SOIL LOSS ASSESSMENT IN KESINGA WATERSHED USING SWAT AND USLE

A DISSERTATION

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FOR THE AWARD OF THE DEGREE
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In
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Submitted by
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CANDIDATE'S DECLARATION

I, **KOTRA GIRISH**, Roll No. **2k18/HFE/07** of **M.Tech (HWRE)**, hereby declare that the project Dissertation titled "**Soil Loss Assessment in Kesinga Watershed using SWAT and USLE**" which is submitted by me to the department Hydraulics and Water Resource Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project Dissertation titled "**Soil Loss Assessment in Kesinga Watershed using SWAT and USLE"** which is submitted by **KOTRA GIRISH,** Roll number **2k18/HFE/07** of M.Tech (**HWRE**), Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or fully for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Land system change i.e. degradation of land is one of the nine principles of earth system which is often used to check the amount of destruction that has caused to nature. The term sixth mass extinction heard nowadays is also related to these principles. In the recent UNCCD (United Nations Convention To Combat Desertification) summit the Indian government announced to restore 26 million hectares of degraded land. The major factor that contributes to land degradation is soil erosion. In this work, the Tel river sub-basin's southern part was taken for analysing the amount of soil getting eroded. The area of the catchment was 11400 sq.km. Soil loss assessment was performed using two models. First using Universal Soil Loss Equation (USLE) which is an empirical equation wherein various maps of factors were prepared and overlay operation was performed using Geographic Information System (GIS). Another model used was SWAT (Soil and Water Assessment Transport) in which HRUs (Hydrologic Response Units) are created and analysis was done. The result obtained from SWAT is then calibrated and validated using SWAT- CUP (Calibration and Uncertainty Procedure). The comparison was done between the output and actual sediment yield from the Annual Sediment Report of CWC (Central Water Commission). The soil loss estimated using USLE was 0.801 MT whereas from SWAT it is 1.092 MT. The observed data is 0.961 MT (million tonnes). Soil loss was overestimated when SWAT was used and underestimated when performed using USLE.

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CHAPTER-1 INTRODUCTION

1.1 General

Soil loss is the global environmental problem throughout the world. It is the reduction in quality of soil due to the improper use of land which include both chemical and physical factors, of which soil erosion (physical factor) is a major contributor. Erosion of soil is a natural process which includes soil particles of top layer to get loosened and displaced. It may be a slow process (geological erosion) or fast process (due to floods, deforestation, tornadoes etc.). As per the study done before a staggering amount of 5334 million tons soil is lost every year in India (Narayan and Babu, 1983). As per the National Centre for Coastal Research report, a staggering one third of coastline is affected due to soil disintegration (due to water) in the past 26 years. The issue of soil loss is predominantly seen in tropical areas where rainfall is maximum. Agriculture is predominant occupation followed in India and due to improper practices like excessive tillage, lack of proper information on usage of fertilizers, poor irrigation management system leads to land degradation. Running water is one of the important agents which takes away soil particles (Eswaran et al., 2001). One is rainfed areas where excessive rainfall occurs and the other is river flows which erodes the banks and takes away the sediments through it. Due to rapid urbanization and need of water for agriculture, conservation of water is necessary. Reservoirs are made for this purpose, but to this flow of sediments they get stored in the reservoir because of which storage capacity decreases. Of the water erosion, sheet erosion which is also called as wash erosion is most common problem found in India (Narayan and Babu, 1983). Proper studies are needed to be performed to analyse the soil erosion problems in multiple perspectives like social, economic context.

1.2. Soil Erosion Impacts

Erosion decreases the quality and water storing capacity of soil. The soil's upper layer which contains nutrients and organic matter is lost resulting in hindering of plant growth. Other impacts include increased siltation in reservoirs, flow of sediments in water courses which also carry the chemicals (fertilizers) effecting the aquatic life. Agricultural productivity also decreases because of this. Soil quality, stability, texture and structure is affected by the soil loss. (A. Balasubramanian, 2017)

1.3. Soil Erosion Types

The erosion of soil has been sorted into various categories on the basis of type of carrier as

1. Aeolian erosion
2. Water erosion
3. Wind erosion

Soil disintegration by water is further categorised according to the nature of erosion and intensity , sheet erosion, raindrop erosion, rill and gully erosion, coastal erosion, landslides , stream bank erosion, glacial erosion.

1.4. Soil erosion modelling

As the problem of soil disintegration is increasing day by day effective conservation methods are necessary for which quantification of soil erosion and mapping of degraded areas need to be done (Yadav and Sidhu 2010). Modelling considers various factors and its interactions which influence soil loss. Numerous models are developed for estimating soil loss. Advancement of technology has generated various mathematical and empirical equations which include USLE and RUSLE (Revised Universal Soil Loss Equation) that are used usually for research. Then significant work has been performed to predict values of soil loss for a specific watershed or an area with the help of computer-based tools that led to development of a software i.e. SWAT (Soil And Water Assessment Tool) which is a continuous time model operating on a daily , monthly , yearly time step at basin scale. Especially for small watersheds, various soil erosion models were developed to find the erosion rates for a particular event to an annual scale. There are various parametric models available for calculating soil loss, such as conceptual that is semi empirical, empirical (statistical), physical process (deterministic) based models. Many of these models involve land use, soil type, land structure, topography, and climate related information for estimating erosion values. These models are used for a particular region with a set of conditions.

1.5. Role of GIS and Remote Sensing in assessing soil erosion

The sources of knowledge that is accessible is uneven and manual procedure is very tedious. Role of RS AND GIS plays a significant role in solving this issue. GIS, a computer based system tool designed for collection, integration storing, transforming, retrieving and display of spatial data for solving complex management and planning problems. This software allows us to do spatial analysis by dividing the entire area into ‘n’ number of pixels and process is carried out. For estimating soil loss in USLE or SWAT, RS & GIS helps for procuring information from satellite and then, processing of DEM, Land Use and Land Cover, map of soil erodibility and for overlay analysis where raster calculation is performed. The usage of Remote Sensing and GIS could estimate soil erosion at various scales and find out regions which are affected from soil erosion (Saha et al., 1992). Thinking about unearthing of the landscape on the off chance that it is a broad territory, RS is fundamental to oblige spatial data and changeability. Spatial demonstration includes the utilization of GIS for the display of theoretical model and basic calculation execution. GIS often determine the output spatially (Kumar and Rastogi, 2005).

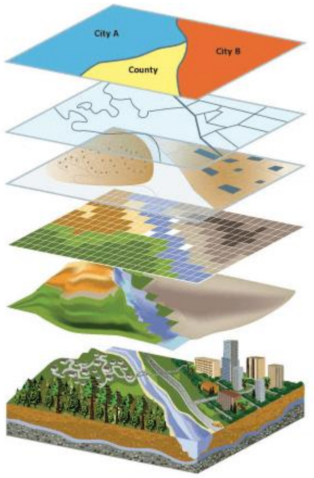

Figure 1 GIS Overlay

(Source: esri.com)

1.6. USLE (Universal Soil Loss Equation)

This model is mostly used for determination of erosion. The application was first limited to selected cropping systems but later it was used for non-agricultural conditions too (Ozcan AU, Erpul G, Basaran M, *et al*, 2008), (Anghel T, Todica S,2008). USLE has been developed by United States Agricultural Research Service (USARS). Wischmeier(1978) developed USLE for estimating soil erosion from rill and sheet erosion in certain conditions from agriculture fields.

The model calculates erosion values by considering various factors and its product. The factors include soil erodibility (K), rainfall erosivity (R), slope percentage (S), slope length in meter (L), support practice factor (P) and cover management parameter (C). Even though USLE is an empirical model, it not only estimates soil loss rate of ungauged watersheds using local conditions of hydrology, climate and characteristics of watershed, but dispense the spatial heterogeneity of soil loss which is more accurate in larger areas (Angima et al., 2003).

As this method determines just soil loss but we need sediment yield which is obtained from the field. For this various equation has been developed. (Walling, 1983) states Sediment Delivery Ratio (SDR) is proportion of yield of sediment at the outlet of basin and soil erosion which occurred in the basin. Also, it depends on the rate of sediment travel and the characteristics of catchment. The computations of SDR have potential uncertainties that include spatial variability and temporal discontinuity (Williams and Berndt 1977; Renfro 1975). Williams and Berndt (1977) found out that for determining SDR mean channel slope plays significant role. This resulted in obtaining a quite reasonable result where data is not adequate.

1.7. SWAT (Soil and Water Assessment Tool)

SWAT, a river basin scale model used for simulating the quantity and quality of ground and surface water and predicting the impact of climate change and land use. It was developed by US Department of Agriculture (USDA) (Arnold et al 1998) and has various applications. SWAT has been able to provide with the solutions for the limitations of USLE. The SWAT model is process based which is computationally efficient, and performs simulation continuously over short and long duration time periods . SWAT has no limitation to area which it can process. It can be used for as small as 32km^2 (Chiang et al. 2010). In SWAT, sub watersheds are created using a single watershed further which are splitted into hydrologic response units (HRUs) which consists of homogeneous land use, topographical, soil characteristics and management. As a part of watershed area the HRU's are presented which may not be contiguous or spatially identified within a SWAT simulation (D. N. Moriasi ,J. G. Arnold et al.2011). The main forces for the processes in SWAT is water balance because it impacts movement of sediments, plant growth, nutrients, pathogens and pesticides. Several data include climatic data, land use data, soil data to run the model. One of the biggest disadvantages of SWAT modelling is it cannot be used in deep aquifer research.

1.8. SWAT-CUP Description

Calibration is done for better parameterizing a model for a set of local conditions which are present, that reduces the uncertainty of prediction. Calibration is done by selecting a set of variable parameter (within the ranges of their respective uncertainty) with prediction of model calibrations (output) with available data for similar conditions. Calibration is performed by two ways , the first is "deterministic" way in which trial and error procedure is followed where in values of input parameters are changed and check with the actual recorded output and parameter values are fixed where it matches. The Second one is "stochastic" process in which focus is on finding out the reasons of uncertainty and error but not on model output. SWAT-CUP (SWAT Calibration Uncertainty Procedures) Is a calibration computer software for the SWAT versions. SWAT-CUP includes various programs. SWAT-CUP is a software that is inn public domain and is free to use. These include Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), and Sequential Uncertainty Fitting (SUFI-2). In this study calibration, validation process is performed using SUFI-2. The process is as follows, a set of parameters are selected and then the model is calibrated. From this the changed parameter values which we obtain is used as input for validation.

1.9. Objectives

The research aims at estimating soil erosion value by both USLE and SWAT. Comparing the values obtained from both the models and figuring out the most affected areas in the basin. The reasons for high erosion in different areas and suggest conservation practices. An overview has been mentioned below:

1. Soil erosion estimation using USLE
2. Soil erosion estimation using SWAT
3. Calibration and Validation using SWAT
4. Comparing the results of both USLE and SWAT
5. Finding of critical erosion areas and suggestion conservation measures

1.10 Thesis Overview

Chapter 1 gives an insight about the various problems occurred due to soil erosion and its causes. Also, it deals about the models and processes used for estimating it.

Chapter 2 deals with the work or research done previously so as to get an idea how to proceed with the process

Chapter 3 is about the describing the study area chosen for this work like, details of its location etc.

Chapter 4 tells about the data procurement process and the detailed methodology used in the work.

Chapter 5 gives detailed analysis of results and discussion using different images and graphs

Chapter 6 is the conclusion and summary of the work and describing about some of the conservation practices that can be performed for reducing the soil erosion effect.

CHAPTER-2 LITERATURE REVIEW

2.1 General

This topic gives an insight about the various works and researches done for quantifying soil erosion. As various models are already available like USLE, RUSLE, MUSLE, WEBB and SWAT, it is easy to improve the concepts and its application for the present study. Literatures consists of USLE (Universal Soil Loss Equation) , SWAT, Remote Sensing and GIS methods.

2.2 Review Papers

Ram babu and Dhruva VV (1983)- In this study , existing yearly soil loss information for 20 diverse regions of land resources of India , sediment data of certain streams ,and erosivity of rainfall(R) for 36 basins, 17 catchments of significant reservoirs were used and statistic regression conditions were developed for sediment yield prediction. Different statistical relationships were established: $y=f(x_1,x_2)$, $y=f(x_1,EI_{30})$, $y=f(x)$, x is the annual total discharge in hectare meters in millions ,x_1 is the catchment area in hectares in terms of millions , x_2=annual average rainfall in cm.EI_{30}=average of annual EI_{30} value, metric units. Soil loss took place at a rate of 16.35 ton per ha per annum. Almost 29% of totally eroded soil was flown into the sea.

Asish Pandey et al. (2007)- In this the author has studied karso watershed located in Hazaribagh, Jharkhand is taken as the study location and the entire area has been divided into a particular grid size and then the study of erosion of each grid has been carried out in order to locate the critical erosion prone areas. This study has been carried out by using GIS and by calculating the erosion for each grid by giving the input parameters. The USLE equation is used for the sediment yield distribution spatially on basis of grids. Sampling of sediment was also performed manually two times a day at watershed's outlet. The difference of sediment yield estimated and the observed sediment yield varied at a range between 1.37 and 13.85 percent which indicated sediment yield estimated accurate from water shed.

Corina Arghius et al. (2011)- In this paper soil erosion rate was estimated in piedmont and Codrului ridge and results are represented spatially by using GIS technique. Starting with the RUSLE equation as that is better over traditional USLE and then the data is given to the ROMSEM (Romanian soil erosion model). The input to this model is DEM and that is obtained through GIS and then a layer for each factor is its output then it has been overlayed by GIS and the results were studied. The results indicated annual average soil loss of 0.575t/ha/yr.

Biswas and Pani (2015)- In this the authors have used integrated approach for estimating soil loss. The integration of Revised Universal Soil Loss Equation model and GIS are being used for estimating soil erosion. Different factors of soilloss equation, such as, the erodibility of soil factor, rainfall erosivity factor etc., has been taken as different overlays and then the entire soil loss is calculated for the whole basin. finally it can be seen that erosion of upper catchment areas depleted the reservoir capacity both live and dead storage.

A L Nurgraha et al. (2018)- Studied the area of beringin watershed, semarang city, Indonesia. RUSLE equation has been used and for each parameter in the equation some weights according to their priority values have been allocated using AHP(analytical hierarchy process). After the weights being applied for different factors. The risk map generated resulted in threatening with high class 1.309%, medium class 48.183%, and low class for 50.508% of Beringin watershed's total area.

A.S. Reddy et al. (2015) – The study Evaluates the impact of various DEMs of varying spatial resolutions (for example TOPO 20 m, ASTER 30 m, CARTO 30 m, GEO-AUS 500 m, USGS 1000m and SRTM 90 m) on basin reaction utilizing SWAT, the Soil and Water Assessment Tool is utilized for Kaddam watershed in India as a contextual analysis to gauge waterway and yield of sediment. It was seen from the after effects of the contextual analysis that arriving at ranges, arriving at slopes, sub-watershed regions, least and greatest rises, land use mapped regions inside the sub-basin and number of HRUs contrasted significantly because of DEM resolutions, bringing about impressive fluctuation in anticipated every day overflow and sediment yields. The normal yield estimations of the residue declined of sub water sheds with coarser DEM resolution. The investigation found that the SWAT model gauge results were not incredibly affected for the estimation of discharge by better resolutions DEMs up to 90 m, yet it certainly impacted sediment yield gauges. The TOPO 20 m and CARTO 30 m DEMs gave dependable appraisals of the sub-watershed, spillover and sediment yield esteems contrasted and different DEMs.

Geun-Sang lee et al.(2010)- The study evaluates the Sediment Delivery Ratio in southern part of Korean peninsula. They prepared a sediment rating curve with the measured discharge and concentration of sediment, which was used for determining sediment yield. A embedded GIS empirical system was used for soil erosion estimation. The ration of yield of sediment and soil loss gives the SDR (Sediment Delivery Ratio). Calibration, Validation was done for two various sets. R factor was also analysed separately by the use of rainfall intensity and amount. R^2 value between calibrated soil loss and the measured sediment yield was 0.632 for Cheonchen and 0.423 for Donghyang; whereas, the values of intensity of rainfall were 0.948 and 0.874.

J. G. Arnold, D. N. Moriasi et al. (2012) – The paper deals with the various calibration techniques adopted for calibrating SWAT output and has also discussed about the recent developments in the techniques. It is also said that the while the calibration of model is done in SWAT range, parameters given should be used within the realistic range as no models in software can replace the physical procedure that is done manually.

Kamaludin, H., Lihan, T., Rahman, et al. (2013)- In this work RUSLE (Revised Universal Soil Loss Equation) was used in Pahanag basin. RUSLE model was used for estimating potential soil erosion and yield of sediment by using data of 10 erosivity of rainfall (*R*) by interpolating data of rainfall, K factor generated by soil map and ground measurement, satellite images were used for C factor, LS factor i.e. topographic factor by the use of DEM and P factor also using satellite images. The results represented most of the basin area was having low soil potential loss .

V.Prassanakumar et al. (2011)- Estimation of soil loss in a sub watershed in Kerala using the RUSLE model. Here also different factor maps were generated and raster calculator was used to merge these factor maps. The result obtained showed a soil loss value of 17.73 t/ha/year where a maximum part of area attributed to steep slopes, grasslands and degraded forests. These resultant maps were used for giving effective input for land management.

A.Prabhanjan et al. (2014)- For Harsul and Khadakohol watersheds SWAT model was applied along with Geospatial techniques for modelling sediment yield and runoff. As there was constraint of observed data regionalising the parameters process was used where in the Khadakohol watershed calibrated parameters were used for Harsul watershed. As per the results obtained it can be analysed that SWAT model predicts the coefficient of determination better for sediment yield than runoff.

