Resource Conservation Service Curve Number) (USDA, 1972) model has been adopted as that requires less parameters and it is practical and tough. This method is also called as the Hydrological Soil Cover Method. This method is based on empirical and basic parameters such as CN, land use land cover,

hydrological soil group, slope, etc. The relationship between rainfall and runoff were developed. Curve number is the watershed coefficient, defined as the combination of land use land cover and hydrological soil group (Mishra *et al.,* 2006 and Chow *et al*., 1988).

The empirical NRCS-CN model was generated by studying runoff in different small experimental watersheds. In this model the runoff equation, the ratio of amount of actual retention to watershed storage is assumed to be equal to the ratio of actual direct runoff to the effective storm rainfall. The assumed relationship in statistical form is:

$$\frac{F}{S} = \frac{OF}{P-I} \qquad \ldots (3.7)$$

Whereas,

F = Actual retention (mm)

S = Initial abstraction and maximum losses after overland flow begins (mm)

OF = Overland flow in a rainfall event or actual direct runoff (mm)

P = Total rainfall (mm)

I = Initial abstraction (mm).

Overland flow (OF) for the Indian conditions to be calculated using the following equation:

$$\text{OF} = \frac{(P - 0.3S)^2}{P + 0.7S} \qquad \ldots (3.8)$$

As the overland flow (OF) will occur when P exceeds 0.3S value (P is the rainfall per rain day or month). Parameter S accounts to CN by US Soil Conservation Model (Murth,2004),

$$\text{S} = \frac{25400}{CN} - 254 \qquad \ldots(3.9)$$

Where, CN is Curve Number value of runoff

The CN is a dimensionless runoff index determined based on land use , land conditions, hydrological soil conditions and antecedent moisture conditions (AMC) and hydrological Soil Group (HSG). It indicates the result of changes in land use on

runoff. The CN value varies from 1 and 100. Higher values of CN represent higher runoff where low values as lower runoff. The NRCS runoff equation is commonly used in estimating direct runoff because of its adaptability, amendibility and simplicity.

AMC is an index of watershed wetness and availability of soil storage prior to a storm. At the time of rainfall, moisture content plays a very vital role for determining overland flow, this moisture conditions can be expressed as AMC conditions, AMC I for dry (wilting point) condition, AMC II to average moisture condition and AMC III for wet (field capacity) conditions.

The formula for conversion of AMC II to AMC I and AMC II to AMC III are follows:

For AMC class I, $$CN_I = \frac{-75CN(II)}{-175+ CN(II)} \quad \ldots (3.10)$$

For AMC class III, $$CN_{III} = \frac{175\, CN(II)}{75+CN(II)} \quad \ldots (3.11)$$

Based on the soil texture, soil depth and geomorphology, HSG is assigned for Pennar sub basin. After assigning, the HSG was combined with land cover map to prepare hydrological soil cover complex and to assign the CN.

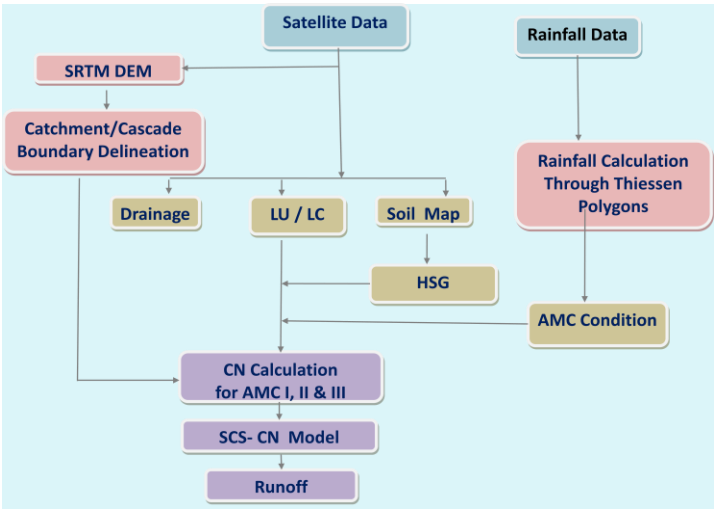


Fig. 3.6 Flow chart of the methodology for SCS-CN model

3.7.1.1.2 Peak discharge estimation

Peak discharge can be calculated using hydrograph method developed by Mockus in the year 1957. The area of triangular hydrograph represents the runoff volume. Accordingly, if Q_v is the runoff volume, height of triangle is Q_p (peak runoff discharge) and width of the triangle is t_{peak} then

$$Q_p = \frac{0.208 \times A \times Qv}{tpeak} \quad \ldots (3.12)$$

Where,

A = Area of the catchment, km²

Q_v = Runoff volume, mm

$$t_{peak} = \frac{\text{effective rainfall duration}}{2} + 0.6\ T_c$$

$$= 0.6\ T_c + \sqrt{T_c} \quad \ldots (3.13)$$

T_c is the time of concentration which is calculated by the Kirpich equation as follows:

$$T_c = 0.02\ L^{0.77}\ S^{-0.385} \quad \ldots (3.14)$$

Where, L = Maximum length of travel, m

S = Slope of the catchment

H = Difference in elevation between remote point in basin and outlet, m

3.7.1.2 Rainfall erodibility (K) factor

The K factor represents both susceptibility of soil to erode by an amount and rate of runoff. K depends on the texture and organic matter content of the soil, its permeability and profile structure. It varies from 0.7 for the most fragile soil to 0.01 for the most firm soil. It is measured on bare reference plots 22.2 m long on 9% slopes, tilled in the direction of the slope and having received no organic matter for three years. It quantifies the cohesive character of a soil type and its resistance to

dislodging and transport (particle size and density dependent) due to raindrop impact and overland flow shear forces. K is a function of complex interaction of a substantial number of its physical and chemical properties. A simpler method to forecast K was presented by Wischmeier *et al.,* (1978) which includes the particle size of the soil, organic matter content, soil structure and profile permeability.

The organic matter (O.M.) content in the sub basin soils are reported about 2%. K values were determined based on locally measured soil properties and using soil erodibility factor monograph for great soil groups in India. These values were annual averaged corresponding to homogeneous different soil groups. K values for study area are shown in Table 3.3

Table 3.3 Estimating soil erodibility based on soil texture and organic matter content

Textural Class	**Soil Composition**			**Mean K (based on organic matter)**		
	Sand	**Silt**	**Clay**	**Average**	**< 2%**	**> 2%**
Clay	0-45	0-40	40-100	0.22	0.24	0.21
Sandy clay	45-65	0-20	35-55	0.2	0.2	0.2
Silty Clay	0-20	40-60	40-60	0.26	0.27	0.26
Sand	86-100	0-14	0-10	0.02	0.03	0.01
Sandy loam	50-70	0-50	0-20	0.13	0.14	0.12
Clay loam	20-45	15-52	27-40	0.3	0.33	0.28
Loam	23-52	28-50	7-27	0.3	0.34	0.26
Loamy Sand	70-86	0-30	0-15	0.04	0.05	0.04
Sandy clay loam	45-80	0-28	20-35	0.2	0.2	0.2
Silty clay loam	0-20	40-73	27-40	0.32	0.35	0.3
Silt	0-20	88-100	0-12	0.38	0.41	0.37
Silty loam	20-50	74-88	0-27	0.38	0.41	0.37

From the above table, the soil erodibility (k) factor value was given for different soil groups in India.

3.7.1.3 Slope length steepness (LS) factor

The LS factor is the ratio of soil loss per unit area from the field slopes to that from a 22.13m length of uniform 9% slope. The topographical factor is one of the main factors of soil erosion. The slope gradient plays a vital role in the process of detachment, transport and deposition of soil particles. The LS factor indicates the topography of the region, which definite itself in two sub-factors: The length of the slope (L) and the slope gradient (S), yet, it is desirable to use both variables as an only topographic value (LS) to evaluate overall the direction of the slope on the speed of erosion. The LS-factor map was produced in the ArcGIS 10.1 from the SRTM DEM. According to MUSLE, the slope length steepness factor was computed by using the following equation:

$$LS = 1.4\left(\frac{As}{22.1}\right)^{0.4} \times \frac{\sin(\theta \times 0.01745)^{1.4}}{0.09} \qquad \text{... (3.15)}$$

Where, θ = Slope inclination, degrees

A_s = Specific surface composition under a GIS in the following method proposed by Moore and Burch 1986: The surface card (As) is determined as the product of flow accumulation map and its resolution (pixel value).

A_s = flow accumulation × resolution

In ArcGIS software, for calculation LS factor the following command was to be given:

LS = 1.4 * Power (Flow accumulation*30/22.13, 0.4)*(Power (sin (slope in degrees * 0.01745), 1.4)) / 0.0896

3.7.1.4 Cover and management (C) factor

To determine the C factor from remote sensing data, Normalized Difference Vegetation Index (NDVI), due to their wide availability of application and processing, and the high facility of the data input is used. The NDVI is a widely used measure of green vegetation vigor by the calculation of the spectral reflectance difference between

red and near infrared bands of the landsat satellite image (Tucker, 1979) with equation (3.16) and it varies from -1 to +1, with the highest values assigned to the areas with higher vegetation cover.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad \text{... (3.16)}$$

Where, NIR is the difference between surface spectral reflectance in the near-infrared band and RED band.

Initially, the estimation of the C-factor was proposed by Durigon *et al.,* (2014) and later adapted by Colman (2018) (C_{rA}), and followed by Van der Knijff *et al.,* (1999) (C_{VK}). The following Equations (3.17) and (3.18) are used for calculating C_{rA} and C_{VK}, respectively.

$$C_{rA} = 0.1 \left(\frac{1 - NDVI}{2} \right) \quad \text{... (3.17)}$$

$$C_{VK} = e^{-\left(\alpha \frac{NDVI}{1 - \beta\, NDVI}\right)} \quad \text{... (3.18)}$$

Where, α and β are parameters related to the shape of the curve that relates NDVI with the C factor, the values generally used are 2 and 1 respectively. The C_{rA} is based on NDVI rescaling under tropical climate conditions, with more intense rainfall.

Colman (2018) examined the comparisons between the C-factor computed using remote sensing application and experimental field studies and found a ten times systematic bias for the method proposed by Durigon *et al.,* (2014) and suggested an adjustment factor of 0.1 for C_{rA} output, in order to reduce the biases. Therefore, in the present study approach by Colman (2018) was adapted.

Landsat 8 OLI surface reflectance ortho-rectified images, which present high resolution accuracy. By using these atmospheric corrected images, NDVI was computed, following suggested recommendations concluded that uncorrected atmospheric effects can influence up to 50% of the results of NDVI calculations.

