HYDROLOGICAL MODELLING OF NARMADA RIVER USING ArcSWAT SOFTWARE

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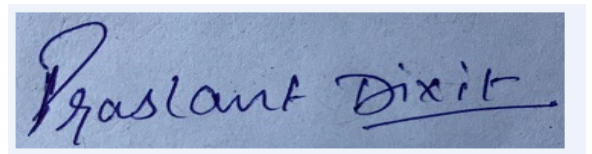
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CANDIDATE'S DECLARATION

I, PRASHANT DIXIT (2K19/HFE/18) of M.Tech (HYDRAULICS AND WATER RESOURCE ENGINEERING), hereby declare that the Project Dissertation titled " HYDROLOGICAL MODELLING OF NARNADA RIVER USING ArcSWAT SOFTWARE" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi is submitted in partial fulfillment 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 the award of any Degree, Diploma Associate-ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation entitled "HYDROLOGICAL MODELLING OF NARNADA RIVER USING ArcSWAT SOFTWARE " which is submitted by PRASHANT DIXIT (2K19/HFE/18) of M.Tech (HYDRAULICS AND WATER RESOURCE ENGINEERING), Delhi Technological University, Delhi submitted in partial fulfillment of the requirement for the award of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 4/08/2021

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Table of Contents

Abstract

A major source of water supply and ground water recharge in the central India is the Narmada River, which flows through the states of Madhya Pradesh, Maharashtra, and Gujarat in central India. As a consequence, it follows that better planning for watershed management and water resource management may be implemented after accurate modelling of hydrologic processes. This research on the Middle Narmada basin used the SWAT (Soil and Water Assessment Tool). The primary objective of this study is to extract parameters for runoff modelling and to forecast runoff in the Middle Narmada basin. The right DEM, land use, soil type, soil properties, and hydro-climatological data were collected for SWAT simulation. For 15 years, the SWAT model was simulated by providing all input data (1995-2010). Over the course of a year, the annual average surface runoff is 254.79 mm. The SUFI-2 calibration and validation process was used to the model. The model's sensitivity study to sub-basin delineation and HRU definition thresholds revealed that the flow is more sensitive to the HRU definition thresholds than the sub-basin discretization effect. While SWAT was shown to be accurate with their predictions, the accuracy of their daily stream flow estimates in the Middle Narmada basin has not been established. In the future, stream flow and soil erosion may be studied using the calibrated model while implementing other types of management scenarios, as well as a changing climate.

Nomenclature

IMD	**India Meteorological Department**
CWC	**Central Water Commission**
GIS	**Geographic Information System**
RS	**Remote Sensing**
QPF	**Quantitative Precipitation Forecast**
BCM	**Billion Cubic Meter**
MCM	**Million Cubic Meter**
Sq. Km.	**Square Kilometre**
CGWB	**Central Ground Water Board**
NBSS & LUP	**National Bureau of Soil survey & Land Use Planning**
NRSA	**National Remote Sensing Agency**
DEM	**Digital Elevation Model**
ASTER	**Advanced Space borne Thermal Emission and Reflection Radiometer**
SWAT-CUP	**Soil and Water Assessment tool- Calibration Uncertainty Program**
95PPU	**95% Prediction Uncertainty**

List of Symbols

M^3	Cubic metre
M	Metre
M^3/day	Cubic metres / day
MM	Millimetres
Min	Minutes
Fig	Figure
%	Percentage
cu kms	Cubic Kilometers
Cm	Centimetre
et al.	And others
m/a	Metres per annum
^{o}C	Degree Celsius
Km	Kilometre
Km^2	Square Kilometre
Tmin	Minimum daily Temperature
Tmax	Maximum daily Temperature
=	Equals to
m/s	Metre per second
Vs	Versus

List of Figures

Chapter 1

Introduction

1.1   Background

The term hydrology is made up of two parts: "hydro" and "logy." "Hydro" is Greek for "water," and "Logy" is Greek for "science." Hydrology is the science of water, and it is described as the study of the origin, distribution, and characteristics of water on the world, including water in the sky as water vapor, on the surface as water, snow, or ice, and under the surface as water, snow, or ice. Hydrology is therefore bounded by meteorology above, geology below, and oceanography at the land's end.