Devatha, C.P., Deshpande, V. and Renukaprasad, M.S,(2015)- the study considered the Kulhan watershed, Chhattisgarh state located at 21°34'20"- 21°24'0.5"N and 81°38'32.80"- 81°55'43.82" E . Watershed include 4 regions Abhanpur, Arang Raipur, and Tandula. Kulhan watershed is portrayed from raster information of SRTM DEM 90 m goals, and the Kulhan watershed riverflow was made utilizing toposheets. It is seen that the sediment disintegration for Kulhan watershed is exceptionally less (0.1783 tonha-1year-1) since gradient of the examination region is delicate undulating about 10.49% and a large portion of the area (78%) is involved by agrarian land. It is discovered that 83.97 percent of the territory is beneath moderate disintegration chance level and just 0.45 percent of the all out zone is under high outrageous level and this is seen along the standard watershed line bank.

Briak et al.((2016)- the studymade an investigation in which SWAT incorporated with GIS was Used to demonstrate the Kalaya catchment stream and silt concentration in northern Morocco for the period 1971-1993. Month to month adjustment and approval of the model was performed utilizing Sequential Uncertainty Fitting (SUFI-2) utilizing 16 boundaries inside SWAT-CUP. Utilizing global sensitivity work in SWAT-CUP the comprehensive impact of every boundary utilized was recorded after alignment. From their examination, hydraulic conductivity in fundamental channel (CH K2) alluvium

,USLE help practice factor (USLE P) and keeping an eye on 'n' esteem for the principle channel (CH N2) with various simulation numbers however with similar sources of inputs were seen as the most sensitive boundaries during various iterations. In contrast to the most significant parameters, the least reasonable parameter was seen as various in either case. The model utilized has been adjusted and validated effectively with a spatial methodology on Kalaya watershed and has created an assortment of results about the hydrological movement of the bowl and its spatial units, just as the creation procedures and silt move inside the investigation region.

Prakasam(2010) - the author has done examinations for analysing changes of land use spread across the Kodaikanal, part of Western Ghats situated in the state of Tamil nadu. The creator has endeavored to explore the adjustments in use of land and land spread in Kodaikanal over a 40-year time span (1969 2008) by applying the Remote Sensing technique utilizing the Kodaikanal (1969) SOI Taluk map and the May 2003 and April 2008 Land Sat images. The investigation uncovers that just about 70 percent of the Kodaikanal region in 1969 has decreased to 33 percent in 2008. The creator has detailed that farming area, developed zone, collected land and waste land likewise have encountered a few changes. He has likewise revealed that developed terrains (Settlement) have expanded from 3 percent to 21 percent of the all out region and it may cause a great deal of natural and biological issues. The author at last infers that proper land use arrangement is required for maintaining the development of Taluk.

CHAPTER-3 STUDY AREA

3.1 General

Mahanadi river is one of the east flowing and peninsular river of India. It flows a total course of 900km. The river originates form the northern foothills of Dandakaranya in Chattisgarh at a elevation of 442m. A famous pilgrimage site Puri is located at one of its mouths. It's tributaries include Seonath, Hasdeo, Mand, Ib which are left bank and Ong, Tel, Jonk that are right bank. Some of the important projects located on Mahanadi river are Hirakud dam, Hasdeo Bango, Mahanadi delta project, Mahanadi reservoir project. The Important industries present in the basin are steel and Iron plant at Bhilai**,** aluminium factories at Korba and Hirakud**,** paper mill near Cuttack and cement factory at Sundargarh. CWC is maintaining 60 stations in Mahanadi Basin, out of which 18 are of type Gauge/ Discharge/Sediment/ Water Quality (GDSQ), 3 are of type Gauge /Discharge (GD) 1 is of type Gauge /Discharge/ Water Quality (GDQ), 3 are of type Gauge/Seasonal Discharge (GD(S)), 12 are of type Gauge (Seasonal), 17 are of type Gauge(G). In addition, there are 6 stations of type Rainfall (RF) where only rainfall is observed.(CWC Annual Sediment Report)

The catchment area of Mahanadi basin is 1,41,600km^2. Major part of basin is comprised of agricultural land i.e. 54.27% of area. One of its tributary i.e. Tel river is taken for study. The origin of Tel river is in open and plain area in a district named Koraput of Orissa. Its tributaries include Indra, Udanti, Sutkel, Lant, Ret, Hatti, Raul, Uttei, and Khadago. The Tel sub-basin is nearly in the shape of rectangle and has a 230km of length in direction of east-west and 182 km in direction of north-south and lies between the north latitudes of 19° 15' and 20°55' and east longitudes of 82°03' and 84°17'. The river flows through a length of 296 km and joins the Mahanadi River, 1.6 km below the Sonepur. The catchment or basin area of Tel River is around 22,818 km^2.

In this study lower portion of Tel river is taken for study as it is difficult to perform quantitative analysis for such a large area. As area increases accuracy decreases. A GDSQ station named Kesinga is located on Tel river where the sediment data is calculated and then compared with actual data. The catchment area of the Tel watershed considered for study is 11400km^2 i.e. about 50% of Tel sub basin. The reason for taking this area is very minute studies have been performed on this watershed yet although adequate amount of soil eroded in this watershed.

3.2 Climate

The southwest monsoon bring most of the rains in this area which is from june to September and remaining months it is dry. The rainfall values ranges between 750 mm to 1900 mm and the temperatures also varies from 43 degree centigrade to a mere 8 degree centigrade

3.3 Land Use And Land Cover

On the basis categorization done for this study i.e. into barren land, agricultural land, vegetation, waterbody, built up land. Agricultural land constitutes larger part of the basin followed by barren land. Major crops grown here in this region are coffee and cotton.

3.4 Outlet Station -Kesinga

The outlet station is a GDSQ station i.e. it measures Gauge, Discharge, Sediment, Water Quality. It is located at 20°11'51"N and 83°13'30"E. The station is operational since 1978 for discharge and from 2006 for sediment.

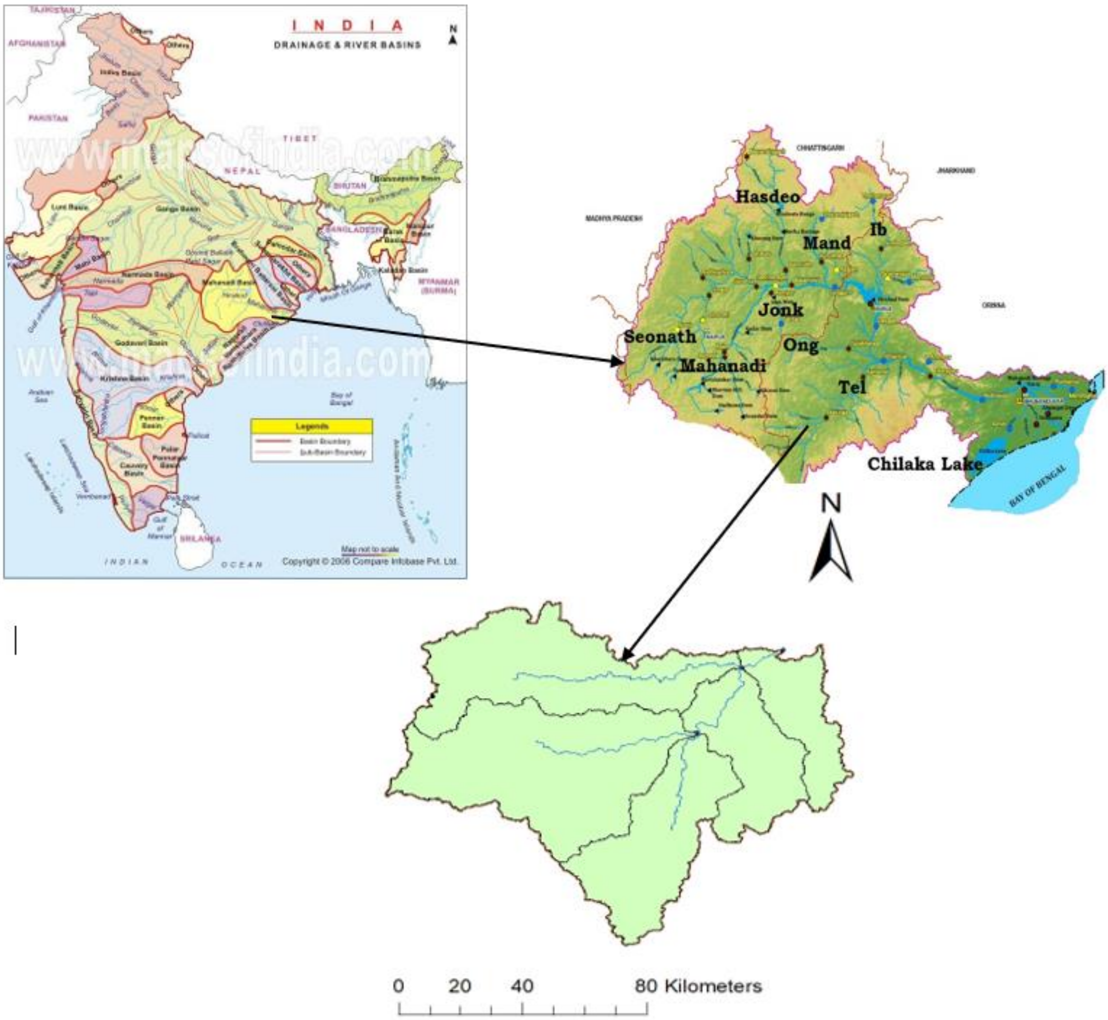

Figure 2 Study area location

(Source: CWC Report and GIS)

CHAPTER-4 DATA AND METHODOLOGY

The chapter tells about the data required and the process by which soil loss estimation is carried out. The two models i.e. USLE and SWAT using Geographic Information System and RS is also explained.

4.1 Data

4.1.1 Topography

The topography of area considered for study i.e. Digital Elevation Model (DEM) is downloaded from United States Geological Survey (USGS) which is having a resolution of approximately 30m or 1-Arc second. Water delineation of the watershed is done using Arc GIS tool.

DEM is a 3D representation of the topography with respect to any datum taken for reference. It has many applications and is used for studies or research done through GIS. A DEM is represented both as raster (while representing elevation as grid of squares known as heightened map) and as a vector-based triangular irregular network (TIN). It is often referred as primary DEM (measured), whereas secondary DEM (computed) is a raster.

Specifications of DEM:

Table 1 DEM Specifications

Projection	Geographic
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Horizontal Datum	WGS84
Spatial Resolution	1 arc-second for global coverage (~30 meters)
Vertical Units	Meters
Raster Size	1-degree tiles
C-band Wavelength	5.6 cm

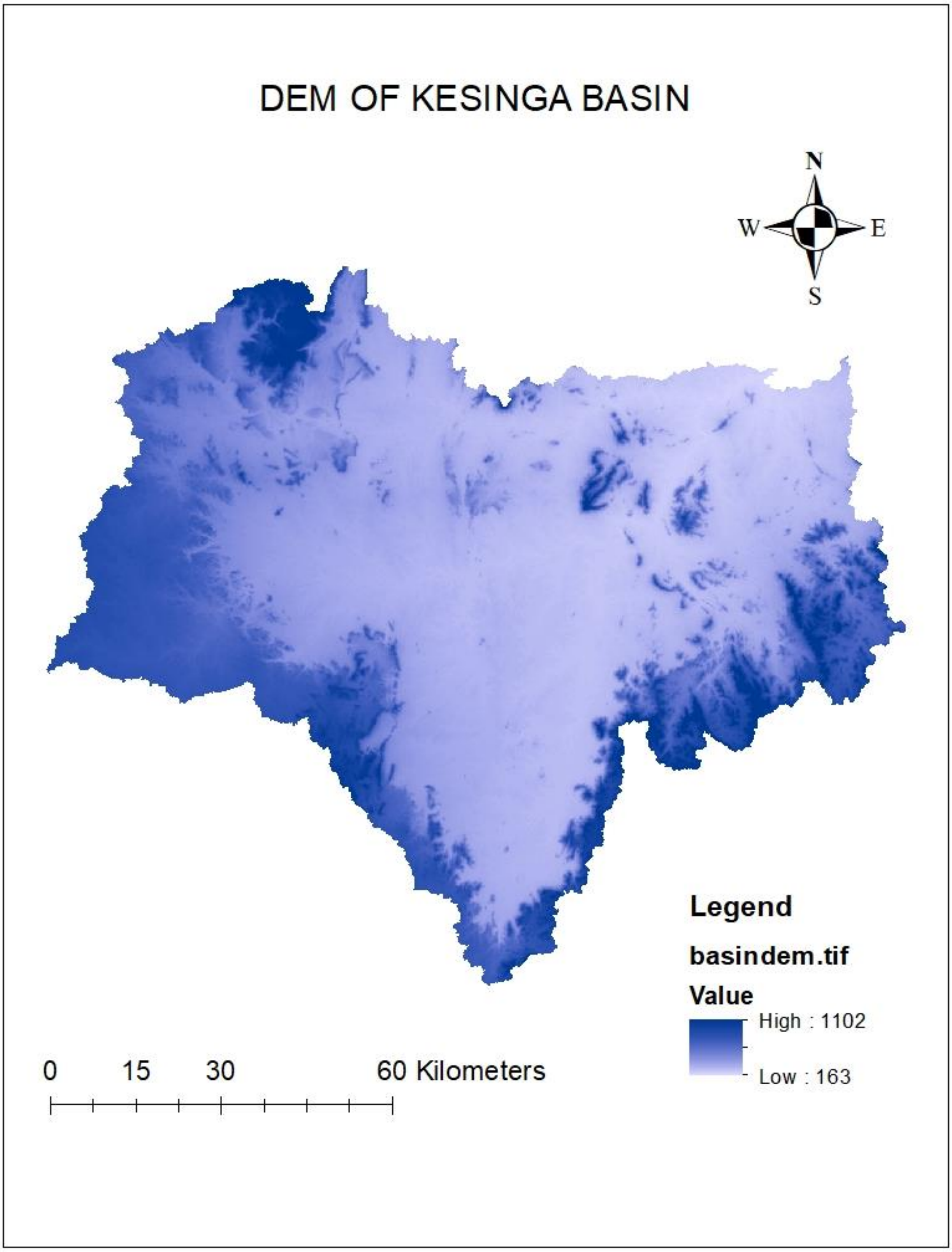

Figure 3 DEM of Kesinga Watershed

(Source: model output)

4.1.2. Meteorological data

Precipitation data is utilized for measuring rainfall erosivity (R) factor by USLE and for SWAT , rainfall and temperature data are needed. The data of rainfall is obtained from the state government website of Orissa that is Orissa Rainfall Monitoring System (https://rainfall.nic.in/) where there is a separate section of validated rainfall data. The daily data of rainfall is available since 1988. But the temperature data which is obtained from CWC (Central Water Commission) is available only for 2 years i.e. from 2016-2018. A total of 9 stations were taken for consideration for analysis. The rainfall map is shown in (Figure 4)

Table 1 Rainfall data

S.NO	STATION NAME	LONGITUDE	LATITUDE	MAP* (mm)
1	sinapali	82.64667	20.09861	809
2	Bhawnipatna	83.16472	19.9075	1384.1
3	Th.Rampur	82.91222	19.51306	1925.4
4	Dharamagarh	82.77472	19.87194	1250.5
5	Junagarh	82.94028	19.86194	1197
6	Kalampur	82.88833	19.61583	1897
7	Jaipatna	82.80694	19.47056	1639.3
8	Koksara	82.70417	19.66833	1874.6
9	Golamunda	82.77389	20.05833	1243.8

*MAP- Mean Annual Precipitation

Note- All the stations are present in Orissa

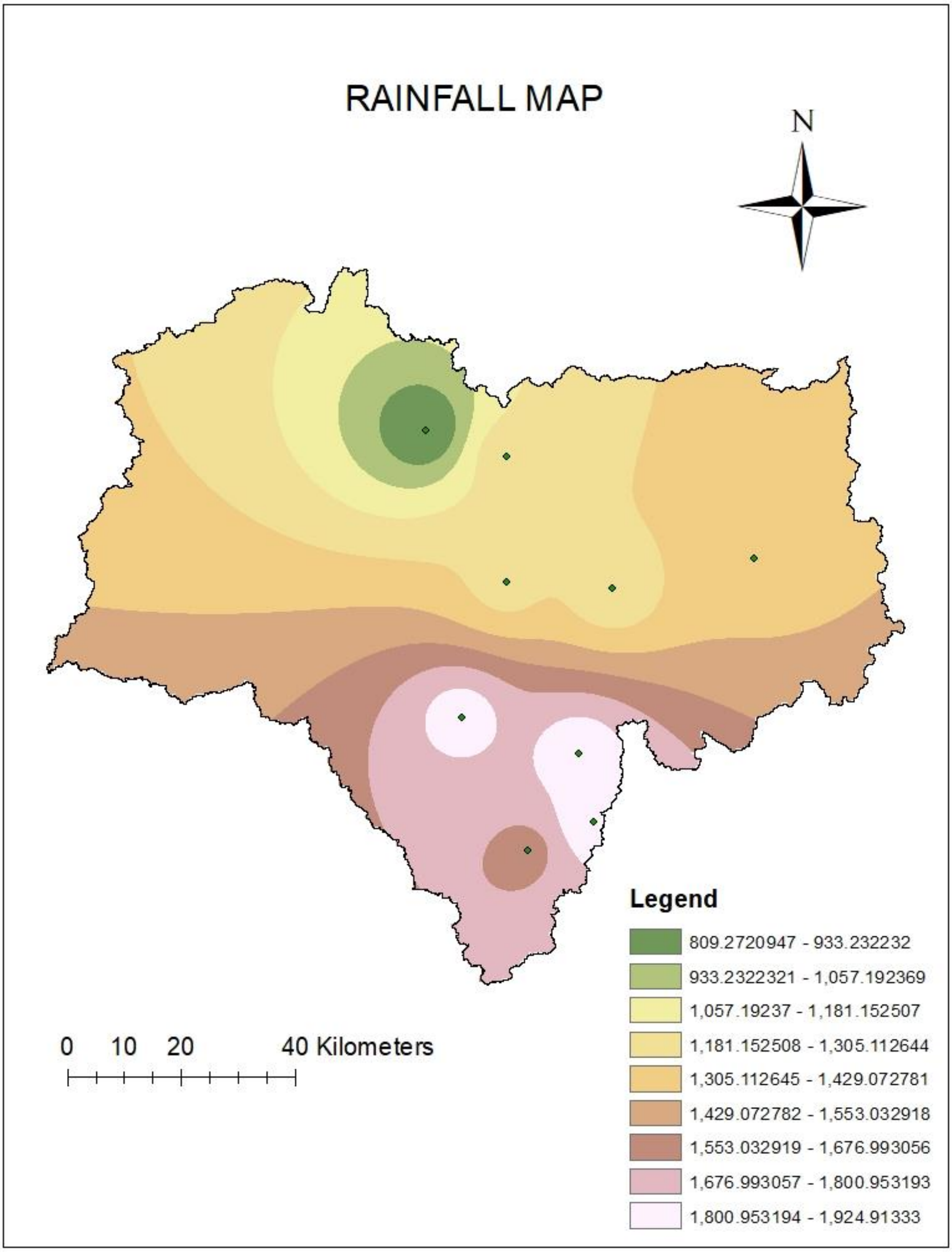

Figure 4 Rainfall map of the Watershed

(Source : model output)

4.1.3 LULC Data

Land cover is the different types of land such as built up area, forest, barren land etc . but the land use determines how the usage of land is. There are two methods to classify satellite data. One is Supervised classification where pixels of similar category of land cover are selected and classified. Other includes usage of statistical algorithm where the number of different classes are described previously and then classified. In this project supervised classification is used.