3.7.1.5 Support Practice factor (P)

P factor is defined as the effect of land use or farming system on the soil erosion. The P factor alters the potential erosion by water runoff through implementing the effective ways of strip cropping, contouring, contour farming and terrace forming (Kuok, Mah & Chiu, 2013; Kim & Julien, 2006; Wischmeier & Smith, 1978). When there is no erosion control solution, then P factor value should be 1.0. P values can be figure out from either image classifications using remote sensing data, recent studies, or by scientist knowledge (Panagos *et al*., 2015). Few scientists suggested the P value is rather dependent on the slope inclination (Shin, 1999; Wenner, 1980; Wischmeier & Smith, 1978) while others by the use farming practices to compute P value (Stone & Hilborn, 2012). In this present study, the P factor is calculated based on slope inclination and cultivation. The following table represents the value of P factor based on method of cultivation and slope (Shin, 1999).

Table 3.4 Support practice factor

Slope (%)	Strip cropping	Contouring	Terracing
0.0-7.0	0.27	0.55	0.10
7.0-11.3	0.30	0.60	0.12
11.3-17.6	0.40	0.80	0.16
17.6-26.8	0.45	0.90	0.18
>26.8	0.50	1.00	0.20

Fig. 3.7 gives a general idea of the systematic representation of the model that presents a summary of the used methodology for estimation of soil erosion.

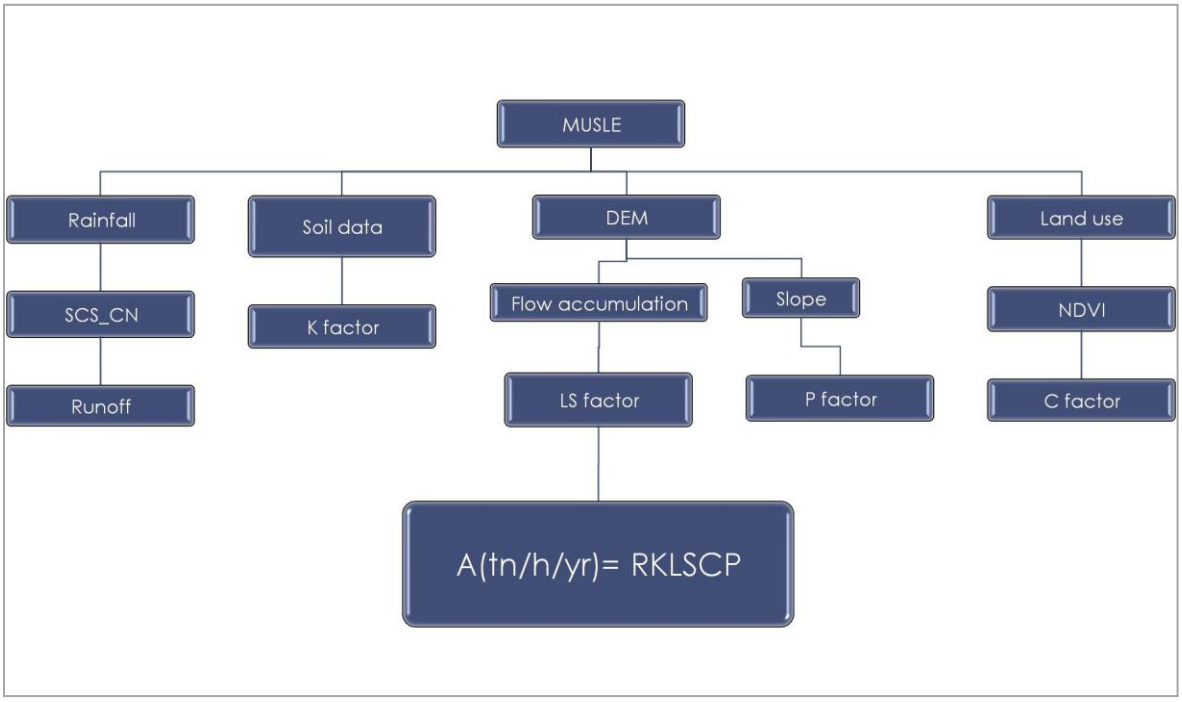


Fig. 3.7 Flow chart of estimation of soil erosion

3.8 Watershed conservation planning

In this research, contour bund farming, terrace farming and agronomical measures were suggested for watershed conservation measures. The scientific conditions for those measures have been explained as follows.

3.8.1 Agronomical measures

The land use land cover type should be agriculture with soil loss rate of greater than 5 ton/ha/yr and slope should vary from 5-8%.

3.8.2 Contour bunding

The land use land cover should be agriculture with soil loss rate greater than 5 ton/ha/yr and slope should vary from 8-15%.

3.8.3 Bench terrace

The land use land cover type should be agriculture with soil loss rate greater than 5 ton/ha/yr and slope should be more than 15%.

3.8.4 Check dam

The land use should be agriculture with the slope varies between 8-15% and stream order of 1-3 and the soil should be HSG class C and D.

Based on above conditions, the site suitable for conservation structures has been suggested using main parameters as land use land cover, soil loss rate, hydrologic soil group, stream order and slope.

CHAPTER IV
RESULTS AND DISCUSSION

In this chapter, the results on changes in the land use land cover both spatially and temporally of Pennar sub basin, morphometric analysis, surface runoff in sub basin and estimation of soil erosion using MUSLE have been presented and suggested conservation measures based on severity of water erosion in sub basin.

4.1 Morphometric analysis

The various morphometric parameters have been determined and the results are shown in Table 4.1, 4.2 & 4.3. The drainage pattern shows that the Pennar sub basin has dendritic type in nature and it is affected by the precipitation, topography and slope. To prepare relief, aspect and slope maps SRTM DEM was used. Depending on the stream order, the Pennar sub basin is categorized as fourth stream order used to understand the morphometric parameters as listed in Table 4.1, Table 4.2 & Table 4.3.

4.1.1 Aspect map

In general, aspect indicates to the direction to which a mountain slope faces and shape of the basin. The hilly conditions have a very strong influence on the regional climate, as the sun radiates in the west during afternoon, and thereby, in most of the cases an east facing slope will be colder than west-facing slope. This can have great effect on the vegetation in the Pennar sub basin area. SRTM DEM represents the direction of the aspect. 0º indicate north, 90º indicate east. The Pennar sub basin has east facing slopes which was shown in Fig. 4.2 and consequently, these slopes contain higher moisture content and high vegetation. The east-facing slopes have higher moisture content and higher vegetation compared to west facing slope (Singh *et al.*, 2014).

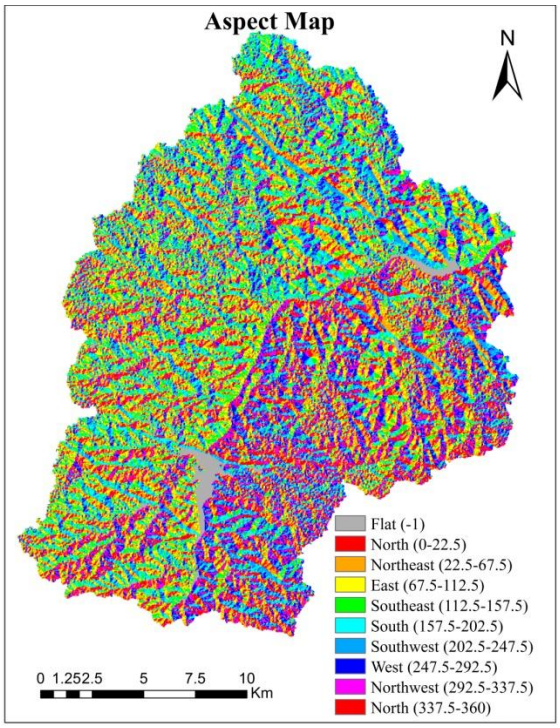


Fig. 4.1 Aspect map of Pennar sub basin

4.1.2 Relief map

The relief map of the study area was depicted in Fig 4.3. It is defined as the difference between the elevation of highest and lowest points on the catchment. The total basin relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (R_h) (Schumm, 1956). It measures the overall slope of the basin and shows the intensity of the erosion processes operating on the slope of the basin. Due to resistant basement rocks and low degree of slope, the basin procures low relief ratios (Kamala and Samynathan, 2018). As the drainage area and size of a basin decreases, R_h increases. In the present study, the R_h for Pennar sub basin is 0.009 (Table 4.1) which indicates low relief with lower degree of slope.

Table 4.1 Relief aspects of Pennar sub basin

Height of basin outlet (m)	**Maximum height of the basin (m)**	**Total basin relief (m)**	**Relief ratio**
334	543	209	0.009

4.1.3 Slope map

Slope is defined as the quantification of change in surface along the distance, expressed as percentage or degrees. In a raster format, the Digital Elevation Model (DEM) is a grid where each cell is a value referenced to a common datum. Any two points on the grid will be sufficient to ascertain a slope. Once the slopes have been computed, then the maximum difference can be found and the gradient can be determined (Jha *et al.,* 2007).

The highest elevations is 543 m & lowest 334 m MSL exists in the western and northeastern locations of the Pennar Sub basin, produces high runoff causes less infiltration. The slope map of the study area has classified in five classes in degrees viz. 1 - 3º (Gentle), 3 - 5º (Moderate), 5 - 10º (Steep), 10 - 35º (Very Steep) and > 35º (Very Very Steep) (Fig. 4.4). It is noticed that almost Pennar sub basin occupied gentle and steep slope that indicates almost flat and undulating topography of the area.

Gentle slopes are rated "excellent" for groundwater management as they facilitate the infiltration due to flat terrain. Moderate slopes come under good zone due to slightly undulating topography which gives maximum percolation or partial runoff. The steep slopes produce high runoff causes less infiltration rates are noticed for the construction of check dams, etc. The slope is an important variable that directly manages the runoff and infiltration of each zone. Runoff on steep slopes will result in less infiltration. This factor has a significant impact on the development of aquifers.