Shortage and abuse of new water represent an expanding and huge danger to supportable turn of events and the safeguarding of the climate. Wellbeing and prosperity, sanitation, modern turn of events and the environments on which they are reliant are completely jeopardized, except if water and land assets are better overseen in the following decade than previously" (ICWE, 1992).

"Water is one of the world's most important components. Water is needed for all plants and animals to survive. If there was no water, there would be no life on the earth. In addition to drinking it to keep it alive, people use water for a number of other reasons. India is the second most populous nation in the world. By the middle of the century, a further billion people will have to be fed. Second, India has a huge economy and a spectacular economic growth in the last decade. The growing economy is changing people's purchasing habits; increasing urbanization is also driving these developments. Food consumption patterns are changing so quickly that they have a significant impact on future demand for food and water. In India there are significant geographical inconsistencies in population and water resources"[7].

Where more people are present and more of the food is grown, less water is accessible. There is already physical water shortage in many river basins. Inadequate use of groundwater is of concern to a few others. Consequently, many recent estimates on food and water demand worldwide (IWMI 2000) and nationally concentrate on how India responds to its growing need for food and water.

Use	Year			
	2010	**2020**	**2030**	**2040**
Irrigation	534	567	628	817
Domestic	40	53	72	121
Industry	40	47	77	91
Power	10	29	43	80
Ecology	10	15	20	30
Evaporation	46	52	60	86
Total	**680**	**763**	**900**	**1225**

Table 1: India's water demand (Cu Kms.) for various applications

Hydrology in it's simplest form is the study of earth's cycle movement as well as the transportation of water contents such as sediments and pollutants, as it flows. Hydrology might instead be described as an applied science concerning the occurrence, distribution and circulation of the waters of the world. It is also a distinct geo-science with a highly interdisciplinary nature. Whereas hydrology focuses on water and its cyclical transmission through the ecosystem, it enables a more global perspective to better comprehend the interdependence and interaction between water, the environment and human activities (Watson and Burnett, 1995).

In reality, it may be time consuming and expensive to determine numerous variables interacting in a hydrological process. For example, it is difficult to determine the amount and quality of water in the field. Excessively difficult to assess field runoff, silt load, pesticide effects, evaporation and other factors. The short- and long-term effects on the environment of natural variables, including temperature, precipitation, solar radiation, land use and land use changes, are often assessed by hydrologists, local geographers and agricultural development planners. The only feasible method would be to use an accurate hydrological model. Suitable data input and technical know-how are often utilised to create effective decision-making using hydrological models. As a consequence, it is essential to have both reliable data and a hydrological model.

In recent years the input data's uncertainties have been assessed in order for decision-makers to establish the confidence level when utilizing the model to make management decisions. This is non-negotiable when it comes to sensitive management decisions that have both human and economic consequences.

Hydrological process

As seen in Figure 1, the hydrological procedure is a natural mechanism in which water cyclically flows between land, atmosphere and ocean. Human activities interrupt natural cycles, which now pose a danger to human existence on the planet.
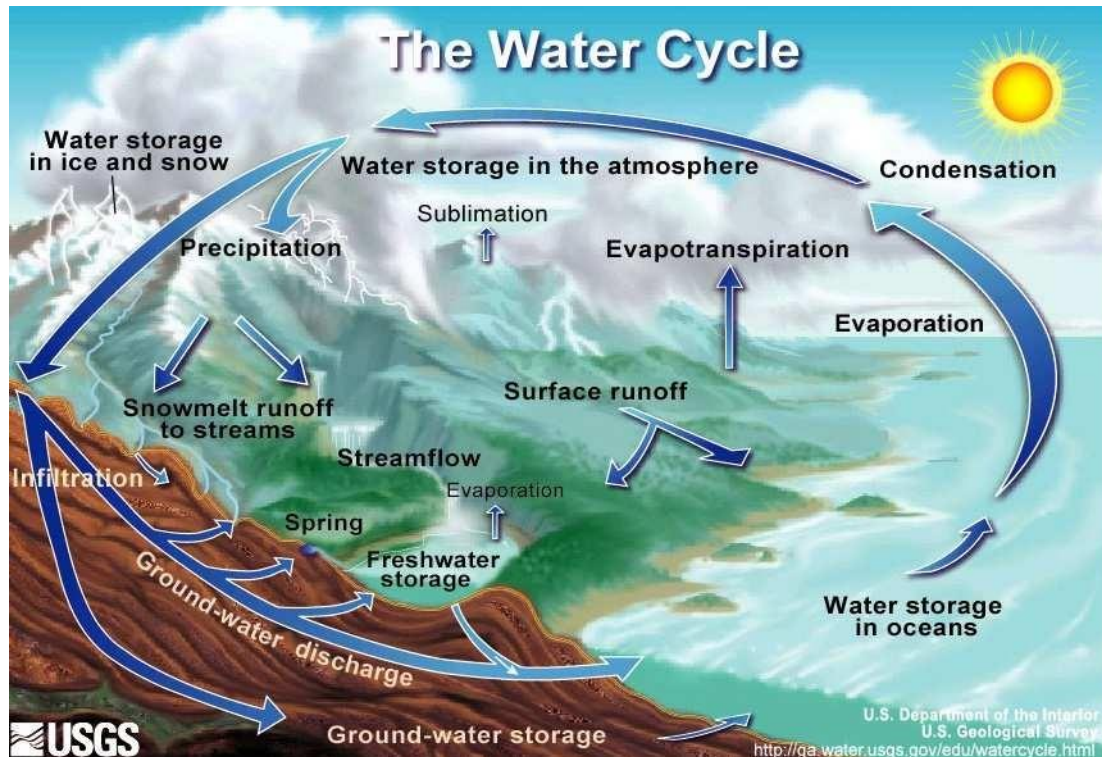
Figure 1: A typical watershed's hydrological process.