The DEM data which is obtained from USGS website is used for LULC classification. Ground truth data gathered alongside field photos and videos were utilized while characterizing training sets. The LULC map is prepared and the classes made in this study area are: Vegetation, Barren Land, Agriculture Land, Water body, Built up land. LULC map is shown in (Figure 5)

Table 2 LULC Classification of Watershed

CLASSIFICATION	AREA (km^2)
Vegetation	1918.881
Barren land	4089.870
Agricultural land	4696.407
Water body	311.84
Built up land	382.756

4.1.4 Soil Data

Different types of soil has different erodibility values due to its different properties like texture, structure and organic matter. In this project for determining the values of soil erosion estimation it is very much necessary to know the various soils which are spread in Kesinga watershed. The data of soil is acquired from the website of Food And Agriculture Organisation (FAO). The entire world's soil map is presented by FAO that has a scale of 1:50000. The soil map available is raster i.e. open source and can be used directly in Arc GIS for any study area. 3 classifications of soil types are there in the present study which are mentioned in Table 3.

Table 3 Soil classification of watershed

S.NO	FAO SOIL TYPE	DOMSOI
1	Ne58-1bc-3830	Ne
2	Lf92-1a-3791	Lf
3	Lc46-2b-3770	Lc

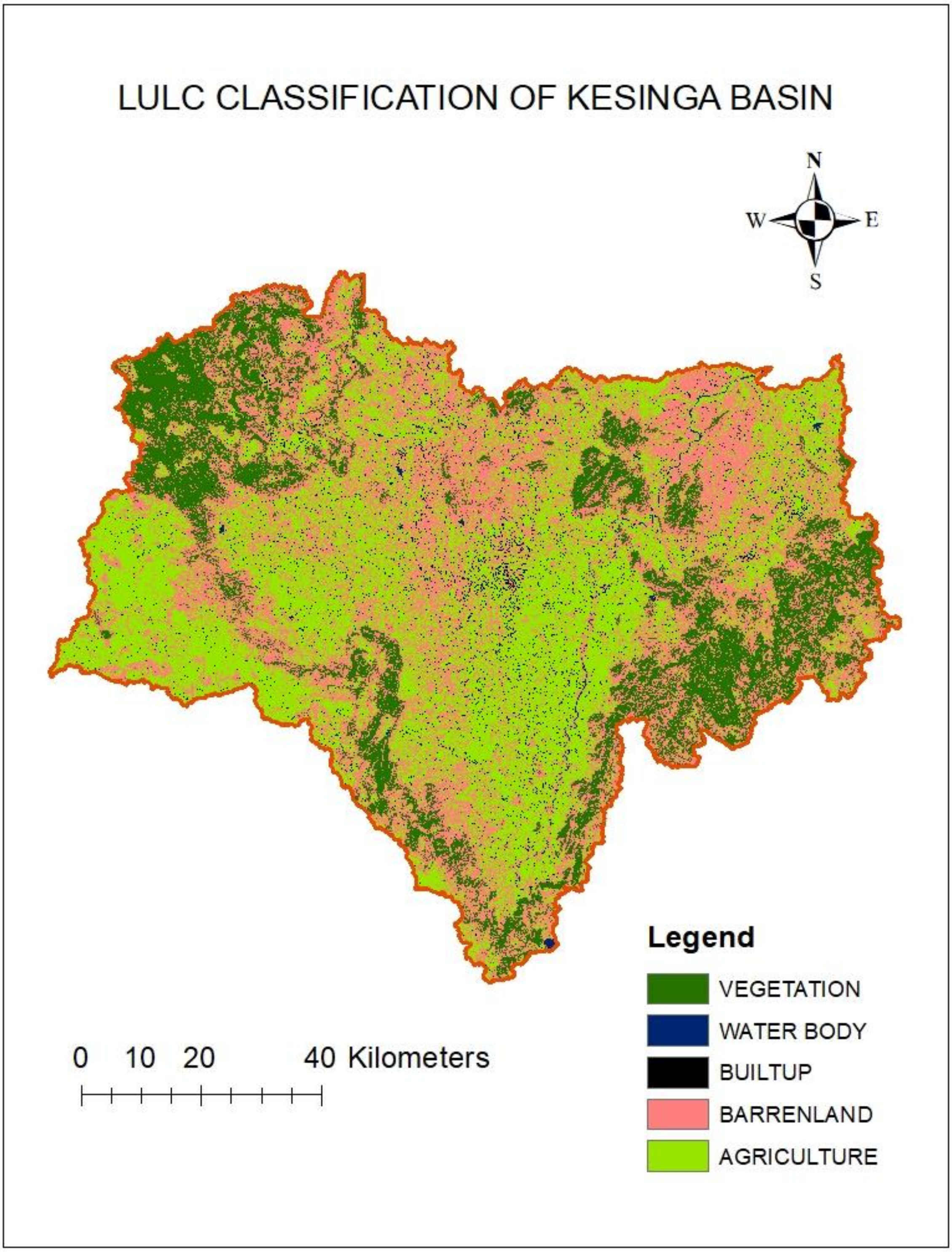

Figure 5 Map of LULC for waershed

(Source : model output)

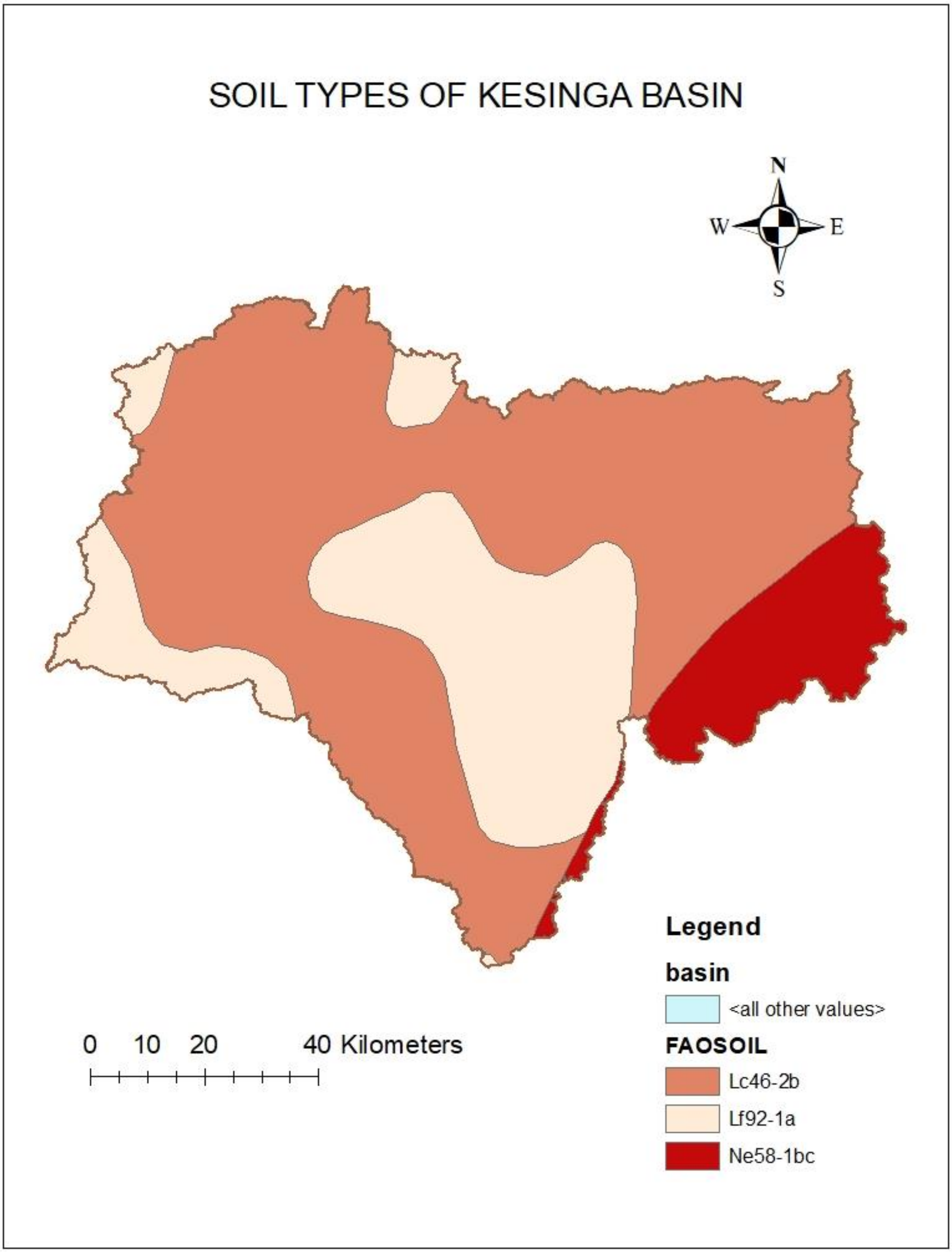

Figure 6 Soil map of Kesinga watershed

(Source : model output)

4.1.5 Sediment Data

The sediment data at the outlet is obtained from CWC Annual Sediment Report in which daily data is provided. This data is used for comparing the actual and calculated data and also for calibrating and validating. The data is available for 3 years i.e. from 2015-18 but due to constraint of temperature data of 2 years, the sediment data of 2 years (2016-2018) is taken for study.

Kesinga is the output gaging station where the sediment data is taken. The data is even classified into fine, medium and coarse. The data is available in the format as mentioned in Table 5.

Table 4 Sediment data from CWC Report

Date	Discharge (m^3/s)	Fine	Medium	Coarse	Total
18/07/2017	889.3	0.68	0.090	0	0.770
19/07/2017	677.9	0.61	0.060	0	0.670
20/07/2017	1077	0.84	0.230	0	1.070
21/07/2017	1910	0.9	0.25	0	1.150
22/07/2017	1206	0.96	0.26	0	1.220
23/07/2017	696.9	0.62	0.06	0	0.680

Table 5 Required data and its Source

S.NO	TYPE OF DATA	SOURCE OF DATA
1.	Digital Elevation Model (DEM)	United States Geological Survey
2.	Rainfall Data	Orissa Rainfall Monitoring System
3.	LULC	USGS
4.	Sediment Data	CWC
5.	Soil Data	FAO

4.2. USLE (Universal Soil Loss Equation)

This equation is used prominently for soil erosion estimation. It's a simple equation which can be applied for any area as it includes many factors which determine changes. USLE is an equation with which each factor map is created using GIS software. The USLE is developed by USDA (Wischmeier and Smith, 1965, 1978) for estimating annual average soil erosion.

Even though USLE is an empirical model, it not only estimates soil loss rate of ungauged watersheds using local conditions of hydrology, climate and characteristics of watershed , also it dispenses the spatial heterogeneity of soil loss which is better accurate in larger areas (Angima et al., 2003).

$$A = R * K * P * LS * C \tag{4.1}$$

A is annual average loss of soil per unit area (t/ha/year)

R the factor of rainfall erosivity that has units of MJ mm $ha^{-1}h^{-1}yr^{-1}$. R is of metric units.

K is the factor of soil erodibility which describes the soil's erosion capacity in quantitative terms and also its susceptibility of detaching and transport through runoff and rainfall.

S , the slope steepness factor and is the ratio of soil eroded in the given slope and the same in the standard slope

L is slope length factor which is the rate of soil eroded in the given slope length and the same in the standard slope length. The parameter is dimensionless

C the cropping management factor and is the proportion of soil eroded from particular crop rotation in the field and the soil eroded from same area's field under land that is fallow, it is also dimensionless number;

P is conservation practice factor that is the proportion of soil eroded from harvested field with control mechanisms to soil eroded from the ploughed field where crop sown is along the slope. It is also dimensionless.

4.2.1 Description Of Parameters

R Factor (Rainfall erosivity)

It is the most important factor because it is an input which drives the cycle of soil erosion. This factor is mostly seasonal particularly in India as much of precipitation is concentrated during June to September. More rainfall contributes a lot to soil erosion.

The R factor is an important factor in soil disintegration appraisal with use of scientific model, Universal Soil Loss Equation (USLE) and its overhauled structure RUSLE (Kamaludin et al., 2013). The greater the intensity and duration of the rain storm, the higher the erosion potential.

Mathematically it is written as,

$$EI_{30} = \sum_{i=1}^{n} (KE * I_{30})/100 \quad (4.2)$$

Where,

KE is the Kinetic energy of storm. The KE is in tonnes/ha-cm and is expressed as:

$$KE = 210.3 + 89logI \quad (4.3)$$

Where,

I is force of precipitation in cm/h ,

I_{30} the highest 30 minutes force of precipitation of tempest

$$R = \sum (Erosion\ Index) = (KE * I_{30})$$

KE is Kinetic vitality of the tempest (MJ/ha)

Babu et al (2004) created a relation for Indian conditions for annual and seasonal. Different gauge stations were installed and the analysis was performed. The relation which they obtained was given below:

Seasonal relationship:

$$R = 71.9 + 0.361R_s(293 \leq R_s \leq 3190mm) \quad (4.4)$$

Annual relationship:

$$R = 81.5 + 0.38R_n(340 \leq R_n \leq 3500mm) \quad (4.5)$$

Where,

R is the erosivity factor,

R_n is normal annual precipitation in mm

R_s is normal seasonal precipitation (mm).

The rainfall data of 2017-18 is taken for study and rainfall erosivity map is prepared.

K Factor (Soil Erodibility)

The factor of soil erodibility (K-factor) is quantitative depiction of innate erodibility of specific soil; the proportion of vulnerability of particles of soil to separation and transport due to precipitation and runoff. The factor of erodibility of soil is rate of disintegration per unit erosion index from a standard plot of area. The factor mirrors the way that various soils disintegrate at various rates when different variables that influence erosion(For e.g., permeability , rate of infiltration, dispersion, total water capacity, abrasion) are similar. Texture, an important factor affecting K factor, but organic matter, structure, permeability also contribute.

In this study the soil erodibility factor is measured using the soil map obtained from Food And Agricultural Organisation (FAO). The soil map of whole world is available and is a an open source.

Williams (1995) equation is used to calculate the K factor and is given below.

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{hisand} * f_{orgc} \quad (4.6)$$

where:

f_{csand} is factor, which has K indicator value higher for soils which has less content of sand and lower for soils that has high content of sand;

f_{cl-si} gives low factors of soil erodibility for heavy clay-to-silt soils;

f_{orgc} decreases K value in organically high carbon soils, where as

f_{orgc} reduces K value for soils containing high amount of sand:

$$f_{csand} = 0.2 + 0.3 * \exp\left(-0.256 * m_s * \left(1 - \frac{m_{silt}}{100}\right)\right) \quad (4.7)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (4.8)$$

$$f_{orgc} = 1 - \frac{0.25 * orgc}{orgc + \exp(3.72 - 2.95 * orgc)} \quad (4.9)$$

$$f_{hisand} = \frac{0.7 * \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left(-5.51 + 22.9 * \left(1 - \frac{m_s}{100}\right)\right)} \quad (4.10)$$

where:

m_s is the content of sand fraction (0.05-2 mm in diameter) [%];

m_{silt} is the silt fraction content (0.002-0.05 mm in diameter) [%];

m_c is the clay fraction content (<0.002 mm in diameter) [%];

orgc is organic carbon (SOC) content [%].

LS Factor (Slope Length Factor)

Slope length and steepness strongly effect the movement of soil particles when they are disintegrated by impact of raindrop or runoff. LS-factor is generally greater than one, it can have a considerable effect on the erosion prediction. The soil loss is more with increase in steepness and length of the slope (Wischmeier and Smith, 1978). More the slope length steepness of slopes impact the soil erosion most.

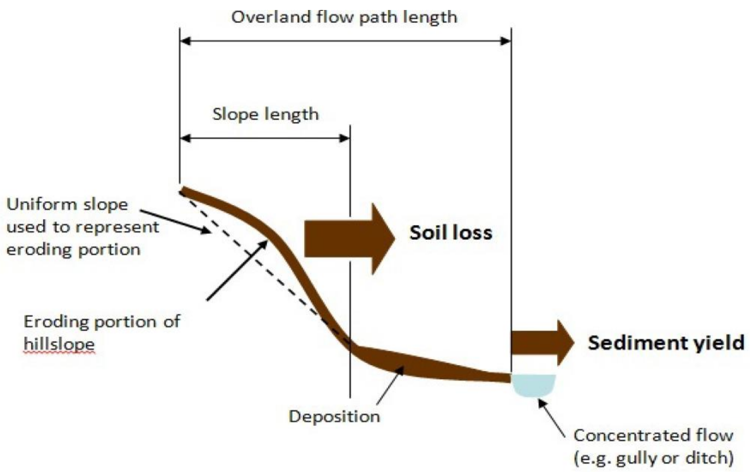

Figure 7 Slope Length Representation

In the basin, the LS factor values are derived from the following equations

$$L = (m+1)(\frac{\lambda_A}{22.1})^m \quad (4.11)$$

Where,

L is factor of slope length,

λ_A is upland flow area,

m=0.4, Which is an value that is adjustable according to the susceptibility of the soil to get eroded, 22.1 is unit plot length.

$$S = \left(\frac{\sin(0.01745 * \theta)}{0.09}\right)^n \quad (4.12)$$

Where

0.01745 is (Π/180) and these are used to convert slope in degree to radians

θ is slope in degrees,

0.09 is constant for slope gradient, and

n = 1.4, Which is the adjustable value according to the susceptibility of the soil to erosion.