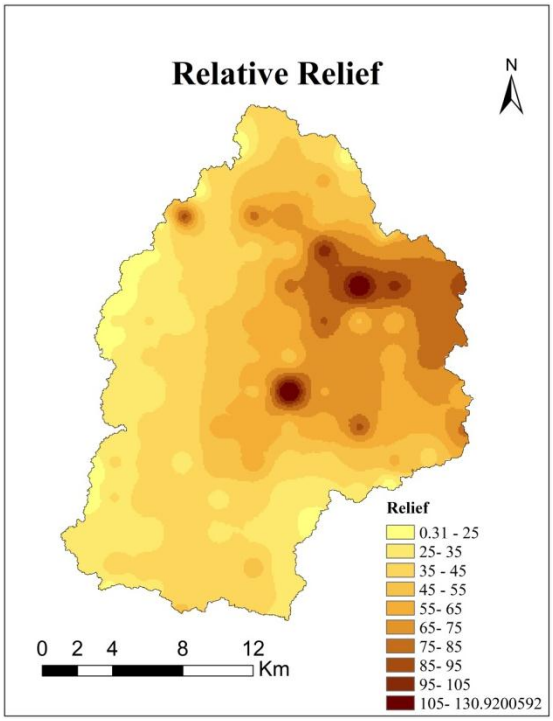


Fig. 4.2 Relief map of sub basin

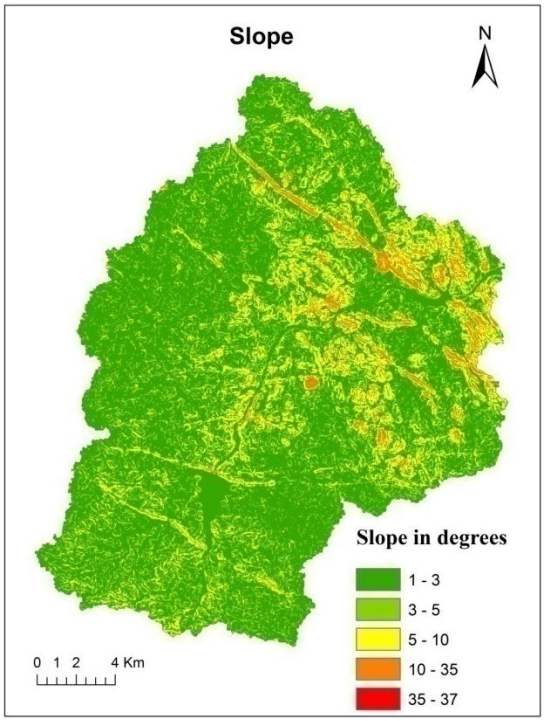


Fig. 4.3 Slope map of sub basin

4.1.4 Drainage map with Stream order (U)

In this research, the stream order ranking has been carried based on the method intended by Strahler (1964). The stream order of Pennar sub basin is fourth order (Fig. 4.2; Table 4.3). The maximum stream frequency observed in first order streams followed by second order streams. Accordingly, it can be concluded that the stream order increased with decrease in stream frequency and vice versa.

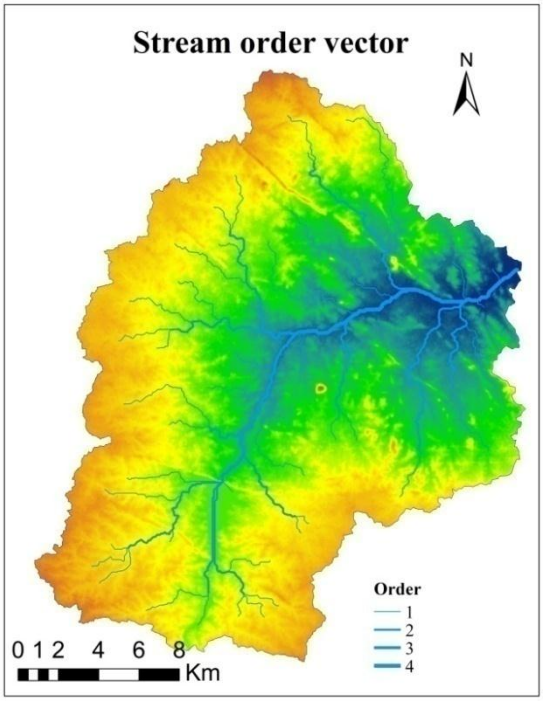


Fig. 4.4 Drainage map of Pennar sub basin

4.1.5 Stream number (N_u)

The total number of stream segments in corresponding stream order is termed as stream number. As per Horton's law (1945) of stream numbers, "the number of streams of different orders in a given drainage basin tends closely to approximate as inverse geometric series of which the first term is unity and the ratio is the bifurcation ratio".

According to Horton's law, the number of streams adds up for each stream order is plotted on the y axis versus stream order on the x axis on logarithmic scale and arithmetic scale respectively. The number of streams of different stream orders and the total number of stream segments in the basin are counted and computed in ArcGIS platform. The difference in stream order and size of tributary basins is mainly depends on geological, physiographical, geomorphological condition of the region (Rai *et al.,* 2017). 85 streams are there in the entire Pennar sub basin, among which 64 streams are 1^{st} order, 16 streams are 2^{nd} order, 4 streams are 3^{rd} order, 1 stream of 4^{th} order indicated that stream frequency decreases with increasing stream order.

4.1.6 Stream length (L_u)

The stream length is quantified as of the hydrological characteristics of the bedrock and the drainage extent. A longer streams of small number are formed when the bedrock and formation is permeable, while large number of smaller streams are formed when the bedrock and formations are less permeable in a well drained conditions.

The result of stream order length wise in Pennar sub basin is shown in Table 4.2. It is obviously evident that stream length is highest in the first order streams and decreased as the stream order increases. The length of the highest stream order (4^{th}) for Pennar sub basin is 23.04 km.

4.1.7 Mean stream length (L_{sm})

Mean stream length (L_{sm}) declares the characteristic size of components of a drainage pattern and its corresponding surfaces (Strahler, 1964). It has been determined by dividing total length of stream of order 'u' by the total number of stream channels in the corresponding order. The Pennar sub basin has mean stream length values ranged from 0.24 km to 23.04 km (Table 4.2). The L_{sm} values differ for various basins, as it is directly relative to the size and topography of the basin.

4.1.8 Stream length ratio (R_L)

Horton's law (1945) of stream length ratio means stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with stream length increasing towards higher order of streams. The stream length ratio of Pennar sub basin showed an increasing trend. The R_L values are tabulated in Table 4.2.

Table 4.2. Linear aspects of Pennar sub basin

Stream order (w)	No. of streams (N_u)	Total length of streams (km)	Mean stream length (L_{sm})	Stream length ratio (R_L)	Bifurcation ratio (R_b)	Mean bifurcation ratio (R_{bm})

I	64	15.65	0.24	5.42		4.00
II	16	84.97	5.31	0.08	4.00	
III	4	7.05	1.76	3.26	4.00	
IV	1	23.04	23.04		4.00	
Total	85	271.5				

4.1.9 Bifurcation ratio (R_b)

In Accordance to Schumm (1956), bifurcation ratio (R_b) can be defined as the proportion of the number of the streams in specific order to the number of streams in the next higher orders. A strong structural control in the drainage pattern refers to the higher values of Rb while the lower values indicate that basin is less affected by structural disturbances (Rai *et al.,* 2017, Hari *et al.,* 2018). The mean bifurcation ratio (R_{bm}) may be defined as the average of bifurcation ratios of all order. In the present study, the basin is not affected by any structural disturbances as R_{bm} is 4.00, whereas Gundlakamma sub basin is affected by structural disturbance due to lithological and geological irregularities (Hari *et al.,* 2018) due to higher elongation ratio (6.00).

4.1.10 Drainage density (D_d)

Drainage density (D_d) is defined as the ratio of total stream length in a given basin to the total area of the basin (Strahler 1964). The drainage density is influenced by the factors that control characteristic length of the watershed. Drainage density is relates to several features of landscape dissection such as climate, vegetation, relief, valley density and channel head source area (Moglen *et al.,* 1998), soil and bedrock properties (Kelson and Wells, 1989) and landscape development processes. The Pennar sub basin possess drainage density of 0.64 km/km^2, refers it contains highly resistant porous sub surface material with moderate to low relief and moderate drainage.

The high D_d (3.67) is developed in Amaravati river basin in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous and low drainage density (0.33) in highly permeable surface and highly resistant surface with

heavy vegetation relief (Kamala and Samynathan, 2018). As compared to Amaravati river basin, a higher density (2.90) was observed during the flow between PABR and MPR, and a lower density (0.26) was observed when there was no flow as indicated in Fig. 4.5. The drainage density of the Pennar sub basin is shown in Table 4.3.

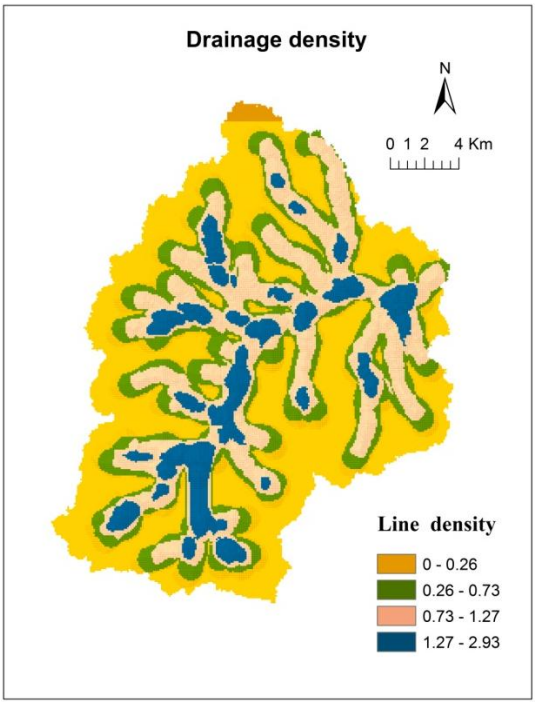


Fig. 4.5 Drainage density of Pennar

4.1.11 Stream frequency (F_s)

Stream Frequency is the number of streams segment per unity area and relates to the ground water recharge characteristics in a river basin (Kamala and Samynathan, 2018). It is the total number of stream segments of all orders per unit area (Horton 1932). Reddy *et al.,* (2004) stated that low values of stream frequency F_s indicate presence of a permeable subsurface material and low relief. The stream frequency value of the Pennar sub basin is 0.20 number/ km^2 reveals the low relief with low runoff (Table 4.3 Stream frequency majorly depends on the drainage texture and basin lithology.

4.1.12 Elongation ratio (R_e)

Elongation ratio defined as the fraction of diameter of the circle having the same area as of the basin to the maximum basin length (Schumm, 1956). It is a measure of the shape of the river basin and it depends on the climate and geologic types. The values which are close to 1.0 have very low relief and 0.6 -0.8 indicates high relief and steep slope. A circular basin is more efficient in runoff discharge than an elongated basin (Singh *et al.,* 2014). In basaltic terrain, Central India, the Higher values of elongation ratio (0.70 & 0.80) showed high infiltration capacity and low runoff, whereas lower values of R_e (0.30 & 0.48) are distinguished by high susceptibility to erosion and sediment load (Reddy *et al.,* 2004) as compared to the Pennar sub basin which possess higher R_e (1.01) and has high infiltration rate with less erosion.

4.1.13 Circulatory ratio (R_c)

Circularity ratio is defined as the ratio of the area of the basins to the area of circle having the same circumference as the perimeter of the basin. Miller (1953) stated R_c as a significant ratio that indicates the dendritic stage of a basin. This is mainly due to the slope inclination and relief pattern of the basin. The circulatory ratio is mainly examined with the climate, land use land cover, relief, slope, length of the stream, stream frequency and geological structures of the basin (Singh P *et al.,* 2014). Low, medium and high values of R_c indicate the young, mature, and old stages of the life cycle of the tributary watershed (John Wilson *et al.,* 2012). In the Narmada Catchment, circulatory ratios for sub-watersheds are 0.15–0.44, indicate that the area is characterized by high relief and structurally controlled drainage system (Gajbhiye *et al.,* 2014). Similarly, R_c for the Pennar sub basin is 0.21 (Table 4.3), indicating that the area is characterized by high relief and structurally controlled drainage system.