A mathematical model may be used to describe or simplify the hydrological cycle, which is made up of numerous natural phenomena that interact (Yevjevich, 1972a; 1972b). The processes that are reflected in the hydrological cycle, according to Uhlenbrook (2006), are as follows:

- Interception, - Precipitation (including utilisation by ecosystem, man and irrigation),

- Plant uptake and absorption into soil materials (including percolation)

- The flow of water from shallow to deep aquifers

- Evaporation, transpiration, and seepage; - Surface and subsurface flow; - Water losses by evaporation, transpiration, and seepage.

The study of hydrology is particularly interested in the last phase of the cycle, i.e., the water's journey from when it falls on the ground to when it is discharged into the sea or returns to the atmosphere. Plants may intercept or transpire precipitated water, flow over the ground surface and into streams, or penetrate into the earth. Evaporation returns a large portion of the collected and transpired water, as well as surface runoff, to the air. The infiltrating water may penetrate deeper zones and be stored as ground water, which may then flow out as springs or seep into streams as runoff, run to the sea, and then evaporate into the atmosphere to complete the hydrologic cycle.

The sun is the primary source of electricity for this massive natural waterworks system. Solar radiation elevates the temperature of air, soil, and water, causing some of it to evaporate and be transported as water vapour to land surfaces at higher elevations. The potential energy is obtained when, following the condensation of the vapour, the water flows deviously across the ground and through the soil and rocks in response to the pull of gravity.

Evaporation of water from the soil, either directly or by the action of plants, activates another force, the capillary force, which is the molecular attraction of soil particles to water. Thus, beneath the soil, there are two main forces that create water movement: gravity and capillary, and these two forces frequently conflict and counterbalance one other.

It is important to differentiate between surface and subsurface flow. Surface flow refers to water that flows through the surface of the earth such as rivers or surface runoff, whereas sub-surface flow refers to water moving through the components of the earth. Since these components of the Earth are varied, their flow tends to choose the route with the least resistance.

Since the early 1960s, water resource planning, management and decision support systems have been used in mathematical models. Longer records in hydrological modelling usually give rise to improved model representation in the industrialized world owing to robust data collection processes, but in developing nations like India, poor data quality and intermittent data recording were frequent.

Methods of Hydrological Modeling

Mathematical models are utilized every day, mostly to overcome decisions. The rational formulation method is one of the oldest types of hydrological models (Mulvaney, 1851). The flux flow rate in small catchments is a quantitative expression in relation to rainfall and watershed size. The method was based on the idea of 'concentration time,' that relates to the time it takes to drain water from the furthest point in the area to the outlet. On the basis of an overlay, Sherman (1932) developed the concept of hydrography.

In relation to the transition from precipitation to runoff, the catchments function as a linear, dynamic, cause system of time variation according to this concept of superposition. The system approach was employed in the 1960s and 1970s to analyses complex dynamic systems (Lewarne, 2009). The answer function was developed from an input and output data analysis and was represented using mathematical formulae.