In Raster Calculator,

the LS- Factor is written as

LS=(0.4+1)*Power(“Fac”*[cellresolution]/22.1,0.4)*Power(Sin(0.01745*“slope_deg”/0.09), 1.4) (4.13)

Where

F ac = Raster for accumulation of flow originating from Flow direction using DEM.

Cell resolution = 30 for DEM

Slope_degree = Slope in degrees derived from DEM

Crop management factor (C factor)

The C-factor examines the effect of activities that are soil-disturbing, crop sequence and its productivity level, plants, subsurface bio-mass and soil cover on soil loss. Defined as proportion of soil lost from cropped land under certain conditions to the corresponding soil loss from clean and tilled, continuous fallow land. Values of this factor varies from zero (soil that is well protected) to 1.5 (for soil which is finely tilled). Conservation practices like zero tillage and less use of machinery will decrease impact of erosion of soil.

The DEM of study area is downloaded from USGS Earth Explorer and then training samples for different classes were created. From the knowledge of field, the training samples are created and were used by classifying the image with the maximum likelihood classification.

The values of C- factor given by Dabral et al. (2008) were considered for the land use and land cover maps and C- factor raster map was prepared by the use of conversion toolbox in ArcGIS 10.4.1 software. Table 7 depicts the values of C factor.

Table 6 C factor values for different classes

Land use/ land cover class	C factor value
Agriculture	0.28
Degraded forest	0.008
Dense forest	0.004
Fallow agriculture	0.180
Jhum cultivation	0.33
Open forest	0.008
Settlement	1.0
Water body	0.280

P Factor (Support Practice Factor)

It deals with practices which are performed like strip cropping, contour tillage to reduce the runoff which in turn reduces soil loss (Wischmeier and Smith, 1978). The P factor is the least accurate of all factors that are present in USLE. The value of P factor is considered as 1 for the present study due to unavailability of exact data. But from some sources it can be concluded that there are no or very minimal conservation practices.

Sediment Delivery Ratio

As this model determines just soil loss but we need sediment yield which is obtained from the field. For this various equation has been developed. (Walling, 1983) states Sediment Delivery Ratio (SDR), the ratio of yield of sediment at the outlet of basin and soil erosion which occurred in the basin. Also it depends on the rate of sediment travel and the characteristics of catchment. The computations of SDR have potential uncertainties that include spatial variability and temporal discontinuity (Williams and Berndt 1977; Renfro 1975). Williams and Berndt (1977) found out that for determining SDR mean channel slope plays an important role.

$$\text{Sediment Yield} = (SDR) * A \tag{4.14}$$

where A is total gross erosion obtained from USLE,

SDR = Sediment delivery ratio.

$$SDR = 0.627 * SLP^{0.403} \tag{4.15}$$

SLP is the slope % of mainstream channel

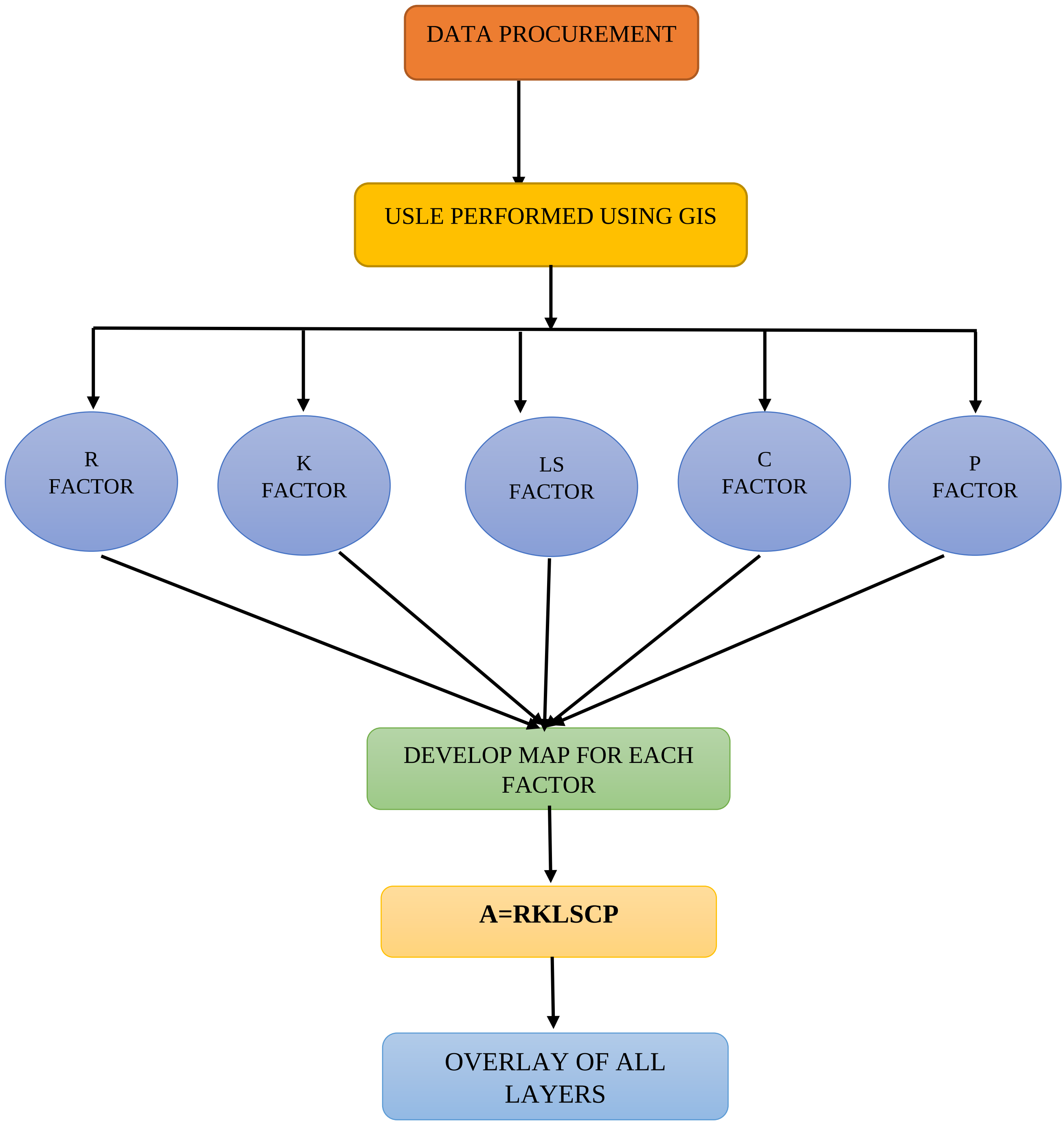

Figure 8 Flow Chart depicting the methodology of USLE

4.3 SWAT (Soil And Water Assessment Tool)

4.3.1 General

SWAT utilizes two-level disaggregation data; on the basis of criteria of topographic sub basin identification is made, further discretization is followed using soil type and land use consideration. Areas of similar soil types, topographic characteristics, land use form a HRU (Hydrological Response Unit) which is a computational unit that is presumed to be analogous in hydrologic response to the land use and land cover change. For each HRU the simulation is carried out and the sediment loss and runoff is calculated. Hydrology, soil erosion, environment, nutrients, crop production, soil temperature, stream routing and agricultural pesticide management, are major parts of model. By the use of equation of water balance, that includes run-off, evapotranspiration, daily precipitation, returns flow elements and percolation, the model estimates hydrological values for all HRU's.

4.3.2 Water Balance Equation- Hydrological Cycle

SWAT's hydrological routines account for processes in the vadose region and (that is drainage, plant absorption, evaporation, lateral flow, percolation) groundwater flows. The hydrological cycle which SWAT simulates is on the basis of equation of the water balance:

$$SW_t = SW_t + \sum\left(R_{day} - ET_i - Q_{surf} - Q_{gw} - W_{seep}\right) \qquad (4.16)$$

Where:

SW_t is final content of soil water in mm,

C is water content of soil initially on the day i (mm),

t is time in days,

R_{day} is rainfall on the day i (mm),

ET_i the evapotranspiration on the day i (mm),

Q_{surf} is surface runoff on the day i (mm),

Q_{gw} is amount of return flow on day i (mm).

$W_{seep\,i}$ is the sum of all water from soil profile that reaches vadose zone on day i (soil interflow; mm)

4.3.3 Surface runoff

SWAT simulates peak runoff and surface runoff values for each HRU by altering the soil conservation service curve number (SCS-CN) or Green & Ampt infiltration method, respectively(Neitsch et al., 2005). SCS-CN method is used when we are using daily rainfall data and Green & Ampt infiltration method used when using sub- daily rainfall data. As in this project daily rainfall data is used so SCS-CN method is used.

SCS-CN (Soil Conservation Service Curve Number Method)

It was developed in 1969 by USA's Soil Conservation Service which is a simple, stable and predictable process for estimating depth of runoff based on rainfall depth.

$$Q = \frac{(R-0.2s)^2}{(R+0.8)^2} \qquad \text{if } R > 0.2s$$

$$Q = 0 \qquad \text{if } R \leq 0.2s \qquad (4.17)$$

Q is surface runoff daily in mm

R = daily rainfall in mm

s = retention parameter which varies for different watersheds

$$S = 254\left[\frac{100}{CN} - 1\right] \qquad (4.18)$$

4.3.4 Evapotranspiration

The evapotranspiration is calculated in SWAT by three techniques ; (i) Hargreaves (Hargreaves et al. 1985), (ii) Penman-Monteith technique (Monteith 1965) and (iii) Priestley–Taylor technique (Priestley and Taylor 1972). In this study, the combination of the ET with Penman-Monteith technique and the CN method for run-off measurement and is best combination to estimate both runoff, evapotranspiration (Kannan et al. 2007).

4.3.5 Sediment Yield

MUSLE equation is used in SWAT for measuring soil erosion at HRU level and the equation is :

$$Q_s = 11.8 * \left(A.Y.q_{peak}\right)^{0.56} * C * K * LS * P * CF \qquad (4.19)$$

where Q_S = yield of sediment in tonnes/day,

Y is the surface run-off in mm/ha/day,

q_{peak} = peak run-off in cumecs,

A = area of the HRU (ha),

K is USLE's soil erodibility,

C is USLE management and cover factor,

LS is USLE slope factor,

P is USLE support practice factor and

CF is the coarse fragment factor.

4.3.6 Flow Routing:

The flow routing can be computed in river channels using the Muskingum method (Chow 1959) and variable storage coefficient method (Williams 1969). The variable storage coefficient method is used in this study.

4.3.7 Sediment Routing:

Bagnold's (1977) stream power equation is used by SWAT model to direct sediment in river. The maximum quantity of sediment that can be carried from reach segment is based on the peak channel speed. The channel sediment routing (Arnold et al. 1995) contains degradation of channel using power of stream (Williams 1980) and deposition of channel with fall velocity.

4.4 SWAT CUP (Configuration And Uncertainty Procedures)

It is a tool aligned with ArcSWAT for calibrating, validating and assessing the results that we obtain from SWAT tool. Sensitivity analysis is also performed with this tool. SWAT-CUP has graph modules for observing uncertainty range, sensitivity graphs, simulation results, statistical reports and visualization of watershed using Bing map.

For yield of sediment and runoff calibration was done. Sensitivity analysis helped in classifying the most important sensitive parameters and was done using one factor at a time which is automated analysis that is implemented in SWAT (Van Griensven and Meixner 2006) and ranks of different parameters that effect both sediment yield and runoff were prepared.

There are 5 algorithms in which anyone can be used :

1. Parameter Solution "ParaSol"(Alamirew,2006
2. Particle Swarm Optimization "PSO"(Eberhart &Kennedy,1995),
3. Generalized Likelihood Uncertainty Estimation "GLUE"(Beven &Binley,1992),
4. Mark chain Monte Carlo "MCMC" (Kassa &Foerch,2007) and
5. Sequential Uncertainty Fitting "SUFI-2" (Abbaspour et al.,2007)

There are two processes , one is deterministic approach where trial and error process is used and the other one is stochastic calibration where uncertainties and errors are recognized and try's to correct it. Uncertainty is necessary because without this the calibration is meaningless. SUFI-2 method is used in this study where certain parameters are selected and the ranges are provided. The fit quality in SUFI-2 was quantified using the percent bias coefficient (pBIAS) , the efficiency coefficient of Nash-Sutcliffe (NSE), linear correlation coefficient (R^2) and between the best simulation and the observed data observed.

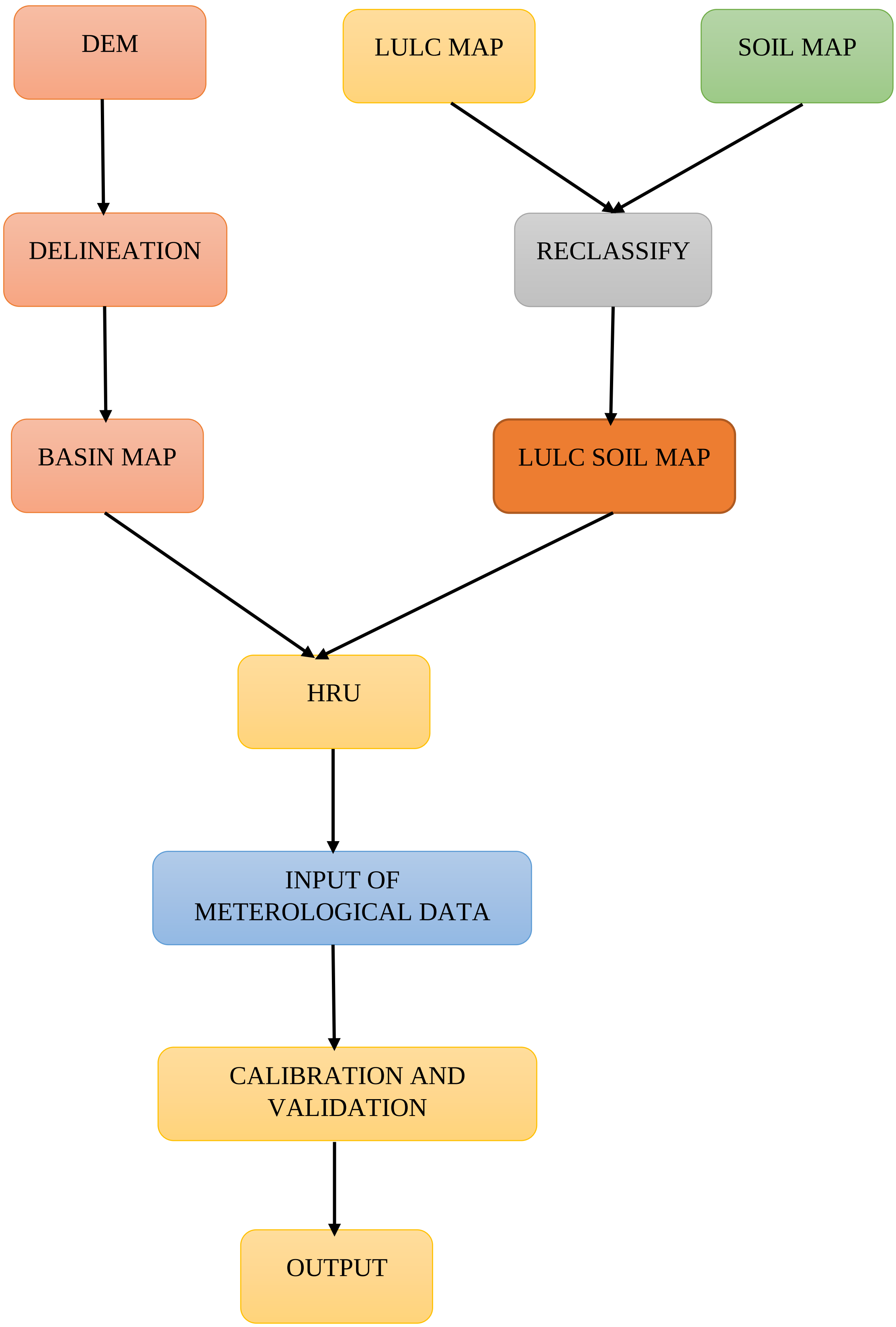

Figure 9 Methodology of SWAT flow chart

CHAPTER-5 RESULTS AND DISCUSSIONS

5.1 General

The present work estimates the amount of soil eroded in Kesinga watershed using two models i.e. using USLE and SWAT. The comparison of data estimated was done with observed data given in the annual sediment booklet of CWC. Various reasons are discussed in the chapter which will give insight on soil erosion using these techniques.

5.2 Delineation of Watershed

The DEM (Digital Elevation Model) of area considered for study i.e. SRTM 1 arc second image which has a resolution of 30m is obtained from the USGS website. Remote sensing method is used by satellites to capture earth data. ArcGIS 10.4.1 along with ArcSWAT is used to conduct this process. The coordinate system was set as WGS 1984 Mercator. The process of delineation using ArcSWAT was carried out which contained Flow direction and accumulation. Then the process included stream and stream network generation. The outlet is then selected using the satellite image. After the selection of outlet point the basin map is generated depicting the streams sub watersheds and connecting points. The delineated map and the sub watershed maps are shown in Figure 10 and 11.

The highest, lowest elevations of watershed are 1102m and 163m. The total number of sub watersheds of the study area include 5 and whole area of watershed obtained is around 11400 km^2 .