4.1.14 Form factor (R_f)

Horton (1932) stated form factor as the ratio of the area of the basin and square of the basin length. Smaller the value of form factor, more elongated will be the basin.

The value of form factor would always be greater than 0.78 for perfectly circular basin (Rai *et al.,* 2017). R_f value of the Kanhar basin is 0.18 shows elongated basin with less runoff. The R_f value of the Pennar sub basin is 0.79 which is greater than Kanhar basin (0.18) indicates basin is circular with higher peak flows for shorter duration.

Table 4.3 Areal aspects of Pennar sub basin

Parameters	Results
Basin area (km^2)	424.21
Perimeter(P) (km)	157.44
Basin length (km)	23.04
Elongation ratio (R_e)	1.01
Circulatory ratio (R_c)	0.21
Form factor (R_f)	0.79
Drainage density (D) (km/km^2)	0.64
Drainage texture (T)	0.13
Steam frequency (F_s)	0.20

From the above morphometric analysis, the Pennar sub basin has high relief, gentle slopes and high infiltration rate, possessing low runoff potential and moderate erosion. Based on drainage analysis computed in ArcGIS environment, decision can be made in selecting artificial recharge sites. The drainage pattern in the present study is dendritic in nature which may be due to homogeneous lithology and structurally controlled. A higher density is observed during the river flow between PABR and MPR, and a lower density is observed when there was no flow i.e., over the porous soils with low relief and high vegetation. Slope is an important parameter in estimating relation between infiltration and runoff. Slope is inversely proportional to infiltration, if slope is gentle then infiltration is more and runoff will be less and vice versa (Singh *et al.,* 2014). The Pennar sub basin has gentle slopes with high relief that results in less runoff and moderate soil erosion.

4.2 Detection of change in land use land cover and land capability classification

4.2.1 Temporal variation in land use land cover

The land use classification of built up land (rural), agriculture (crop lands and fallow lands), barren lands, water bodies (reservoirs, lakes, canals and ponds) and forest has been done and mapped using landsat 5 TM and landsat 8 OLI satellite imageries for three different time periods i.e., 2011, 2015 and 2020 and depicted in Fig. 4.6 to 4.8.

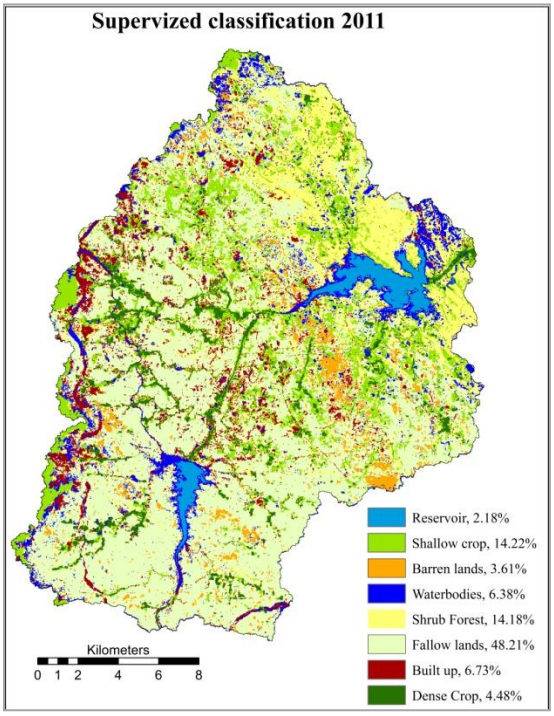


Fig. 4.6 LULC during the year 2011

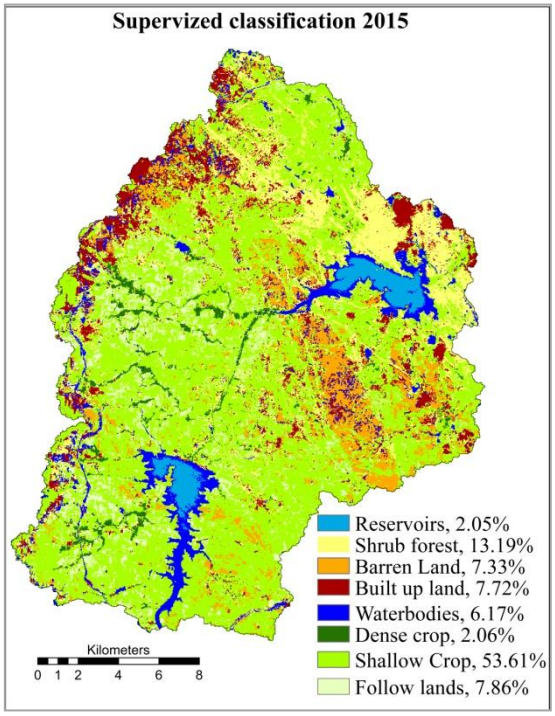


Fig. 4.7 LULC during the year 2015

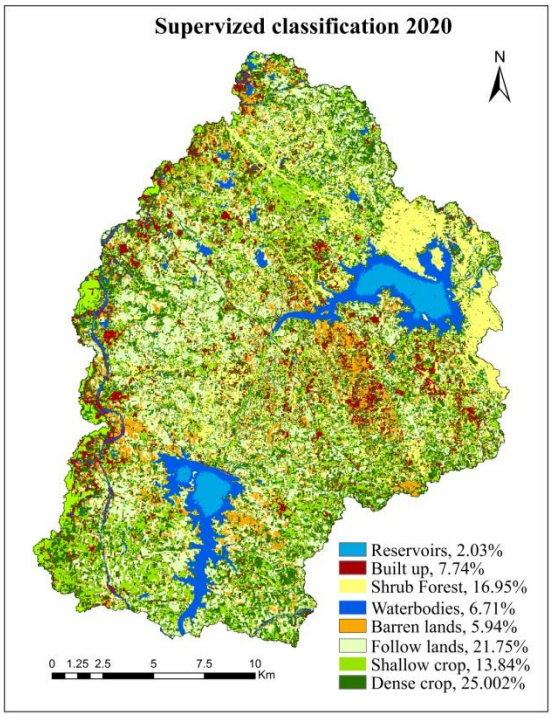


Fig. 4.8 LULC during the year 2020

About 2.18 % of area has been occupied by the reservoirs in 2011 whereas 2.05% in 2015 and 2.03% in 2020 in the Pennar sub basin. The area under the reservoir is initially high and gradually decreased in 2015 and there is little reduction in 2020. Streams and water bodies (ponds, streams) in 2011, 2015 and 2020 are 6.37%, 6.16% and 6.71% respectively which indicates slight decrease of area from 2011 to 2015 and then increased in 2020.

On an average 6.72% of area is occupied by built up land in 2011 and where as 7.72 % in 2015 and 7.75 % in 2020. The built up land in rural areas is gradually increased spatially and temporally. Barren lands in 2011, 2015 and 2020 occupied 3.61%, 7.33% and 5.94 % of area. There is rapid increase from 2011 to 2015 and then reduction in 2020. The area occupied by the Agriculture is 18.69% during 2011 and 55.67% during 2015 and 38.84% during 2020. The area under cultivation of crops has been increased from 2011 to 2015 and then decreased in 2020. The area occupied by fallow land in 2011, 2015 & 2020 are 48.22%, 7.87% and 21.76% respectively. There is decrease in area from 2011 to 2015 and gradually increased from 2015 to 2020. The

area under fallow lands and barren lands may have been converted into crop lands thus there is increase in agricultural lands from 2011 to 2020.

The forest area in Pennar sub basin is about 14.18% (2011), 13.19 % (2015) and 16.95 % (2020) during different time periods. The above classification reveals that there is little decrease of forest area from 2011 to 2015 due to deforestation and little increase from 2015 to 2020. Table 4.4 shows the area under different land use land cover during different time periods.

Table 4.4 Area under different land use land cover categories during 2011to 2020

LULC class	**2011 (km^2)**	**Area (%)**	**2015 (km^2)**	**Area (%)**	**2020 (km^2)**	**Area (%)**
Reservoir	9.25	2.18	8.72	2.05	8.64	2.03
Built up	28.54	6.72	32.75	7.72	32.87	7.74
Agriculture	79.32	18.69	236.18	55.67	164.79	38.84
Fallow land	204.54	48.22	33.36	7.87	92.29	21.76
Barren land	15.33	3.61	31.10	7.33	25.20	5.94
Forest	60.16	14.18	55.94	13.19	71.92	16.95
Water bodies	27.05	6.37	26.15	6.17	28.49	6.72
Total	424.21		424.21		424.21	

The magnitude of change (MC) during the period 2011 to 2020 is in the increasing trend for agricultural lands, built up, barren lands, forest and water bodies as 85.47 km^2, 4.21 km^2, 9.87 km^2, 11.76 km^2 and 1.44 km^2 respectively. However, it was in the decreasing trend for reservoir and fallow lands as 0.61 km^2 and 112.25 km^2 respectively.

The percentage of change (PC) during 2011 to 2020 for reservoirs is 6.59%. Built up area, agriculture land, fallow land, barren land, forest and water bodies have registered the PC as 14.75%, 107.75%, 54.88%, 64.38%, 19.54% and 5.32% respectively.

The Annual rate of change (ARC) during 2011 to 2020 is in raising trend for agricultural lands, built up, barren lands, forest and water bodies with 9.49 km^2/yr (11.97%), 0.47 km^2/yr (1.63%), 1.09 km^2/yr (7.15%), 1.30 km^2/yr (2.17%) and 0.16 km^2/yr (0.59%) respectively. Furthermore, it was in decreasing trend for reservoir as 0.07 km^2/yr (0.73%) and fallow land with 12.47 km^2/yr (6.09%).

4.2.2 Land capability class

Land capability class was developed in ArcGIS environment by overlaying the slope map, DEM, soil group map and land use land cover map of 2015. Weighted overlay tool of Spatial Analyst tool box was used for developing land capability classification (LCC). Fig. 4.9 shows the LCC classification.

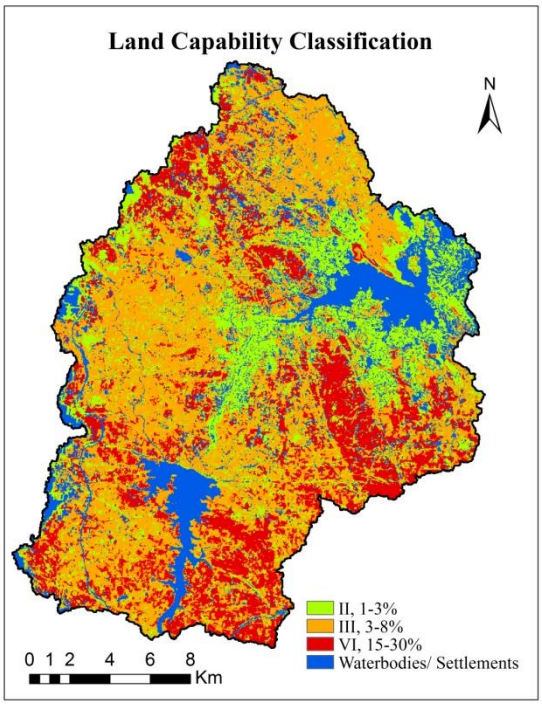


Fig. 4.9 Land Capability Classification of Pennar sub basin

Class II land capability was observed near the river bank of the **MPR**. Class III lands are suitable for cultivation with better management practices covering 41.07% of the study area. The lands which are not suitable for cultivation, i.e. class VI are covered by barren land with 21% of area and water bodies, settlements covered an

area of 17.08% of Pennar sub basin. Table 4.5 reveals the percentage area covered under different land capability classes.