The response function of the system was irrelevant. During this time, computers became more widely accessible and powerful enough to contribute significantly to the modelling process. A number of hydrological methods are available that may be categorized on the basis of the addressed pollutants, the complexity of contaminant sources, whether the model is stable or dynamic and the period under consideration. Another consideration in selecting a model is whether it is distributed or lumped (i.e., able to forecast a number of locations within a river).

Models that are "deterministic" in nature

"These models are based on complex physical theory and need considerable data and computational effort. The development and operation of the models is therefore very costly (Liddamentet. Al., 1981). The hydrological processes are represented in the distribution of these models by non-linear component differential equations. It should be emphasised that there are seldom analytical solutions to the equations.

Partial differential equations, including the demanding and time-consuming approach for finite differences (Freeze, 1971), finite element method (Beven, 1977; Rosset al., 1979), integral finite difference and border integral techniques, must thus be employed. Some simplifications were made and instead the idea of cinematic waves was utilized. These

models can reproduce the whole runoff and the consequences of catchment changes that are extremely helpful in the management of resources"[11]. One of the main benefits of deterministic models is that such models provide an internal vision of the process which makes it possible to better comprehend the hydrological system.

Stochastic Models

Stochastic hydrological models produce results from inputs that use mathematical concepts and statistical principles. Models based on the principles of neural networks, regression analysis methods, etc (Lewarne, 2009). These models are frequently used for predicting water resources, where precipitation, fluctuation and a history of humidity are linked**.**

1.2   Problem Statement

The accessibility of water is fundamental for human prosperity and efficiency. A huge number of individuals presently have deficient admittance to safe drinking water. While these individuals are broad around the world, they experience such genuine deficiencies inferable from sub-countries in water supplies that they are delegated water-care or water-stress; this is generally because of expanded interest because of financial and populace development. Interestingly, environmental change might worsen periodical and constant water deficiencies and increment dry season recurrence and seriousness in specific areas. Changes in local hydrological cycles and along these lines changes in waterway stream systems might be perhaps the main environmental change impacts possible.

These hydrological changes will impact on essentially every part of human prosperity, from agribusiness yield and energy use to different areas. Water stockpiling, in any case, builds the limit of provincial destitute individuals to manage climatic shocks by boosting agrarian yield and diminishing instability. Since soil stockpiling is significant for horticulture and impacts genuine vanishing, groundwater re-energizes and surging out, the impact on agribusiness and other hydrologic patterns of environmental change.

The proposed research uses factual strategies to decide the reactions of accessibility of soil water and agrarian creation to a scope of environmental change situations. It furnishes all

partners and policymakers with fundamental data to empower them make imaginative capacity and efficiency thoughts as a reaction to stresses over environmental change and take suitable decisions.

1.3   Research Question

- Is it feasible to calculate the effects of a sub-basin HRU (Hydrologic Response Unit) on the main River Basin?

- What role do the various influencing parameters have in the Stream flow?

- Parameters that can be influenced:

    - Slope, Topographic-DEM

    - LU/LC Terrain, Soil Type, and Soil Moisture

    - Temperature, Precipitation – Meteorological

1.4   Research Objective

- The aim of this study is to use GIS methods to forecast the hydrology of the Middle Narmada Basin using the SWAT model.

- The study consists of

    i.   This Research aims to evaluate possible changes in the mid-Narmada basin surface runoff.

    ii. The effects of changes in land use on runoff are assessed using an integrated approach integrating SWAT models, remotor sensing and GIS techniques.

    iii. Use the ArcSWAT HRU tool for land use, soil type, and slope demarcation.

    iv. To examine how HRU impacts the performance of the SWAT model.

    v.   The automated calibration method was used in the calibration and validation of the basin SWAT flow model.

    vi. To assess the hydrological water balance of the Middle Narmada Basin

1.5 Software Used

- ArcMap

- ArcSWAT tool

- SuperGIS 3.1

- ERDAS Imagine 9.1

- Microsoft Office

- Acrobat Reader

Chapter 2

Literature Review

2.1 Hydrological Modelling

Hydrological models are important for the analysis of climate change and water balance (Singh et al., 1995). As a consequence, they enable the assessment and management of water resources while rewarding several alternative outcomes. A variety of sophisticated and sized hydrological models are now available from basin-scale models to macro-scale models such as ECOMAG (Rajat et al 2000; Motovilov etal 1999) which approach a GCM scale (105 km2) (Yuri et al 1999). Some of the most frequently used distributed hydrological models include MIKE-SHE (Abbott et al 1986), TOPMODEL (Beven and Kirkby,1979 and 2000), WATBAL (Knudsen et al 1986) and HMS (Capehart and Carlson 1994).