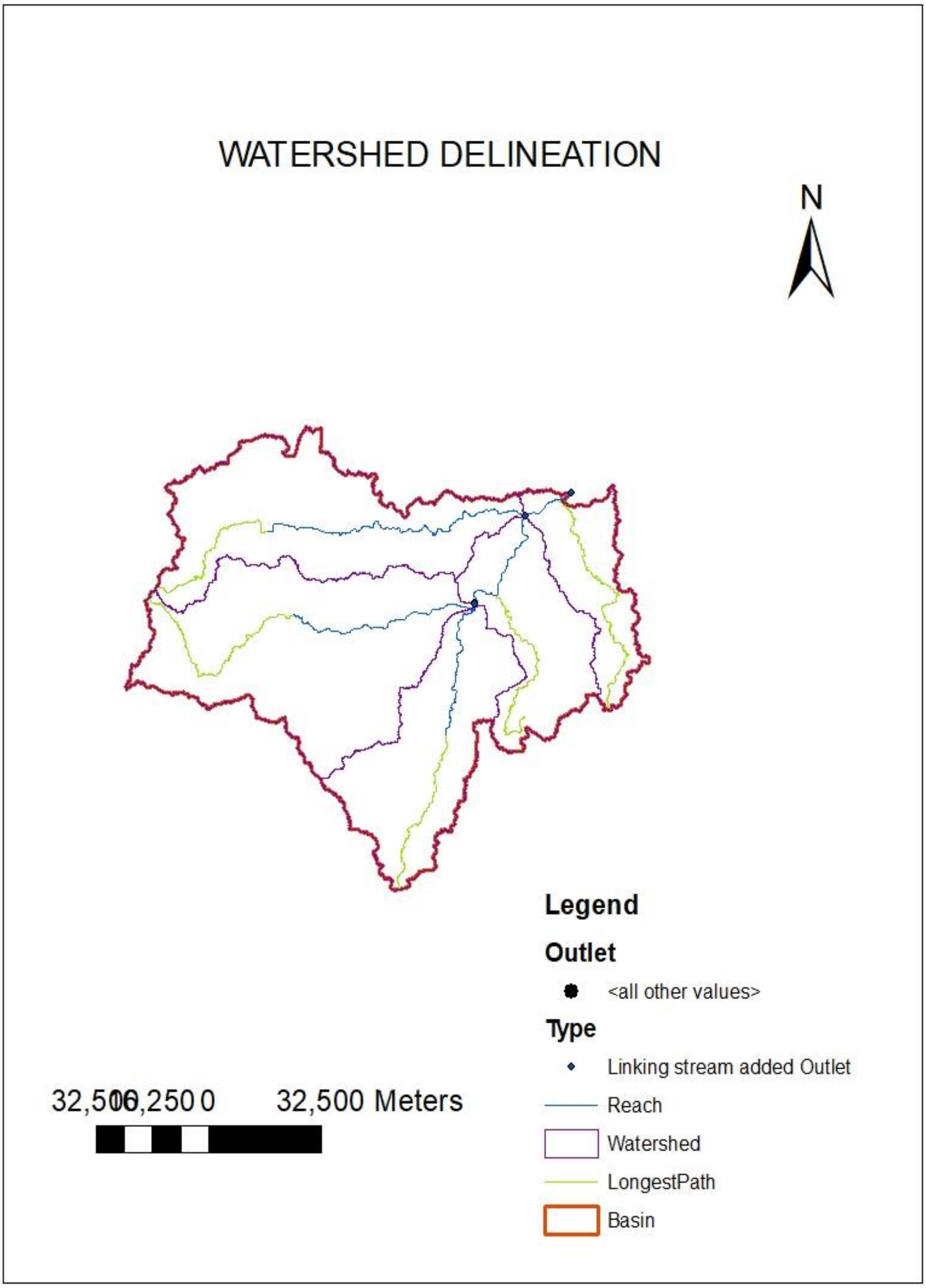

Figure 10 Delineated Watershed map

(Source : model output)

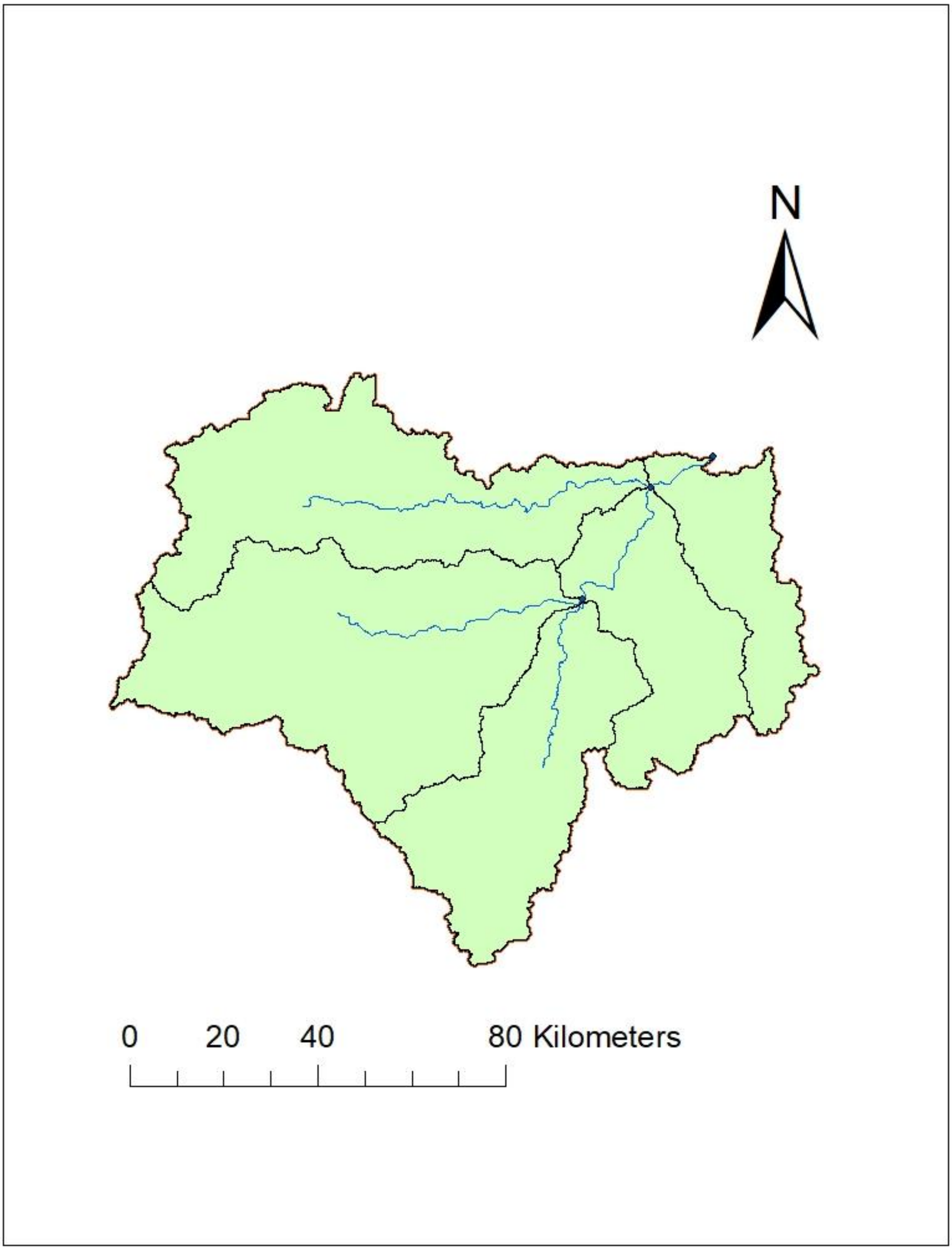

Figure 11 Sub watersheds map

(Source : model output)

5.3 Soil Loss Determination Using USLE

First the soil loss was estimated using the USLE equation. For this maps of each factor was made using ArcGIS. Factors include are map of rainfall erosivity, soil erodibility , slope factor , cover and management factor. After that the process of overlay was performed wherein using raster calculator all the factor maps were multiplied resulting in soil erosion values.

5.3.1 R Factor (Rainfall Erosivity)

It is significant factor that contributes to soil loss. The erosion capability depends on the force of precipitation by which it separates the particles from the area. The rainfall data of of 9 gauge stations that are presented in Table 2 is used for the preparation of the rainfall erosivity map.

The process of preparing the map is as follows – daily rainfall data of different stations which are present in the investigation area are collected and are then summed up to obtain yearly rainfall values in mm. Then excel sheet is prepared depicting the latitudes and longitudes values and with rainfall values and station names. The excel sheet is imported into ArcGIS10.4.1 and basin boundary is added. Then rainfall map of entire watershed is prepared using Inverse Distance Weighted method (IDW) as interpolation needs to be done. After obtaining the rainfall map, the raster calculator is used where the equation given by Babu..et al is used to arrive at rainfall erosivity values of the entire kesinga watershed.

The map of rainfall erosivity is shown in Figure 12 and the value ranges from 372.766 to 777.744 MJ mm $ha^{-1}h^{-1}$

5.3.2 Soil Erodibility (K) Factor

It determines the innate soil erodibility in quantitative nature and is because of complex chemical and physical property interactions affecting soil's infiltration capacity , transportability and detachability. The value varies for different types of soil and class. The soil map is generated using the data which was obtained from FAO website. This factor depends on proportion of loam, clay and silt fraction. The equations provided by Williams (1995) were used in excel and K factor values are calculated which are then added to ArcGIS to prepare the map.

There were three types of soils detected in the watershed and the K factor value varies from 0.17355 to 0.18344. K factor for different soil categories are mentioned in Table 8

Table 7 K Factor value for different soils

S.NO	SOIL TYPE (FAO)	DOMSOI	TYPE	K FACTOR
1	Ne58-1bc	Ne	Nitosols	0.17845
2	Lf92-1a	Lf	Luvisols	0.18344
3	Lc46-2b	Lc	Luvisols	0.17355

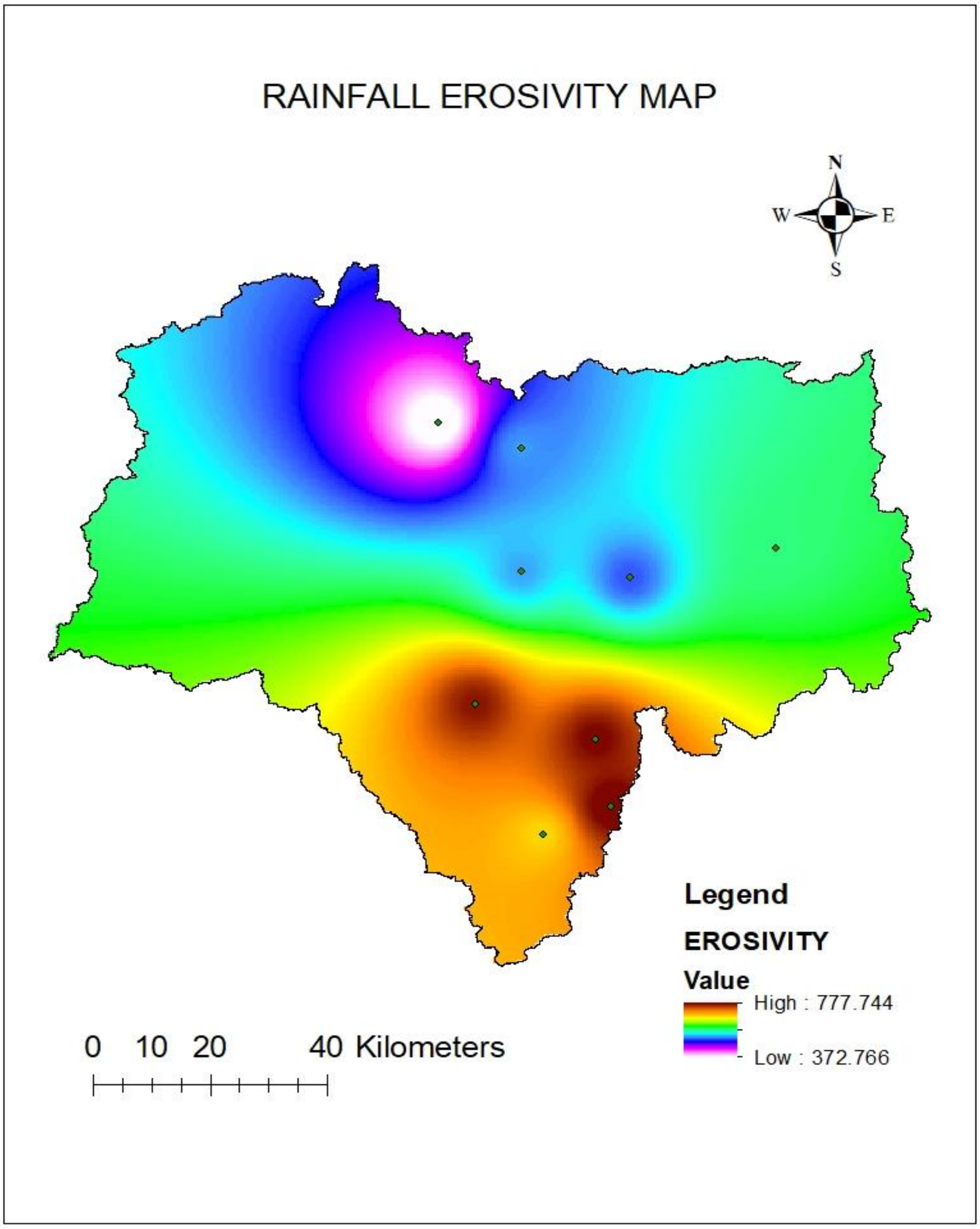

Figure 12 R (Rainfall Erosivity) Factor map

(Source : model output)

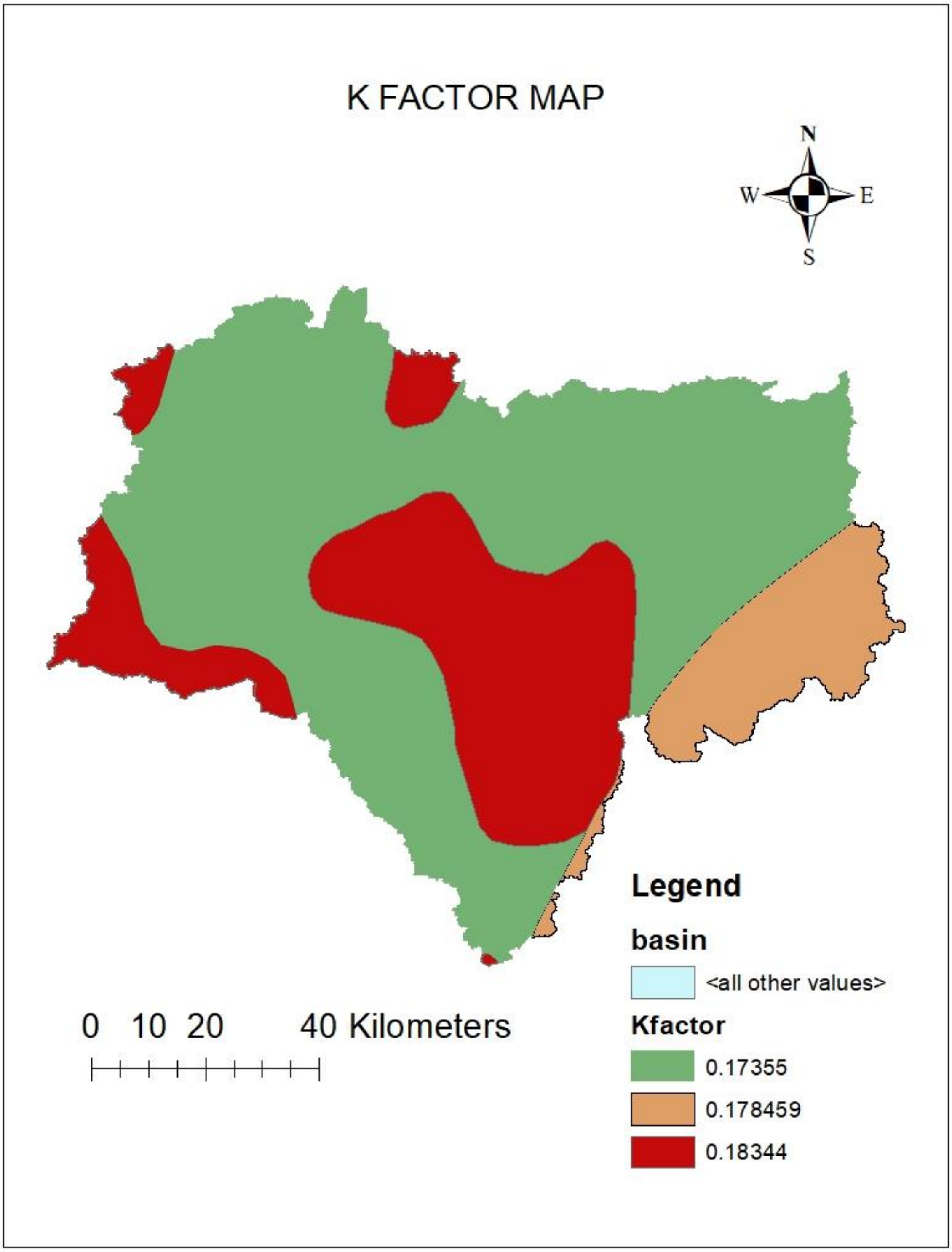

Figure 13 K Factor map

(Source : model output)

5.3.3 Slope Length And Steepness (LS) Factor

The DEM (Digital Elevation Model) of study area is used for determining the LS factor. DEM of area, which was obtained from USGS Earth Explorer and subsequently the sinks are filled up using the ArcGIS toolbox. Then the flow direction was measured and also flow accumulation. The topographic (LS) factor was determined by using the equation provided by Wischmeier and Smith, 1978 . Values obtained were from 0.324-5.619. The map is shown in the Figure 14.