Table 4.5 Area under different land capability classes

Land capability	**Area (%)**
Land suitable for cultivation	
Class II	20.82
Class III	41.07
Land unsuitable for cultivation	
Class VI	21.00
Settlements	17.08

4.3 Soil loss estimation

4.3.1Runoff estimation by SCS CN method

For estimation of runoff, SCS-CN method has been adopted which gives the accurate runoff volume for a drainage basin. The rainfall data obtained from RARS, Rekulakunta and Chief Planning Office, Anantapuram was used for the present study. The runoff was calculated for a period of 1990 to 2018. The average rainfall was computed by thiessen polygon method. For the calculation of curve number, supervised classification of land use land cover 2011 has been taken. The collected rainfall data of the period 1990 - 2018 was shown in APPENDIX-A

The calculation of weighted curve number (WCN) using land use land cover classification of 2020 was shown in Table 4.6. SCS Curve Number method is especially diplomatic to CN values and demands for accurate determination. CN is a function of Antecedent Moisture Conditions, Hydrologic Soil Group and Land Use. Therefore for the determination of rainfall runoff for various classes of LULC, HSG and AMC will be mandatory. Based on the area occupied by the each class, WCN was calculated.

The rainfall data from 1990 to 2018 was used for computing average rainfall for the growing season (wet season) from June to December and used for computation of curve number for AMC conditions. The calculation of average rainfall of Pennar sub basin was presented in Table 4.7. There are mainly 3 different stations viz. Kudair, Uravakonda and Vajrakarur. The computation of thiessen polygon was shown in Fig. 4.10.

Table 4.6 Calculation of CN using LULC 2020

Class Name	Area	HSG	CN	Area × CN	WCN=(Area× CN)/TA
Reservoir	8.64	B	100	864.00	2.03
Barren land	25.20	B	71	1789.20	4.21
Shrub forest	71.92	C	79	5681.68	13.39
Shallow crop	58.72	B	75	4404.00	10.38
Streams, canals	28.48	B	97	2762.56	6.51
Built up area	32.86	B	75	2464.50	5.80
Dense crop	106.06	B	58	6151.48	14.50
Fallow land	92.29	B	86	7936.94	18.70
Total	**424.21**				**75.53**

Approximate curve number is 75

Generally, the WCN computed represents the condition of AMC II which means the WCN value is the CN II value. The CN II will be converted for AMC I and AMC III conditions i.e. CN I and CN III by using the eq. (3.10) and (3.11) from Chapter III.

Therefore, CN I = 56

CN III = 87.5

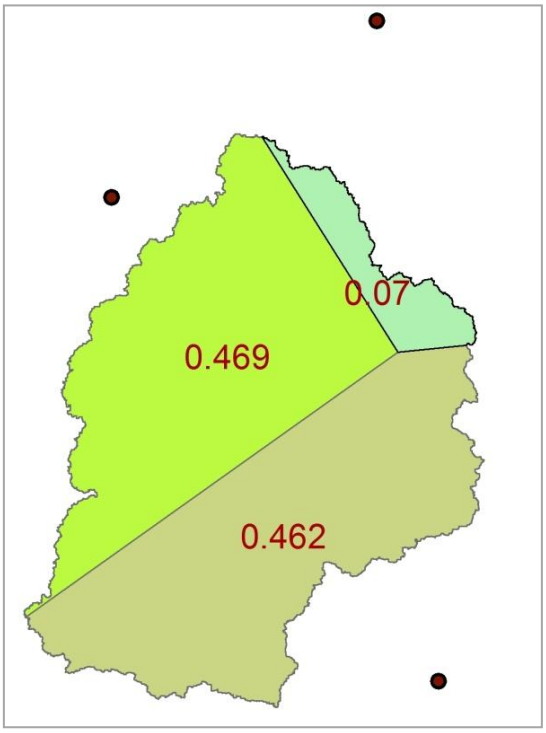


Fig. 4.10 Average rainfall of Pennar sub basin by Thiessen polygon

Table 4.7 Average rainfall computation using Thiessen polygon

Year	Total rainfall	Kudair	Uravakonda	Vajrakarur	0.462*K	0.469*U	0.07*V	Annual Average Rainfall
1990	1124.50	124.50	471.20	528.80	57.50	221.00	37.00	315.50
1991	1272.20	305.70	503.60	462.90	141.20	236.20	32.40	409.80
1992	1218.50	239.80	538.60	440.10	110.80	252.60	30.80	394.20
1993	1314.50	410.00	393.20	511.30	189.40	184.40	35.80	409.60
1994	657.90	176.80	247.10	234.00	81.70	115.90	16.40	214.00
1995	1207.40	293.80	466.20	447.40	135.70	218.60	31.30	385.70
1996	1822.20	443.40	771.80	607.00	204.90	362.00	42.50	609.30
1997	1158.30	341.40	363.90	453.00	157.70	170.70	31.70	360.10
1998	1513.40	533.60	517.80	462.00	246.50	242.80	32.30	521.70
1999	1057.50	216.40	467.10	374.00	100.00	219.10	26.20	345.20
2000	1246.20	311.20	528.00	407.00	143.80	247.60	28.50	419.90

2001	1551.40	522.80	575.00	453.60	241.50	269.70	31.80	543.00
2002	707.70	208.60	320.30	178.80	96.40	150.20	12.50	259.10
2003	695.80	111.20	306.20	278.40	51.40	143.60	19.50	214.50
2004	864.20	407.20	301.00	156.00	188.10	141.20	10.90	340.20
2005	2157.40	521.40	777.00	859.00	240.90	364.40	60.10	665.40
2006	998.60	319.60	446.40	232.60	147.70	209.40	16.30	373.30
2007	1813.80	615.40	664.00	534.40	284.30	311.40	37.40	633.10
2008	1843.20	565.00	676.20	602.00	261.00	317.10	42.10	620.30
2009	1878.40	392.60	848.80	637.00	181.40	398.10	44.60	624.10
2010	1279.80	411.00	375.00	493.80	189.90	175.90	34.60	400.30
2011	938.60	347.80	311.40	279.40	160.70	146.00	19.60	326.30
2012	1244.60	359.80	401.40	483.40	166.20	188.30	33.80	388.30
2013	914.40	304.00	284.80	325.60	140.40	133.60	22.80	296.80
2014	983.00	353.80	277.90	351.30	163.40	130.30	24.60	318.40
2015	1048.80	312.20	191.40	545.20	144.20	89.80	38.20	272.20
2016	860.40	293.20	259.90	307.30	135.50	121.90	21.50	278.90
2017	1794.20	562.10	532.60	699.50	259.70	249.80	49.00	558.40
2018	852.10	227.00	303.40	321.70	104.90	142.30	22.50	269.70
Total					4726.80	6153.90	886.70	11767.30

The annual average rainfall computed from the thiessen polygon revealed that the highest rainfall observed in the year 2005 (665.4 mm) and the lowest rainfall observed (214.0 mm) in the year 1994. Thus there is high and low runoff in the year 2005 and 1994 respectively, as the rainfall is proportional to runoff (Raju *et al.*, 2018).

4.3.1.1 Determination of runoff using SCS CN model

After the calculation of annual average rainfall using thiessen polygon method, the AMC conditions presented in Table 4.8 was used for the computation of runoff. The time of concentration calculated using the eq. (3.14) from Chapter III was

$$Tc = 429.17 \text{ min} = 7.15 \text{ hr}$$

Using eq. (3.13) $T_{peak} = 0.6\ T_c + \sqrt{}\ T_c = 6.96$ hr

Table 4.8 AMC conditions

AMC	Five-day precipitation	
	Dormant season	*Growing season*
I	< 12,7 mm	< 35,6 mm
II	12,7 – 28 mm	35,6 – 53,4 mm
III	> 28 mm	> 53,4 mm

By using the eq. (3.6) $R = 11.8\ (Q \times Q_p)^{0.56}$

Using eq. (3.12), $Q_p =$ $\frac{0.208 \times \square \times Qv}{\square\square\square\square\square}$

Rainfall erosivity factor R (MJ-mm/ha/h/year) has been calculated for the period 1990-2018. The calculation of R factor was shown in the Table 4.9.

Table 4.9 Calculation of Rainfall Erosivity factor

Year	Annual Avg R (P) mm	AMC	CN	S=(25400/ CN)-254	I= 0.3S	Runoff (Q)m	$Q_p(m^3/s)$	R
1990	315.50	III	87	37.95	11.38	0.270	3427.63	541.22
1991	409.80	III	87	37.95	11.38	0.363	4611.90	754.62
1992	394.20	III	87	37.95	11.38	0.348	4415.35	718.69
1993	409.60	III	87	37.95	11.38	0.363	4609.35	754.15
1994	214.00	III	87	37.95	11.38	0.170	2162.79	323.14
1995	385.70	III	87	37.95	11.38	0.339	4308.52	699.24
1996	609.30	III	87	37.95	11.38	0.562	7127.82	1228.83
1997	360.10	III	87	37.95	11.38	0.314	3986.97	641.06
1998	521.70	III	87	37.95	11.38	0.474	6021.81	1017.36
1999	345.20	III	87	37.95	11.38	0.299	3800.23	607.53
2000	419.90	III	87	37.95	11.38	0.373	4738.64	777.88
2001	543.00	III	87	37.95	11.38	0.496	6289.95	1068.23
2002	259.10	III	87	37.95	11.38	0.214	2723.28	418.29

2003	214.50	III	87	37.95	11.38	0.171	2169.21	324.22
2004	340.20	III	87	37.95	11.38	0.294	3737.37	596.28
2005	665.40	III	87	37.95	11.38	0.618	7836.89	1366.54
2006	373.30	III	87	37.95	11.38	0.327	4152.66	670.97
2007	633.10	III	87	37.95	11.38	0.585	7428.81	1287.09
2008	620.30	III	87	37.95	11.38	0.573	7266.69	1255.68
2009	624.10	III	87	37.95	11.38	0.576	7314.08	1264.85
2010	400.30	III	87	37.95	11.38	0.354	4492.37	732.75
2011	326.30	III	87	37.95	11.38	0.281	3562.77	565.17
2012	388.30	III	87	37.95	11.38	0.342	4341.47	705.23
2013	296.80	III	87	37.95	11.38	0.251	3193.79	500.04
2014	318.40	III	87	37.95	11.38	0.273	3463.70	547.60
2015	272.20	III	87	37.95	11.38	0.227	2885.89	446.37
2016	278.90	III	87	37.95	11.38	0.234	2969.56	460.89
2017	558.40	III	87	37.95	11.38	0.511	6485.40	1105.48
2018	269.70	III	87	37.95	11.38	0.225	2855.10	441.04

The rainfall erosivity factor developed in ArcGIS 10.1 using krigging interpolation of spatial analyst tools was shown in Fig. 4.11. The highest erosivity of 1366.54 MJ-mm/ha/h/yr was recorded in the year 2005 and the lowest erosivity of 323.14 MJ-mm/ha/h/yr was recorded in 1994. The rainfall and estimated runoff for the period 1990 to 2018 was displayed in Fig. 4.12.

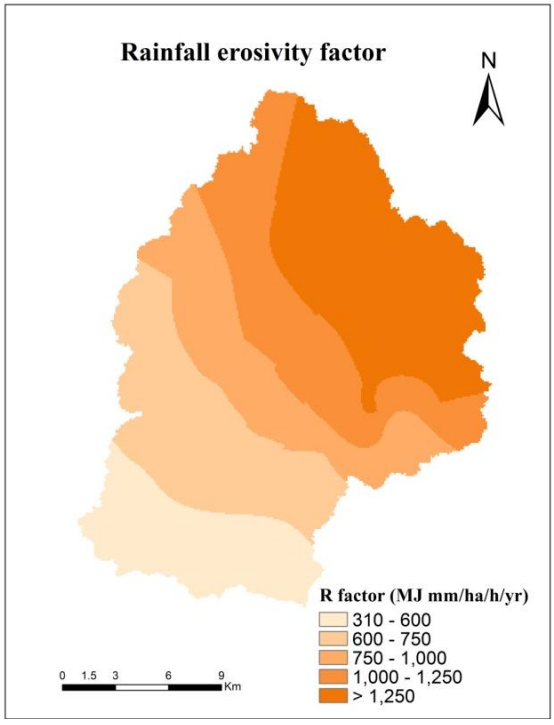


Fig. 4.11 Rainfall Erosivity of Pennar sub basin

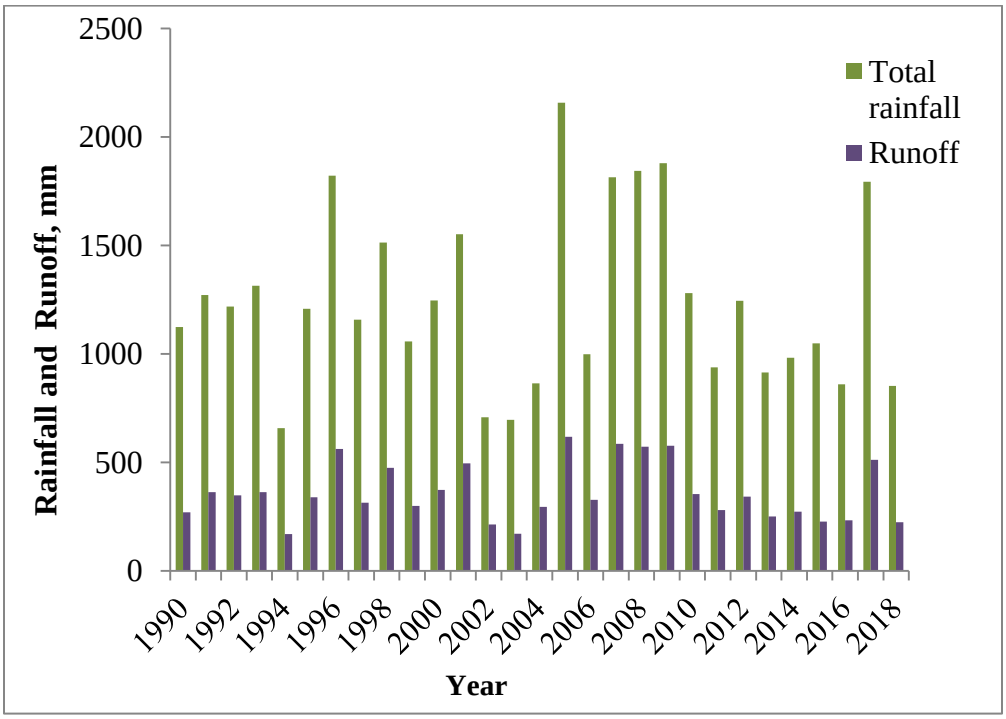


Fig. 4.12 Rainfall and Runoff during the period 1990 to 2018

The present research revealed that the rainfall from 1990 to 2018 varied from 657.90 mm to 2157 mm and runoff ranged from 170 mm to 618 mm. From the above Fig. 4.12, it is evident that runoff is proportional to the rainfall erosivity. In the similar study conducted by Raju *et al.* (2018), rainfall from 1995 to 2014 varied between 340 mm to 1008 mm and runoff is 229 mm to 706 mm in Mandavi basin of Kadapa district.

4.3.2 Soil Erodibility (K) factor

K values were figured out based on locally measured soil properties and soil erodibility factor monograph for great soil groups in India. Based on the soil map, assigned K factor values (Nayak *et al*., 2016). These values were annual averaged corresponding to homogeneous different soil groups as shown in Fig. 4.13. The values of K factor for Pennar sub basin, presented in Table 4.10.

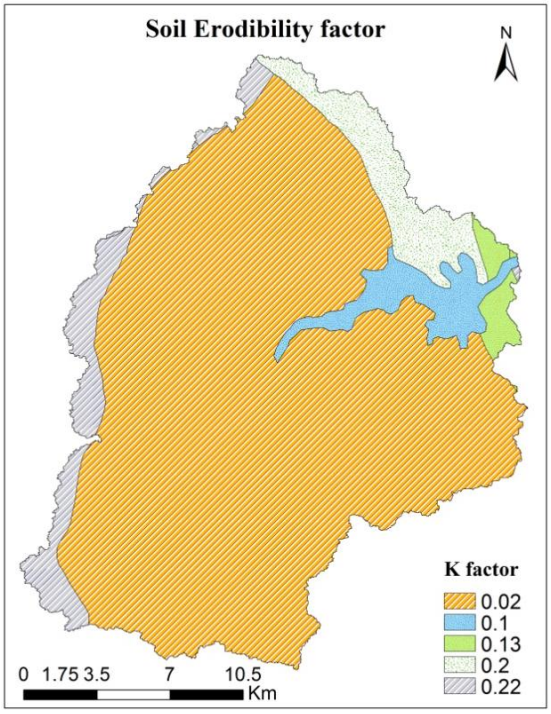


Fig. 4.13 Soil erodibility factor in Pennar sub basin

Table 4.10 Soil erodibility (K) factor

Soil Class	Area (%)	K factor
Sandy soil	82.18	0.02
Sandy loam	1.69	0.13
Loamy fine sand	4.29	0.10
Sandy clay	5.95	0.20
Clay	5.88	0.22

4.3.3 Slope Length Steepness (LS) Factor

The topographic factor of MUSLE was worked out using Eq. (3.15) suggested by Moore and Burch (1986). Slope length was replaced by upslope contributing area of flow divergence, convergence in three dimensional terrain aspects. So, the slope inclination and upstream contributing area were considered and used for determination of slope length steepness factor. From Fig. 4.14, the slope length is high in the lower part of the sub basin due to high flow accumulation, and low flow contributing pixel upstream of the ridge.

The combined LS factor was prepared as shown in Fig. 4.14. As a result, the LS factor of MUSLE varies from 0 in the flat regions of the Pennar sub basin to 382.27 in the steepest slope lower part of the sub basin. Therefore, the basin is subjected to a high probability of erosion from upstream to downstream (Djoukbala *et al.*, 2018).

Erosion has been shown to increase exponentially depending on the degree of inclination of slope (Pham *et al.*, 2018). Similarly, it has been reported that as the degree of inclination of slope increases, the kinetic energy of the rain remains constant while the transport of water accelerates downward due to an increase in the kinetic energy of the runoff. This directs the effect of topography factor (LS) for soil loss in lower part of Pennar sub basin is significant while the middle and upper part was insignificant (Fig. 4.14) as studied from the Wadi Ghazouana watershed (Djoukbala *et al.*, 2018).

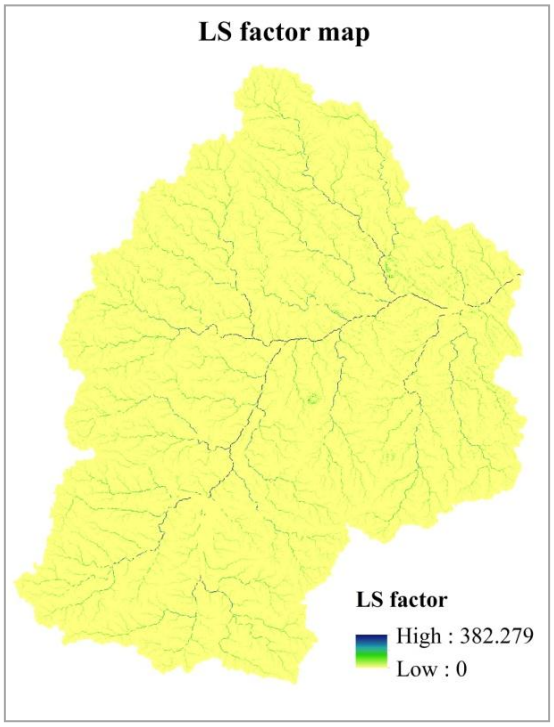


Fig. 4.14 Slope length steepness (LS) factor map

4.3.4 Crop cover (C) factor

The C factor map has been produced using maximum likelihood supervised classification of Landsat 8 OLI image of 2015. The assigned map, verified with google earth image, classified the study area into Water bodies, built up lands, Agricultural lands, shrub, barren lands (Fig. 4.15). Calculated C- factor values as discussed in materials and methods, using the Eq. 3.17 & 3.18.

The C-factor values in the Pennar sub basin varied from 0.20 for water bodies (reservoirs, canals, lakes) to 0.56 for healthy vegetation of the study area.