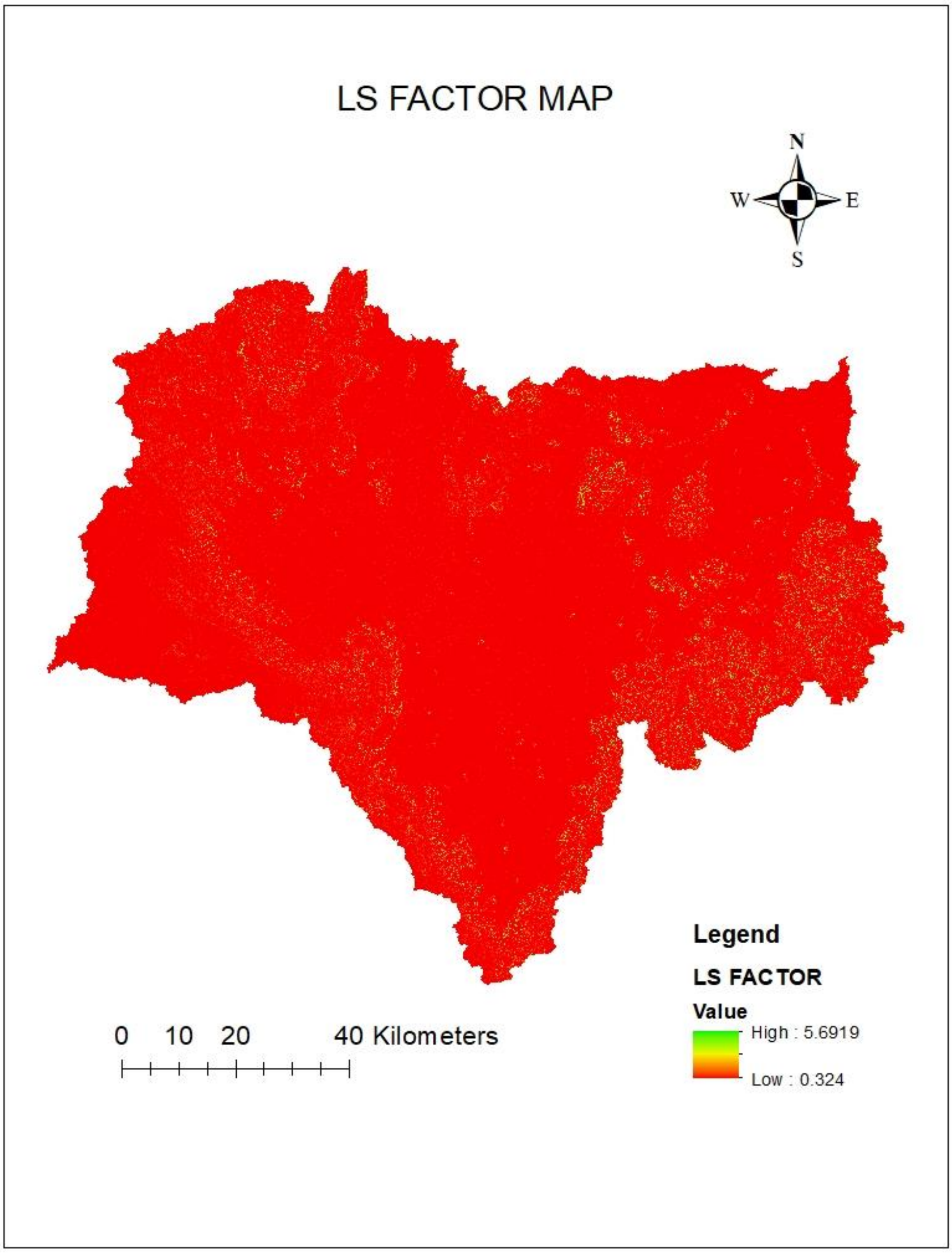

Figure 14 LS Factor map

(Source : model output)

5.3.4 C Factor (Cover And Management)

This factor tells us how soil loss affects due to soil cover and plants. It also takes into consideration the human activities and measures the effects of management variables and interrelated cover. In this work, LULC map was obtained from satellite images from USGS website and then the processing was done in ArcGIS. It is like a guiding principle in allocation OF P and C factor for various land use classes (Dabral et al., 2008). For different classes values of C factor differ.

After performing the analysis of the satellite images obtained from USGS in ArcGIS. In the next step for each class different number of polygons are drawn. This is done in order to give the input to the software to classify different classes. Then the LULC map is prepared and the classes made in this study area are:
Vegetation, Barren Land, Agriculture Land, Water body, Builtup land

Table 8 C Factor values for different classes

CLASSIFICATION	AREA (km^2)	C FACTOR VALUES
Vegetation	1918.881	0.004
Barren land	4089.870	0.18
Agricultural land	4696.407	0.28
Water body	311.84	0.28
Built up land	382.756	1

The values of Cover And Management Factor varies from 0.004 for vegetation to 1 for built up land. From the table it is oserved that the most part of watershed is covered by agricultural land and least by water body. Figure 15 depicts the C Factor map.

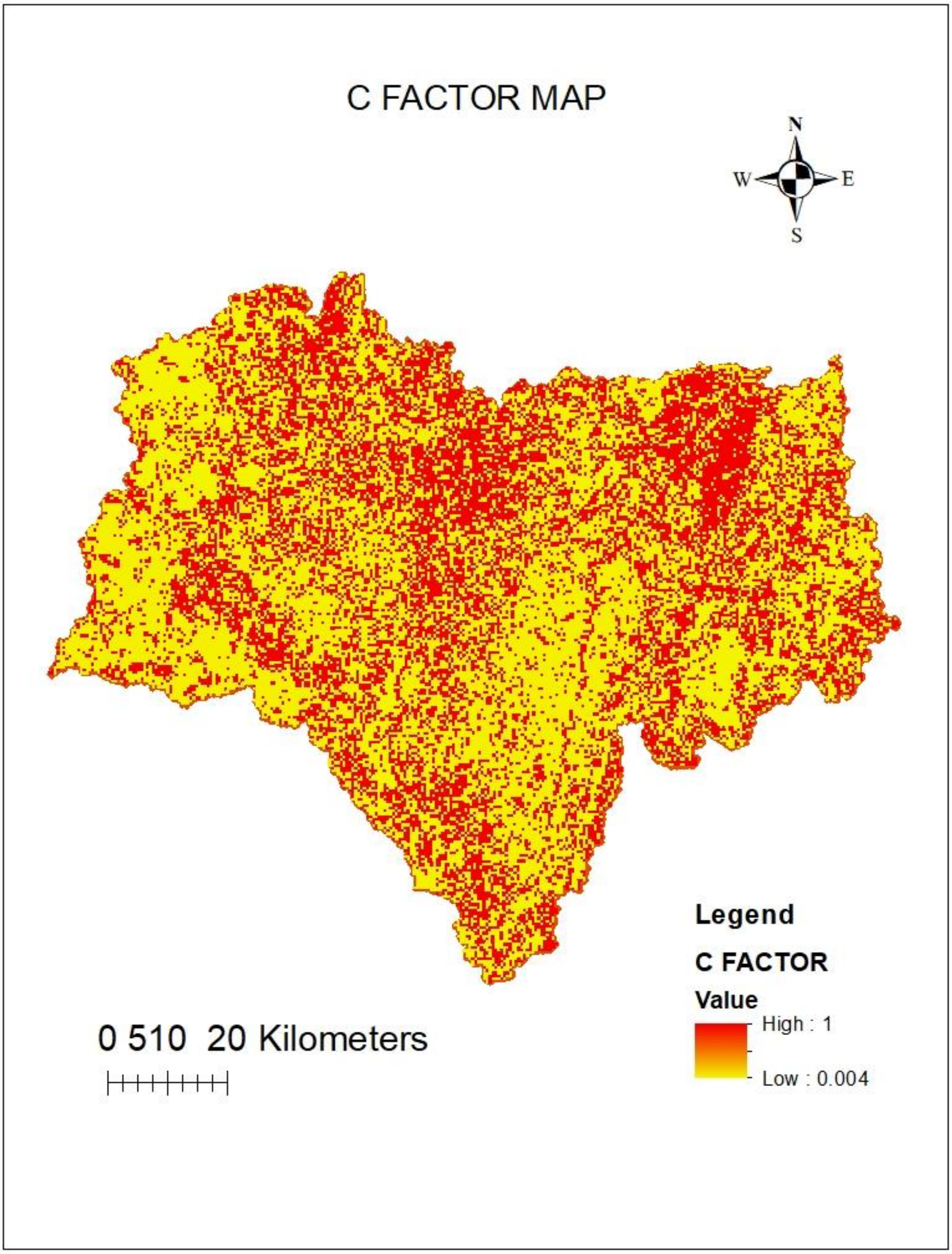

Figure 15 C Factor map of Kesinga watershed

(Source : model output)

5.3.5 P Factor (Support and Conservation)

It deals with the practices which are performed like strip cropping, contour tillage to reduce the runoff which in turn reduces soil loss (Wischmeier and Smith, 1978). The factor is the least accurate of all factors that are present in USLE. The value of P factor is considered as 1 for the present study area due to unavailability of exact data. But from some sources it can be concluded that there are no or very minimal conservation practices.

5.3.6 Soil Loss Calculation

The raster maps prepared for each factor is processed in ArcGIS using raster calculator where in the values of soil eroded for each pixel can be determined. Reclassification of gross soil erosion values was done using Singh et al. (1992) for Indian conditions and are divided as slight (0–5 tonnes/ha/year), moderate (5–10 tonnes /ha/year), high (10–20 tonnes/ ha/year), very high (20–40 tonnes /ha/year), severe (40–80 tonnes/ ha/year), and finally very severe (80 t/ ha/year). The USLE equation is used for estimation annual average soil loss.

From the output which is obtained by multiplying different factor maps, it can be inferred that the average soil erosion is estimated as 7.336 tons/ha/year. The SDR (Sediment Delivery Ratio) calculated on the basis of empirical equation provided by Williams and Berndt was found to be 0.38. The sediment yield is obtained by the multiplication of average annual soil erosion and sediment delivery ratio and area of the watershed. The estimated sediment yield is compared with observed sediment data at the outlet which is mentioned in Annual Sediment Report of Central Water Commission.

The sediment yield is calculated as follows:

Total sediment yield = Annual Average Soil Loss * Area * SDR *100

= 7.113 * 11400 * 0.38 * 100

= 0.3081 million tons

Table 9 Observed and Estimated Sediment values

STATION NAME	KESINGA
AREA	11400 Km^2
DURATION	2017-2018
OBSERVED SEDIMENT LOSS (MN TONS)	0.3652
ESTIMATED SEDIMENT LOSS (MN TONS	0.3081

From the Table 11 it can be inferred the more than 74 % of the area falls in low and moderate class and very less part of the water shed that is around 3000 km^2 has soil loss greater than 10 t/ha/year. Therefore major part of watershed is safe from high risk of erosion. The Table 11 shows the area covered and its corresponding soil loss.

Table 10 Soil erosion values with different risk classes

SOIL ERODED IN (Tons/ha/year)	DIFFERENT CLASSES	AREA IN (KM^2)	AREA (%)
<5	Low	2214	19.42
5-10	Moderate	6233	54.67
10-20	High	1683	14.76
20-40	Very High	321	2.84
40-80	Severe	665	5.83
>80	Very Severe	284	2.49

All the factors have an impact on the soil loss but two factors that has more effect is LS factor and the Rainfall factor. It can be best observed that the places where the slope factor and rainfall is high, there the soil loss estimated is more as it is generally known that the high slopes with the windward rainfall leads to drastic erosion. It can be seen from the table 5.4 that only 284km^2 has the soil loss value greater than 80 tons/ha/year but it contributes a major part in total soil loss. Various conservation practices are needed to be taken in area above high category to reduce soil loss effect.

The watershed's soil loss map is shown in Figure 16. As we have the value of sediment yield from the observed data, it need to be converted to soil loss for comparison which is obtained by dividing the yield of sediment with sediment delivery ratio. The comparison is shown in Table 12. Overall we can say that the soil loss estimated using USLE model has predicted less than the observed value. It can be due to discrepancies in data as it is obtained from satellite images which can be different from actual data and also the model does not take into account many other meteorological factors that include temperature, wind and humidity.

Table 11 Estimated and Observed Soil loss

Observed sediment loss (million tonnes)	0.3652
Estimated sediment loss in (million tonnes)	0.3081
Observed soil loss in (million tonnes)	0.961
Estimated soil loss (million tonnes)	0.801

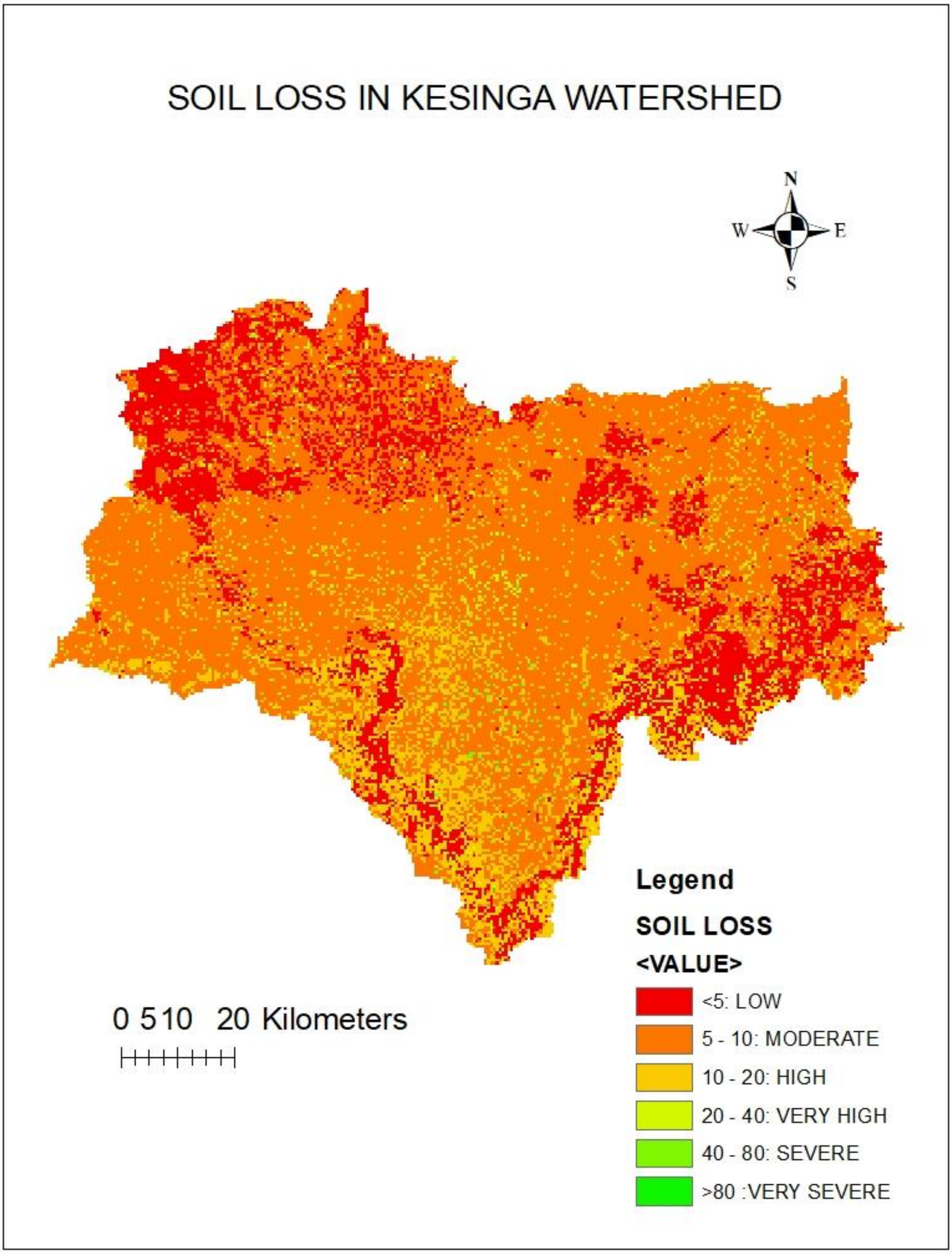

Figure 16 Soil loss in the watershed

5.4. Soil Loss Estimation Using SWAT Modelling

5.4.1 Introduction

SWAT utilizes two-level disaggregation data; on the basis of criteria of topographic sub basin identification is made, further discretization is followed using soil type and land use consideration. Areas of similar soil types, topographic characteristics, land use form a HRU (Hydrological Response Unit) which is a computational unit that is presumed to be analogous in hydrologic response to the land use and land cover change. For each HRU the simulation is carried out and the sediment loss and runoff is calculated.

SWAT model has been used for calculating the soil and sediment loss in the Kesinga watershed. Both the sediment and runoff are estimated using this model which are then calibrated and validated using SWAT CUP.

5.4.2 SWAT Model

The process was conducted using ArcSWAT 2012 which is an extension used in ArcGIS 10.4.1. The first step is watershed delineation similar to the process used in USLE. There are 5 sub watersheds and the total area of watershed is seen to be 1081913 km^2 . The maximum and minimum elevation is found to be 1102m and 163m.

For HRU generation first the slope, soil and land use maps with 5 classes of slope dividing as follows (0-10% , 10-20% , 20-30%, 30-40% and 40-9999%), 3 classes of soils and 5 classifications of land use. The total number of HRU's obtained were 121.

After defining HRU the meteorological data has to be given as input. First the weather stations and its details are to be updated. Due to scarcity of data only temperature and rainfall data were updated. There is a specific format for loading the data and the format is shown below. The Penman- Monteith method was used and processing was done in SWAT.

pcpall - Notepad

File Edit Format View Help

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ID,NAME,LAT,LONG,ELEVATION
1,pbhawnipatna,2247533.813,9257854.282,248.000
2,pdharamagarh,2243349.122,9214439.681,302.000
3,pgolamunda,2265294.049,9214347.286,241.000
4,pjaipatna,2196180.214,9218026.395,528.000
5,pjunagarh,2242172.496,9232869.736,216.000
6,pkalampur,2213238.098,9227086.688,241.000
7,pkoksara,2219406.581,9206586.091,275.000
8,psinapali,2270039.937,9200185.22,261.000
9,pthrampur,2201169.039,9229746.111,723.000
```

Figure 17 Format for updating data of precipitation data in SWAT

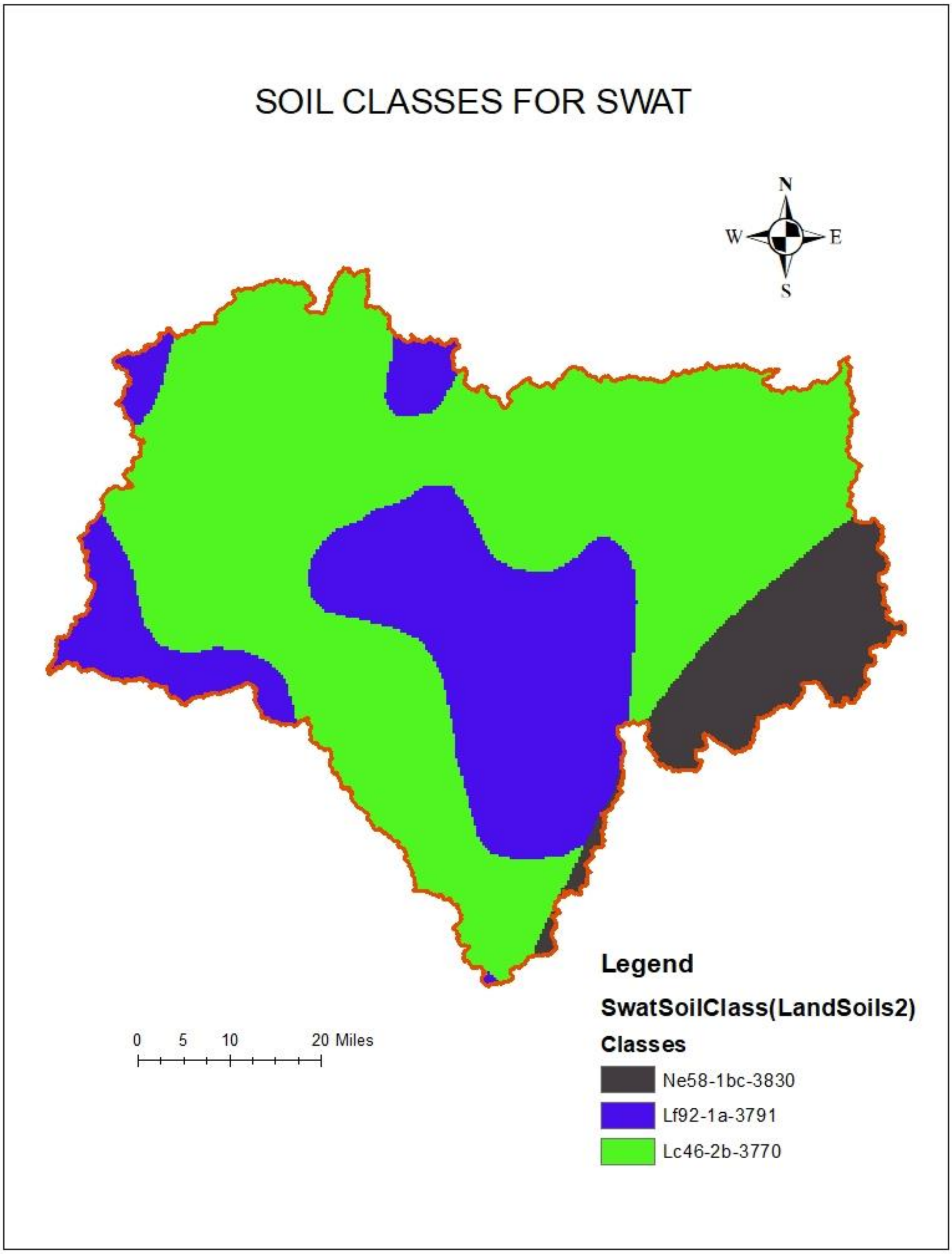

Figure 18 Soil classes for SWAT

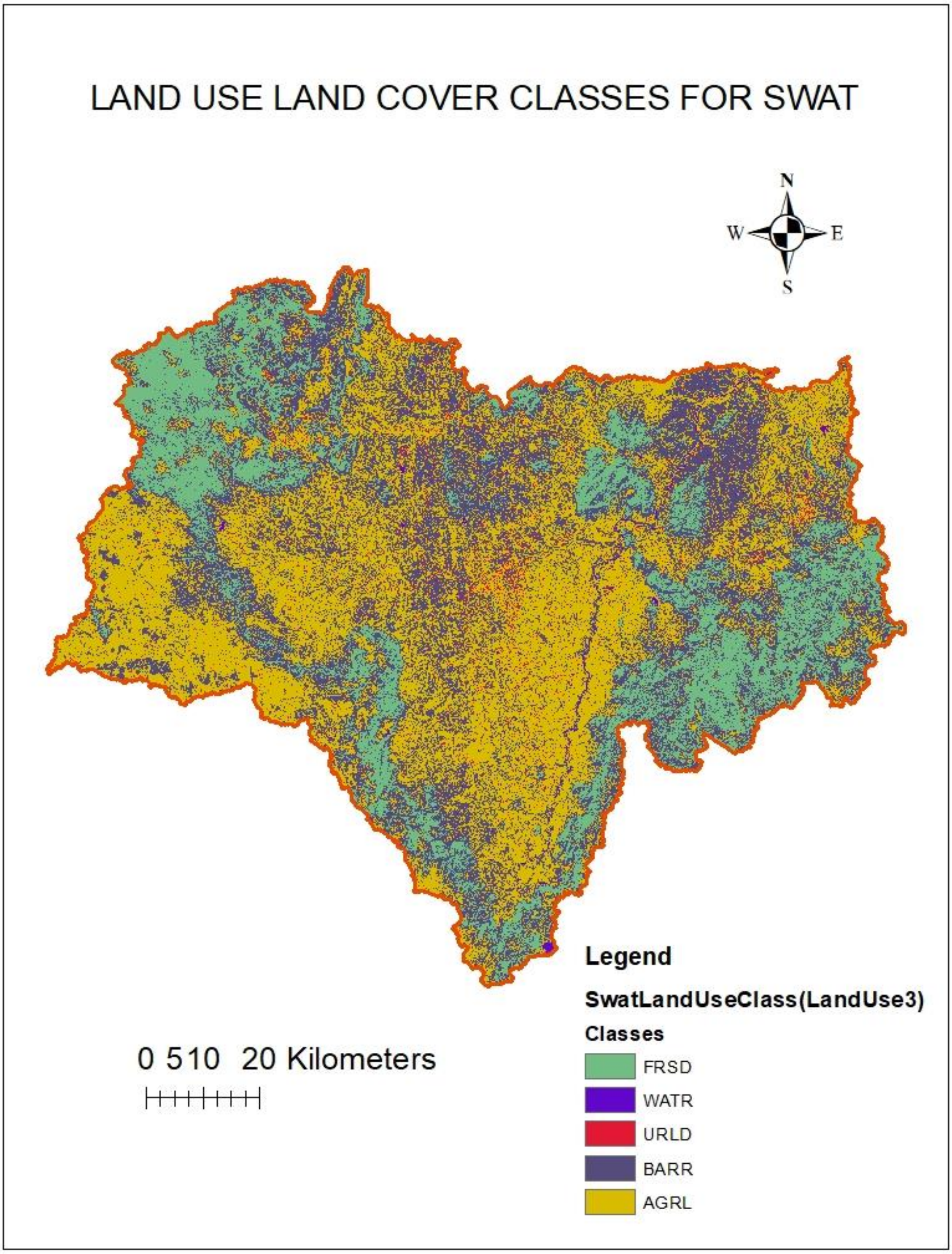

Figure 19 Land use classes for SWAT

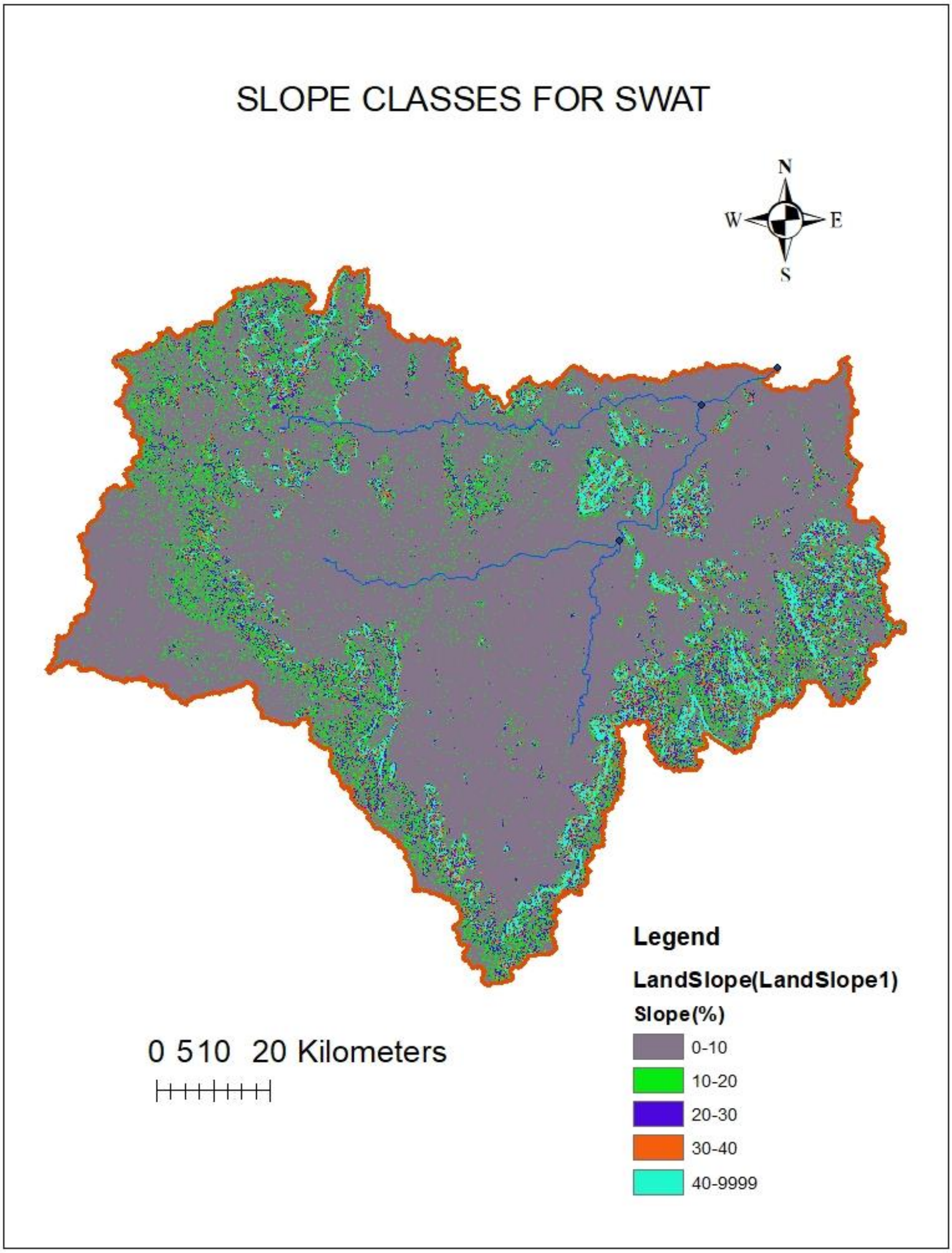

Figure 20 Slope classes for SWAT

The areas covered by different land use classes, slope classes and soil classes are clearly mentioned in Tables 13, 14, 15.

Table 12 Areas of different slope classes

TYPES	AREA(sq.km)	% AREA
0-10	740938.3	68.48
10-20	141766.1	13.1
20-30	76034.46	7.02
30-40	55849.48	5.16
40-9999	67325.13	6.22

Table 13 Areas of different soil classes

TYPES	AREA (sq.km)	%AREA
Lc46-2b	661205	61.11
Lf92-1a	301273.2	27.84
Ne58-1bc	119435.3	11.03

Table 14 Areas of different land use classes

TYPES	AREA(sq.km)	% AREA
FRSD	203257.2	18.78
WATR	18812.3	1.73
URLD	33640.87	3.1
BARR	394276.8	36.44
AGRL	431926.3	39.92

The total area obtained during the SWAT process is 1081913 km2. As uncertainties persist because of the fact that model is developed in software. The model is to be calibrated and validated for output to acquire proper results. The model that is calibrated and validated can be used for further erosion studies.

5.4.3 SWAT CUP (Calibration And Uncertainty Procedures)

The model was simulated using SUFi-2 (Sequential Uncertainty Fitting) algorithm in SWAT- CUP for calibration (01/06/2016- 31/05/2017) and validation (01/06/2017-31/05/2018). Initial 6 months of 2016 were given as warm up periods. The parameters used for this process were taken from M.P Tripathi et.al. who worked on Mahanadi basin. As the study area is under the Mahanadi basin these parameters were used directly. Table 5.9 shows the list of parameters. Same parameters were used for runoff and sediment as the parameters were considering the effect of both. The new limits are obtained after the calibration process which were used for validation.

Table 15 Parameters used for calibration and validation

Sensitivity Order	Parameters	Limits used for calibration	Limits used for validation
1	CN	25 to 98	10-150
2	ALPHA_BF	0 to1	0 to 1
3	GW_DELAY	-30 to 90	-21 to 110
4	GWQMN	-1000 to 1000	-500 to 500
5	ESCO	0 to 1	0 to 1
6	EPCO	0 to 1	0 to 1
7	GW REVAP	0 to 1	0 to 1
8	CH_N2	0 to 1	0 to 1
9	SOL_AWC	-25 to 25	-20 to 20
10	RCHRG_DP	0 to 1	0 to 1
11	CH_K2	1 to 150	20 to 200
12	OV_N	0.01 to 0.6	0.05 to 0.1
13	SOL_Z	-25 to 25	-25 to 25
14	SURLAG	0.05 to 24	0.01 to 50
15	CANMX	0 to10	0 to 5
16	BLAI	0 to 1	0 to 1
17	CH_K1	0 to 1	0 to 1
18	USLE_P	0 to 1	0 to 1
19	CH_COV	0 to 1	0 to 1
20	CH_EROD	0 to 1	0 to 10
21	SPEXP	1 to 1.5	0 to 3

Description of Parameters

CN – Runoff curve number

ALPHA_BF = Base-flow alpha factor (days);

GW_DELAY = Groundwater delay (days);

GWQMN=Threshold depth of water required for return flow to occur in the shallow aquifer (mm);

ESCO = Soil evaporation compensation factor;

EPCO = Plant uptake compensation factor;

GW_REVAP = Groundwater "revap" coefficient;

CH N2 = Manning 'n' value for main channel;

SOL_AWC = Available water capacity of the soil layer;

RCHRG_DP = Deep aquifer percolation fraction;

CH K2 = Effective hydraulic conductivity in the alluvium main channel;

OV_N = Manning's "n" value for overland flow;

SURLAG = Surface runoff lag time;

CH K1 = Effective hydraulic conductivity in the alluvium tributary channel;

USLE_P = USLE equation support practices (P) factor.

CH_COV = Channel cover factor;

The results obtained were plotted in the form of graph for easy understanding.

Calibration Period Of Runoff (01/06/2016 to 31/05/2017)

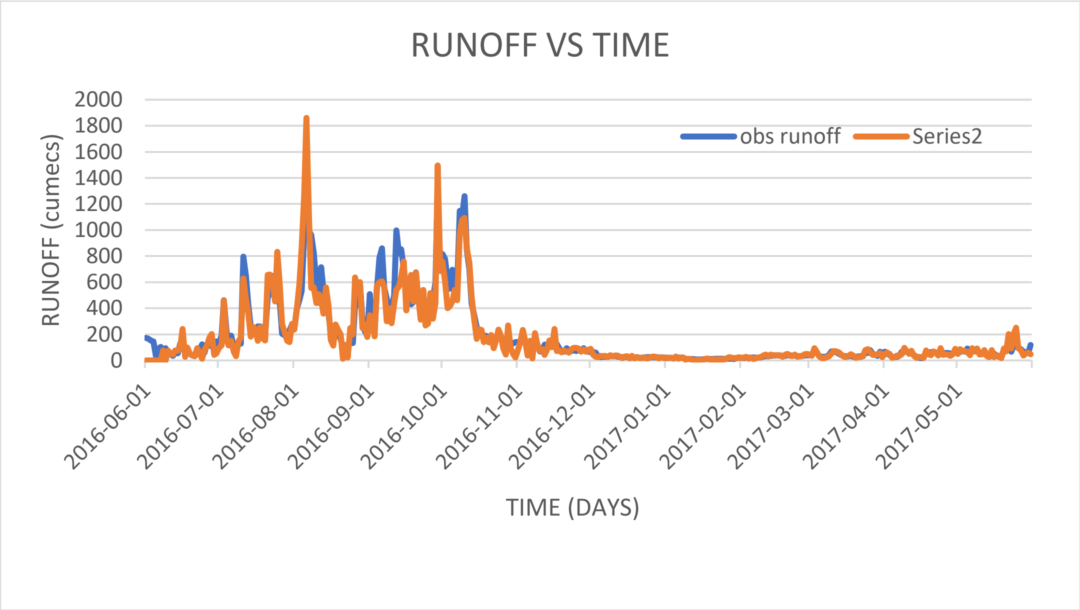

Figure 21 Observed and simulated runoff vs time for calibration period

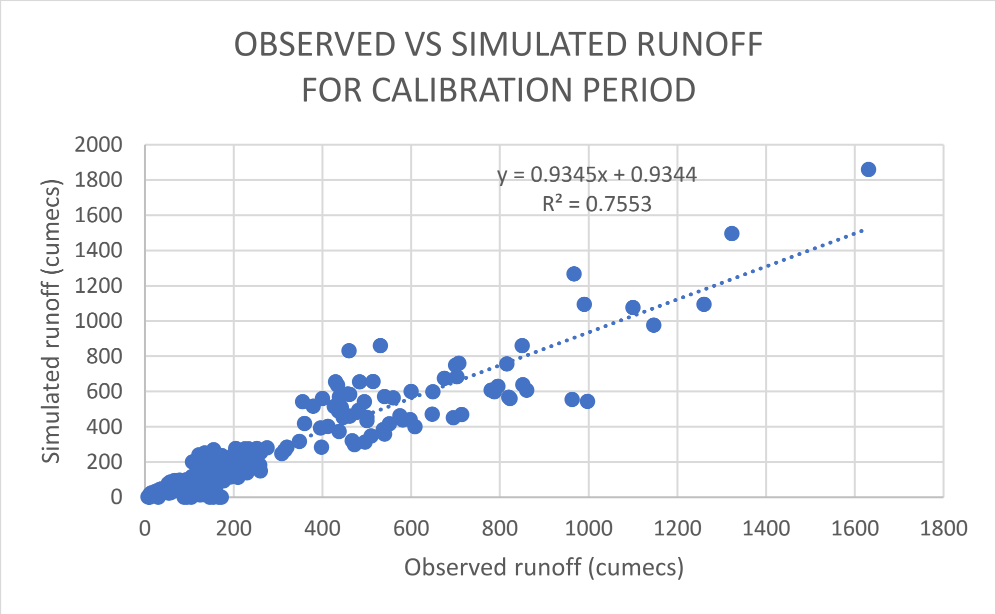

Figure 22 Scattered graph of runoff for calibration period

From the plot it can be observed that from June to January beginning the runoff values are quite high due to the north east and south west monsoon. The season when there is immense rainfall the runoff values are high. After January there is a runoff but its quite less as the rainfall decreases after January. Also it is inferred that the observed runoff values are little bit more than the simulated runoff but the peak values of both simulated and observed are almost same. The peak runoff has reached to nearly 1900 cumecs in august. The calibration was done for a total of 365 days from 1st of June 2016 to 31st of may 2017.

Validation Period Of Runoff (01/06/2017 to 31/05/2018)

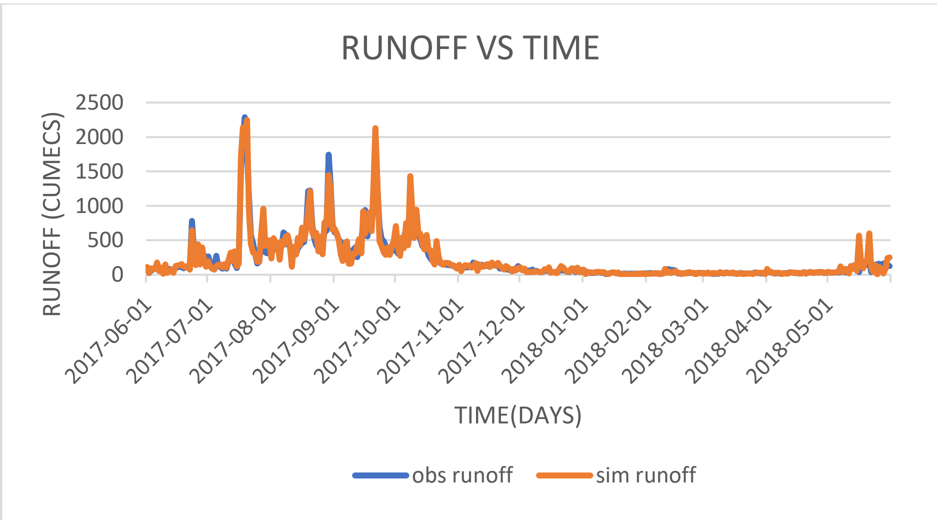

Figure 23 Observed and simulated runoff vs time for validation period

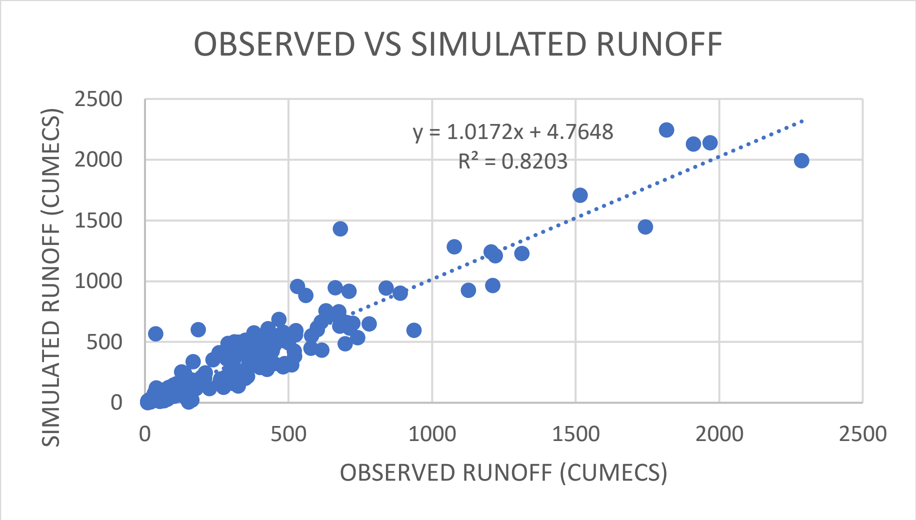

Figure 24 Scattered graph of runoff for validation period

From the plot it can be observed that june to October the values of runoff were quite high due to the presence of rainfall. The peak runoff was seen in between July and august and has a value of about 2300 cumecs. Here also similar to calibrated graph the values of observed runoff is seen little more than the simulated runoff. The r^2 value obtained for the graph is 0.82. The graph is plotted for 365 days i.e. from 1st June of 2017 to 31st may 2018. It can be said that the values simulated were less than the observed values.

Calibration Period Of Sediment loss (01/06/2016 to 31/05/2017)

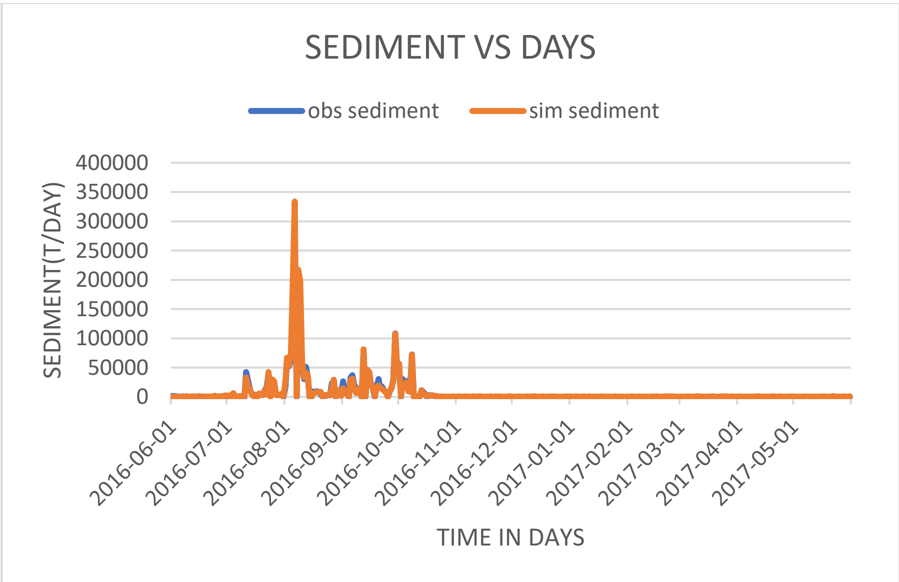