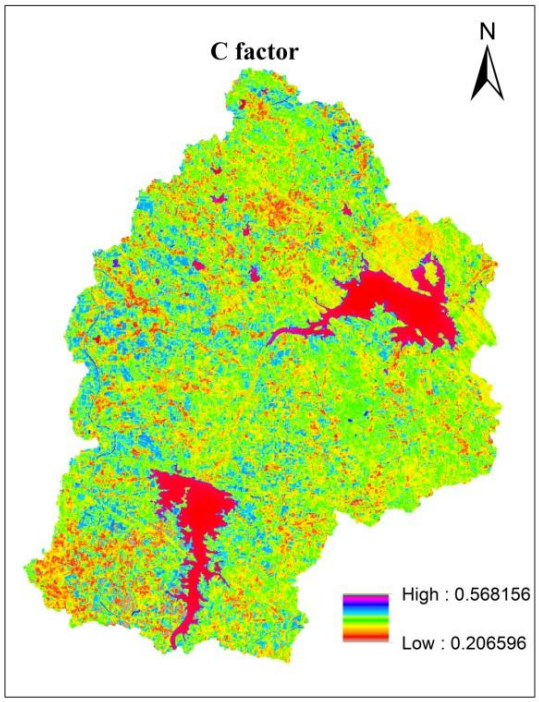


Fig. 4.15 Cover management (C) factor map

4.3.5 Support Practice (P) factor

Land use type impacts the rate of soil erosion based on the P and C factors. For example, the soil is protected by vegetative cover to avoid erosion depending on the land use type (Saowanee, 2012). For each land use type, the land use will have different farming patterns, thus affecting the P value.

Pennar sub basin is flat, such that there is no contour cultivation. In this research, P factor values are calculated by the cultivation and slope based on the land use land cover 2020 satellite of landsat 8 OLI image. The P factor values assigned for Pennar sub basin based on Table 3.4 of Shin (1999). The Fig. 4.16 shows P factor values based on slope inclination.

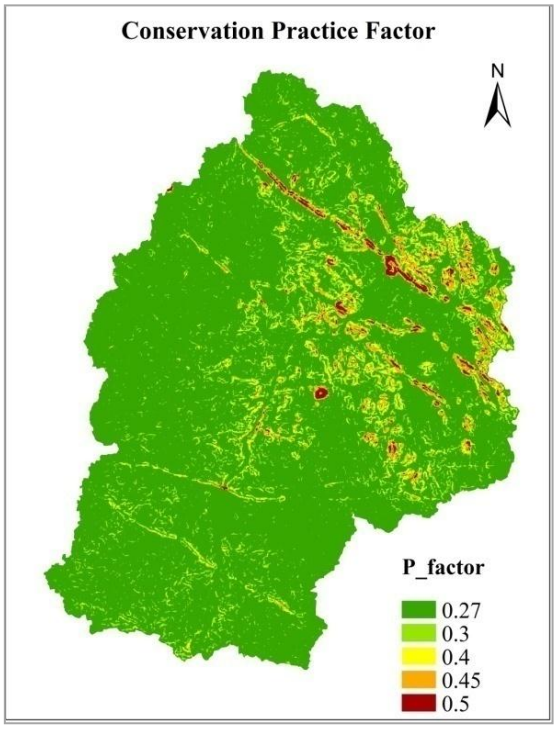


Fig. 4.16 Support practice (P) factor map

4.3.6 Soil loss estimation

The final map that results the potential annual soil loss of the sub basin was generated by overlaying the above five parameters (R, K, LS, C and P) using Eq. (3.5), and raster calculator of geo-processing tools in ArcGIS10.1 software (Fig. 4.17). Each component layer was structured in a raster format with resolution (30 × 30 m) of the DEM. In addition, the statistical tool (raster calculator) of ArcGIS was used to determine the potential annual soil loss and categorize the soil loss risk in the Pennar sub basin. For the management prioritization, soil erosion map of the sub basin is grouped into six classes as shown in Table 4.11 and Fig. 4.17. The annual soil loss of 96.49% in Pennar sub basin varied from 0 (the lower and middle part) to 7 ton/ha/year (the upper catchment) indicates low erosion and remaining 3.5% varies 7 to 720 ton/ha/year indicates moderate to very severe erosion. Furthermore, the soil loss rate of 720 ton/ha/year was observed at one place nearby MPR reservoir. Moderate soil loss is observed at the outer edges of the Pennar sub basin as that contains clay soil

with moderate vegetation. Middle catchment has more soil loss as it has steep slopes and barren lands.

Table 4.11 Soil erosion assessment of Pennar sub basin

Soil loss rate (t ha^{-1} year^{-1})	**Soil erosion risk class**	**Area (km^2)**	**Total area (%)**
0 – 7	Low	402.95	96.49
7 – 15	Moderate	7.617	1.82
15 – 25	High	2.77	0.66
25 – 45	Very high	1.90	0.45
45 – 60	Severe	0.66	0.15
>60	Very severe	1.73	0.42

The high rates of erosion i.e., > 60 ton/ha/year are observed at downstream i.e., at lower elevation and lands characterized by steep slopes of Pennar sub basin due the soil type is sandy loam and the reservoir soil type is fine loamy sand. There is high erosion explains that there is high soil degradation. Hence the agronomical measures need to be implemented where the erosion is > 7 ton/ha/year.

4.3.7 Conservation measures

According to Kiriwongwattana *et al.*, (2013), the conservation structures have to be planned as discussed in Chapter III. By overlaying the stream order, slope map and soil loss map, and observing land use map of 2020, the suitable site for construction of conservation structures are identified in the region with greater soil loss condition and having higher slopes. The Fig. 4.18 & 4.19 presents a clear view of the location for the conservation structures, namely, check dams, contour farming, bench terrace and agronomical measures.

The agronomical measures were suggested for the slopes of 5 - 8% with cultivated land and soil loss at the rate of > 5 t/ha/year. Check dams were suggested

for the slopes of 8 - 15% with agriculture around 2 km bearing 1 - 3 stream order and soil group should be C and D. Contour bunding should be planned for the slopes of greater than 8 - 15% slopes and soil loss rate of > 5 t/ha/year with agriculture land use. The sites should be treated with contour farming. Bench terrace are constructed for the slopes greater than 15 % with agriculture land use and soil loss rate of > 5 t/ha/year.

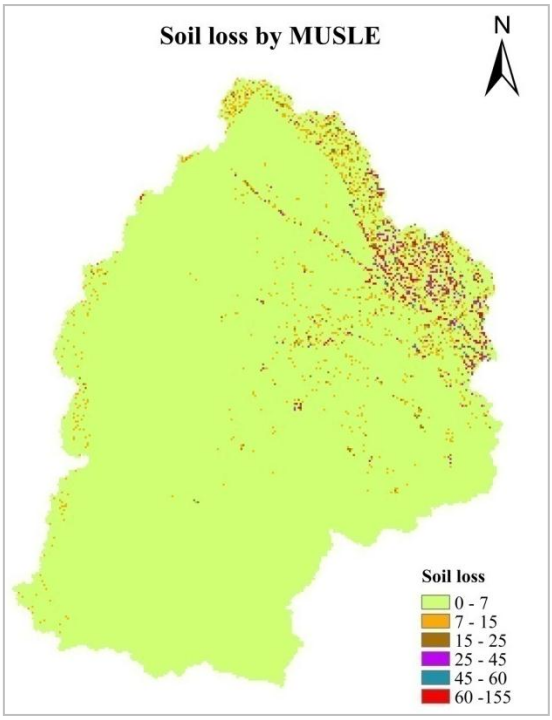


Fig. 4.17 Soil loss estimation by MUSLE

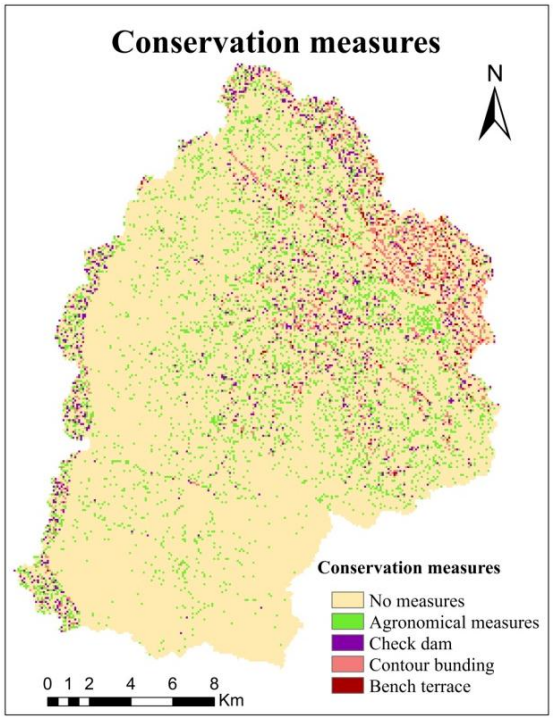


Fig. 4.18 Site suitable for Conservation measures

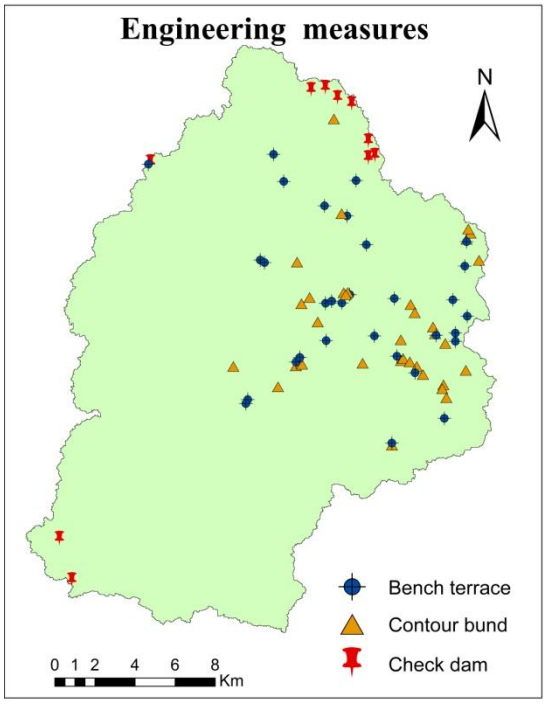


Fig. 4.19 Site suitable for engineering measures

It was concluded from the above results that the average runoff in the Pennar sub basin from 1990 to 2018 varied from 170 to 614 mm with soil loss rate of majority 96.49% cover an area of 0 to 7 ton/ha/year with low risk of soil erosion and further 3.5% of area occupied 7 to 720 ton/ha/yr indicated that there is moderate to very severe soil erosion. Hence it is required to plan the conservation measures (agronomical and engineering measures) to reduce the soil erosion. Totally there are 75 sites are identified for construction of engineering structures out of which contour bunds are suggested in 33 places, bench terraces in 31 places and check dams in 11 places (APPENDIX B).

CHAPTER V

SUMMARY AND CONCLUSIONS

Watershed development demonstrates to the conservation; restore and the practical use of all the natural resources particularly soil, water and vegetation within the watershed. Characterization and prioritization of watersheds are essential steps in the integrated watershed resources management. The remote sensing combined with GIS, offers possibilities for integration of multi-layered information (both spatial and non-spatial) that helps in reorganization of potential limitations and management needs of land and water resources on an integrated basis. Hence, the present study has been undertaken to analyze the land and water resources of Pennar sub basin for sustainable development using RS and GIS. Pennar sub basin located in Anantapur district of Andhra Pradesh has a semi-arid catchment with wide variations in the annual flows due to erratic rainfall and poor quality of water. It comprises three mandals of Anantapur district, namely, Uravakonda, Vajrakarur and Kuderu having an area of 424 km². The climatic data pertaining to 1990 to 2018 has been collected and used for the estimation of runoff and soil erosion.