Figure 25 Observed and simulated sediment loss vs time for calibration period

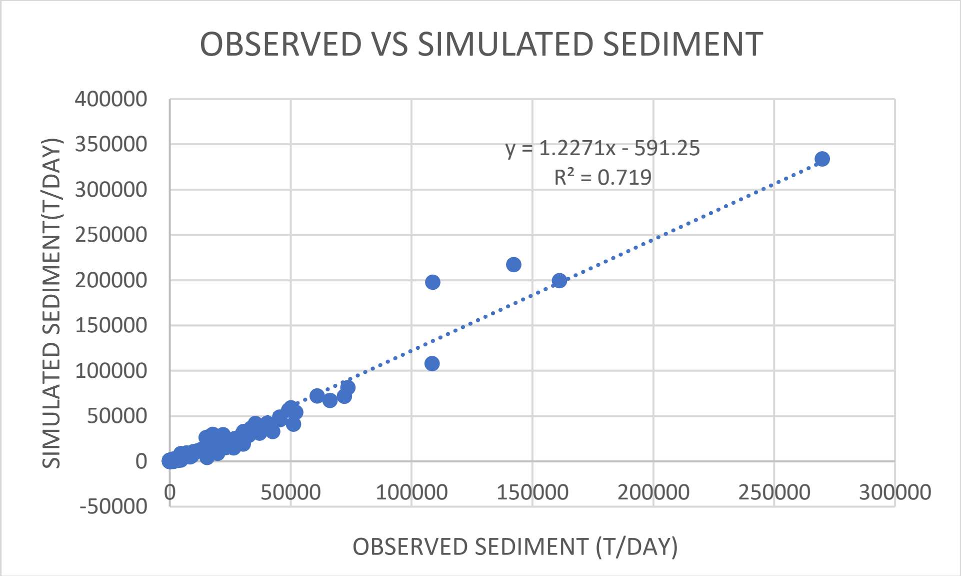

Figure 26 Scattered graph of sediment loss for calibration period

The sediment loss was calibrated for 365 days, from 1st June 2016 to 31st may 2017. It can be observed that the sediment values are high when the runoff is maximum which means more rainfall. The period of July to January is showing the sediment values when the rainfall is maximum. The peak value of observed sediment loss is 269899 t/day and the simulated sediment loss is 333789 t/day which means that observed peak sediment loss is less than simulated sediment loss. In other days for maximum days the observed values are more than the simulated values. The r^2 value obtained is 0.719 and the equation is y = 1.2271x - 591.25.

Validation Period Of Sediment loss (01/06/2017 to 31/05/2018)

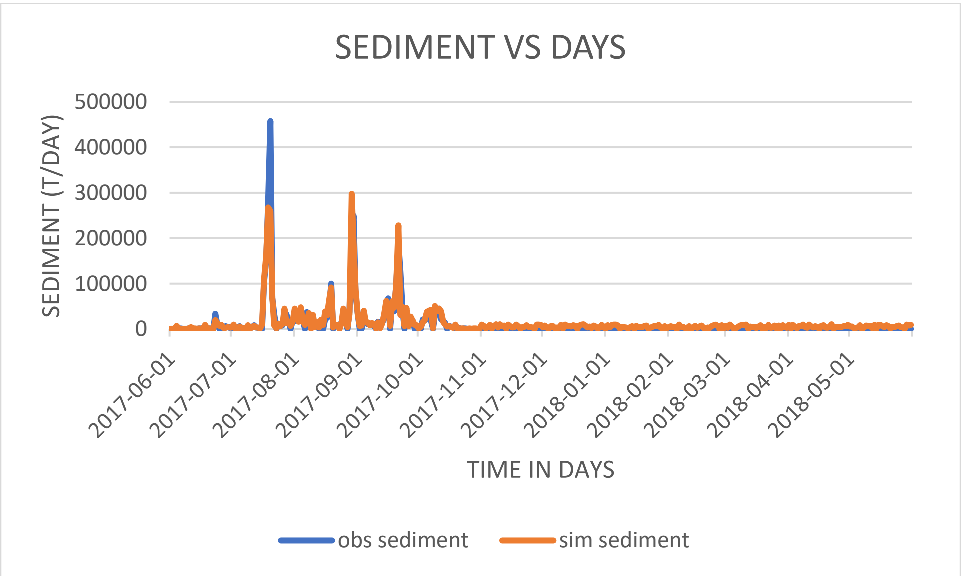

Figure 27 Observed and simulated sediment loss vs time for validation period

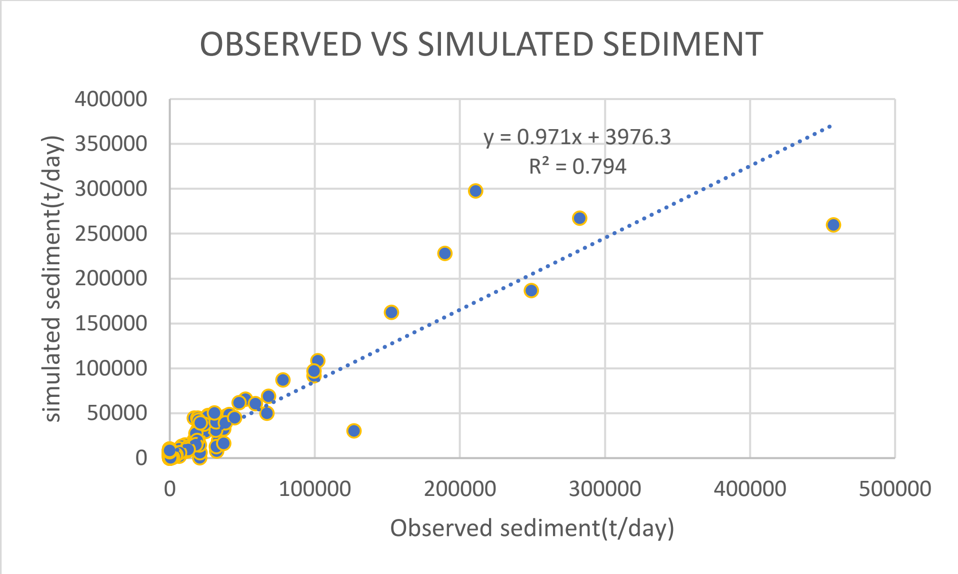

Figure 28 Scattered graph of sediment loss for sediment loss period

The sediment loss was validated for 365 days, from 1st June 2017 to 31st may 2018. It can be observed that the sediment values are high when the runoff is maximum which means more rainfall. The period of July to January is showing the sediment values when the rainfall is maximum. The peak value is observed in between July and august. The peak value of observed sediment loss is 457673 t/day and the simulated sediment loss is 259623 t/day which means that the peak observed sediment loss is more than simulated sediment loss. In other days for maximum days the values simulated are more than values observed. The r^2 value obtained is 0.794 and the equation is y = 0.971x + 3976.3.

Table 16 sediment and runoff r^2 values

R^2	Runoff	Sediment
Calibration	0.75	0.71
Validation	0.82	0.79

5.5 Comparison of Soil Loss from SWAT and USLE

Table 17 Soil loss comparison between USLE and SWAT

Model	Observed sediment loss(million tonnes)	Simulated sediment loss(million tonnes)	Observed soil loss(million tonnes)	Simulated soil loss(million tonnes)	Error in million tonnes
SWAT	0.3652	0.415	0.961	1.092	0.131
USLE	0.3652	0.3081	0.961	0.801	-0.16

The soil loss estimated from SWAT and USLE were 1.092 million tonnes and 0.8363 million tonnes. The observed soil loss is seen to be 0.961 million tonnes which was provided by Annual Sediment Report of CWC (Central Water Commission). The USLE model underestimated the value by 0.16 tonnes whereas the SWAT model has overestimated by 0.131 tonnes. When we see as a whole the error is seen less in SWAT. One reason can be in SWAT more meteorological data is used for soil erosion estimation.

CHAPTER-6 SUMMARY AND CONCLUSION

6.1 Summary

Soil plays a significant role on the earth and conservation of it is necessary. The human interference is leading to increase the pace of soil loss. The effects of soil disintegration are mainly on reduction in production of agriculture and also on quality of soil. Water ways can be blocked resulting in affecting the quality of water. Due to soil loss, the components that are need for agriculture is lost, leading to mass starvation and ecological collapse. The cultivable part of the land is comparatively more prone to erosion. Soil erosion can also affect big projects such as drainages, dams, and embankments. The sediment accumulation in reservoirs decreases the efficiency and operational timeperiod. Also, the silt up support life of plants that causes cracks and structures gets weak. Soil erosion due to water results in cracks on roads, especially if proper stabilizing techniques are not used.

The soil loss was estimated using both USLE and SWAT. For the DEM image was obtained from USGS website which was then used for delineation. For USLE different factor maps were created like K, LS, R, P & C and then overlay analysis was performed in ArcGIS using raster calculator. For SWAT the soil, slope and land use classes maps were generated and given as input and then rainfall and temperature data are noted which leads to the creation of HRU's and then the output is generated. The output obtained is then utilised for calibration and validation in SWAT-CUP where 21 parameters were used. This work has been helpful in determining the most impacted areas of the watershed

6.2 Conclusion

- For the validation period soil loss estimated from SWAT and USLE were 1.092 million tonnes and 0.8363 million tonnes. The observed soil loss is seen to be 0.961 million tonnes which was provided by Annual Sediment Report of CWC (Central Water Commission). The USLE model underestimated the value by 0.16 tonnes whereas the SWAT model has overestimated by 0.131 tonnes.
- The parameters used in SWAT CUP were CN – Runoff curve number ALPHA_BF , GWQMN, GW_DELAY, ESCO , EPCO, GW_REVAP, SOL_AWC, CH N2, RCHRG_DP, CH K2, OV_N, SURLAG, CH K1, USLE_P, CH_COV
- From the result's analysis it can be inferred that soil erosion was high in places where the slopes are high and the places where more rainfall has occurred. Both the north east monsoon and south west monsoon caused rainfall here in this region.
- The r^2 value for calibration and validation of runoff is 0.75 and 0.82 and for sediment is 0.71 and 0.79.

- Conservation practices are necessary as the problem of soil erosion is increasing day bay day. Some of the conservation practices include crop rotation which is growing of crops in succession without leaving the field left idle. As leaving the field idle leads to soil getting eroded. So in this period grasses or any crop is grown. This helps regaining soil lost minerals. Terrace farming- In hilly areas, along the slope steps are made and farming is practiced results in slowing down the flow of soil and water. The removed soil is deposited in the next step. Therefore, the soil never get's lost. Zero tillage needs to be practiced

6.3 Scope For Future Work

- Individual factors effect can be seen like how they are impacting.
- Prioritizing high risk areas of soil eroded and suggesting conservation practices for that areas.
- Soil loss can be estimated using other models too.

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