The Digital Elevation Model (DEM) was downloaded from USGS earth explorer for the delineation of boundary of the Pennar sub basin and extraction of drainage map. Quantitative morphometric parameters of the basin can address linear, areal and relief aspects to understand conditions of drainage and their relationship with soil and water. The morphometric parameters, stream ordering, stream length, stream length ratio, texture ratio, circulatory ratio, elongation ratio, form factor, stream frequency, drainage density and bifurcation ratio were analyzed to know the characters of the Pennar sub basin. Land use land cover map has been prepared for three intervals i.e., 2011, 2015 & 2020 to identify a temporal change in the classes of agriculture, built up lands, reservoirs, barren lands, water bodies, etc. Different types of soils have been classified by developing soil map of Pennar sub basin. Land capability map has

been prepared and class II, Class III and Class VI type lands are observed in Pennar sub basin. Runoff was calculated by using SCS CN method. Rainfall Erosivity (R) factor, soil erodibility (K) factor, Slope length Steepness (LS) factor, Crop cover (C) factor, Support Practice (P) factor were estimated for the estimation of Soil Erosion using MUSLE. As discussed in Chapter IV, soil erosion estimation by MUSLE has been computed in ARCGIS 10.1 by overlaying all the factors of R, K, LS, C and P. The estimated erosion was further classified into five classes viz., low, moderate, high, very high, severe, very sever classes. For the erosion ranges from high to very severe classes, soil conservation measures (agronomical and engineering measures) have been suggested for reducing soil loss.

The results of preparation of different thematic maps, quantitative estimation of morphometry, surface runoff and soil erosion of Pennar sub basin are presented below.

- The Morphometric analysis has been carried out and identified number of streams in stream order of 1^{st} was 64, 2^{nd} order 16, 3^{rd} order 4, 4^{th} order 1 and stream frequency (Fs) was 0.2. It shows dendritic drainage patterns.
- The elongation ratio of Pennar sub basin is 1 and circulatory ratio is 0.2 and form factor is 0.79 indicating that the basin has high relief and good infiltration with less runoff and less prone to soil erosion.
- The cultivation area was increased during 2011 to 2020 by 18.69 % to 38.84%. It indicated that there is effective utilization of land and water from the Pennar tributaries for agricultural purposes.
- The Annual rate of change (ARC) during 2011 to 2020 is in raising trend for agricultural lands, built up, barren lands, forest and water bodies with 9.49 km^2/yr (11.97%), 0.47 km^2/yr (1.63%), 1.09 km^2/yr (7.15%), 1.30 km^2/yr (2.17%) and 0.16 km^2/yr (0.59%) respectively. Furthermore, it was in decreasing trend for reservoir and fallow land 0.07 km^2/yr (0.73%) and 12.47 km^2/yr (6.09%).
- Class II & Class III lands are suitable for cultivation with better management practices covering 20.82% & 41.07% of the sub basin as per land Capability

Classification. The lands which are not suitable for cultivation, i.e. class VI are covered by barren land with 21% of area and water bodies, settlements covered an area of 17.08% of Pennar sub basin.

- Slope is a analytical parameter which directly governs the infiltration rate and runoff of terrain. As the slope increases, runoff increased with decreased infiltration rate. The Pennar sub basin covers almost flat and undulating topography with gentle (1-3^{o}) and steep slopes (35-37^{o}).
- The highest rainfall was observed in the year 2005 (2157 mm) and the lowest rainfall observed (657 mm) in the year 1994 & 2003 with runoff varied from 167 to 614 mm for the Pennar sub basin during the period 1990 to 2018.
- The rainfall erosivity (R) factor varied from 316 to 1356.56 MJ mm/ ha/ h/ year indicating low to high erosivity and prone to high erosion.
- The average annual loss in the Pennar sub basin was ranged from 0 to 720 ton/ ha/ year which classified into 6 classes. Among which, the major portion (96.49%) of sub basin has low soil erosion i.e. 0 - 7 tons/ha/year and remaining 3.5% has moderate to very severe soil erosion.
- The agronomical measures were suggested for the slopes of 5 - 8% and land use in cultivation and soil loss rate of > 5 t/ha/year. Check dams were suggested for the slopes of 8 - 15% and agriculture should be around 2 km with stream order of 1- 3.
- Contour bunding has recommended for the slopes of greater than 8 - 15% and soil loss rate of > 5 t/ha/year and land use in agriculture and such sites should be cultivated with contour farming. Bench terrace are constructed for the slopes greater than 15 % and land use in agriculture and soil loss rate of > 5 t/ha/year.
- Seventy five sites are identified for construction of engineering structures, out of which contour bunds are suggested in 33 places, bench terraces in 31 places and check dams in 11 places.

Conclusions

Based on the above results, it can be concluded that;

1. The Pennar sub basin is possess high relief and good infiltration with less runoff and less prone to soil erosion. Further, the stream order increased with decreased stream frequency.
2. The agricultural lands, water bodies, built up lands, forest land, barren lands have been increased from 2011 to 2020. Furthermore, fallow lands were decreased due to conversion into agricultural lands.
3. The year 2005 has highest rainfall among 1990-2018, and it is considered as wet year and the years with low rainfall were 1994 & 2003 considered as dry year. Similarly the runoff is high in 2005 and lowest in the year 1994 & 2003 which clearly shows that rainfall is directly proportional to runoff.
4. The soil erosion increased with increase in runoff. Hence the conservation structures (agronomical and engineering measures) have been suggested for the soils with high risk of erosion and conserving water in dry seasons.

SUGGESTIONS FOR FUTURE WORK

Runoff from Pennar sub basin was estimated by SCS – CN method which is empirical in nature and does not represent spatial variability of runoff. Soil erosion was assessed using MUSLE in ARCGIS environment for sub basin. MUSLE does not estimate gully or stream channel erosion caused by raindrops. Thus further study is required on the following aspects

Estimation of runoff using hydrological models, namely, SWAT, KINEROS

Estimation of sediment delivery ratio and sediment yield of sub basin.

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Appendix A

Rainfall data of Pennar sub basin i.e., three stations (Kudair, Uravakonda and Vajrakarur) from 1990 to 2018.

Place	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Kudair	124.5	305.7	239.8	410.0	176.8	293.8	443.4	341.4	533.6	216.4	311.2	522.8	208.6	111.2
Uravakonda	471.2	503.6	538.6	393.2	247.1	466.2	771.8	363.9	517.8	467.1	528.0	575.0	320.3	306.2
Vajrakarur	528.8	462.9	440.1	511.3	234.0	447.4	607.0	453.0	462.0	374.0	407.0	453.6	178.8	278.4
Total	1124.5	1272.2	1218.5	1314.5	657.9	1207.4	1822.2	1158.3	1513.4	1057.5	1246.2	1551.4	707.7	695.8

2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
407.2	521.4	319.6	615.4	565.0	392.6	411.0	347.8	359.8	304.0	353.8	312.2	293.2	562.1	227.0
301.0	777.0	446.4	664.0	676.2	848.8	375.0	311.4	401.4	284.8	277.9	191.4	259.9	532.6	303.4
156.0	859.0	232.6	534.4	602.0	637.0	493.8	279.4	483.4	325.6	351.3	545.2	307.3	699.5	321.7
864.2	2157.4	998.6	1813.8	1843.2	1878.4	1279.8	938.6	1244.6	914.4	983.0	1048.8	860.4	1794.2	852.1

Appendix B

Location points suggested for conservation measures of Pennar sub basin

Name	Latitude	Longitude
Bench terrace	77.27514726	14.92193505
Bench terrace	77.32653355	14.87814605
Bench terrace	77.32853455	14.87701666
Bench terrace	77.33320891	14.92575337
Bench terrace	77.37136301	14.91354167
Bench terrace	77.37907735	14.84340252
Bench terrace	77.38847763	14.86019474
Bench terrace	77.37580503	14.88457716
Bench terrace	77.33781658	14.91349736
Bench terrace	77.35660088	14.9023118
Bench terrace	77.36697111	14.89763731
Bench terrace	77.32011161	14.81533147
Bench terrace	77.3191602	14.81352727
Bench terrace	77.35659351	14.85839096
Bench terrace	77.35946496	14.85930403
Bench terrace	77.36415934	14.85843461
Bench terrace	77.36792485	14.86214985
Bench terrace	77.35671596	14.84151796
Bench terrace	77.40769827	14.84338793
Bench terrace	77.34263201	14.83201878
Bench terrace	77.34444971	14.83408413
Bench terrace	77.3894139	14.83414792
Bench terrace	77.38664775	14.79504579
Bench terrace	77.42225682	14.88547669
Bench terrace	77.42130204	14.87442547
Bench terrace	77.41559149	14.85929313
Bench terrace	77.42217621	14.85185103
Bench terrace	77.41657559	14.84431877

Bench terrace	77.41656822	14.84061131
Bench terrace	77.39771707	14.82659977
Bench terrace	77.41106001	14.80593557
Check dam	77.36319922	14.95101457
Check dam	77.36972255	14.94822334
Check dam	77.37724496	14.93138695
Check dam	77.35096883	14.95476456
Check dam	77.35758667	14.95564718
Check dam	77.27608046	14.92294185
Check dam	77.23213246	14.75359499
Check dam	77.23770636	14.7348837
Check dam	77.37718154	14.92380148
Check dam	77.38021688	14.92482107
Contour bund	77.35289696	14.84998692
Contour bund	77.39601462	14.85742068
Contour bund	77.34923649	14.86103942
Contour bund	77.39790119	14.85368648
Contour bund	77.3426019	14.83030685
Contour bund	77.34538349	14.83102739
Contour bund	77.39131811	14.83217624
Contour bund	77.39223713	14.83315969
Contour bund	77.39536481	14.83157624
Contour bund	77.39856176	14.82950129
Contour bund	77.40143966	14.82575476
Contour bund	77.41080237	14.82104259
Contour bund	77.41026698	14.81929978
Contour bund	77.41209633	14.81525679
Contour bund	77.42791215	14.87700287
Contour bund	77.42227576	14.88651332
Contour bund	77.42414028	14.8892287
Contour bund	77.42313208	14.89113718
Contour bund	77.36448582	14.89867084

Contour bund	77.39129887	14.84155484
Contour bund	77.37346048	14.83119544
Contour bund	77.33418167	14.82094743
Contour bund	77.36506272	14.86307146
Contour bund	77.36696337	14.86314407
Contour bund	77.36598232	14.86212589
Contour bund	77.34360585	14.87705769
Contour bund	77.34541937	14.85831477
Contour bund	77.3613871	14.94143644
Contour bund	77.40723879	14.84411756
Contour bund	77.4062518	14.84713524
Contour bund	77.38667674	14.79412169
Contour bund	77.31354513	14.83034047
Contour bund	77.4212571	14.8274683
Contour bund	77.41187915	14.83970684

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