The effect of regional climate change on water resources has been investigated in the Rio Grande Basin by utilising a combined atmospheric and groundwater model (Keeley et al 2000). When statistics on precipitation charge are used in a groundwater hydrology model, they provide the basis for modelling spatio-temporal variations in the water table structure (Yu and Schwartz 1995, Yu and Schwartz 1998). Gongbing et al. (2002) released Environmental Modeling and Prediction including short and long-term hydrological modelling and prediction, with short examples of several of its major hydrological models.

The GIS hydrological model SWAT (Rosenthal et al. 1995), has a modular structure and consists of hydrological, sedimentological and chemical subroutines adapting to the watershed dimensions. In the hybrid model, which is spatially based on hydrological response units, conceptual and physical methods are utilised. An essential aspect of SWAT is the overall water balance equation. The method of SCS curve number is used to calculate surface runoff. According to Frede et al, physical soil features have a moderate effect on overall runoff, but have a significant impact on surface runoff in SWAT (2002). In a semi-arid shift, the model was found to be less efficient in anticipating runoff in

connection to the land shift (Hernandez et al., 2000). SWAT was sufficient for the prediction of annual flow volumes, sediment and nutrient loading (Borah and Bera, 2004). Typically, monthly predictions were correct. Except months with strong tempests and hydrological conditions (Borah and Bera, 2004).

Computer-based hydrological models have been developed and deployed at an ever-increasing pace in the past four decades. The primary causes for this are two: (a) new models and methods are being developed regularly by the research community, and (b) the demand for improved instruments is rising in conjunction with increasing pressures on the water resources. Fleming (1975) and Singh (1975) give an assessment of the state of watershed modelling and development patterns over the same era (1995).

2.2   Description of SWAT Model

The USDA-Agricultural Research Service has created SWAT, an instrument for soil and water appraisal (Neitsch et al., 2002). This model has been created to consider watersheds of two or three hundred thousand square kilometers of surface region. Smack is a circulated model that runs and runs continually consistently. Some particular data is needed on the environmental conditions, soil properties, geology, vegetation and land the board strategies and relapse conditions to describe the connection among passage and leave factors (Neitsch et al., 2002).

This model gauges the transitions of water, supplements, pesticides and residue. It has been displayed at numerous watershed events in worldwide history. Numerous factors were pre-characterized based on US information.

Different variables should be adjusted to neighborhood conditions to acquire precise outcomes. The Hydrological Response Unit (HRU), which is the aftereffect of a blend of soil type, land cover class and sub-bowl, is the essential geological estimation unit. For displaying, the watershed should be separated into sub-bowls. To get right outcomes, numerous factors should be changed in accordance with nearby conditions.

The Hydrological Response Unit (HRU) is the primary topographical unit for estimation. It is a blend of soil type, land cover class and a sub-bowl. The watershed should be parted into sub-bowls for demonstrating to work.

Smack is a waterway bowl or watershed model intended to anticipate the effect of land the board strategies on water, dregs and farming items in enormous, complex watersheds with evolving soils, land use and the executives conditions throughout extensive stretches of time (Arnold et al., 1994). The model consolidates experimental and actual conditions, utilizing inputs that are promptly open and empowers clients to look at long haul outcomes.

The eight fundamental parts of the SWAT are hydrology, climate, disintegration and sedimentation, soil temperature, plant development, supplements, pesticides and land the board. Smack is currently being used in an assortment of huge bowl projects. The United States Hydrological Unit Model (HUMUS) project expands on the displaying abilities of SWAT (Srinivasan et al., 1993). The USGS has distinguished around 2,100 hydrologic regions and the HUMUS project recreates the hydrological financial plan and the vehicle of residue for those spaces.

The examination results are used in the appraisal of the Resource Conservation Act (RCA) of the Natural Resources Conservation Service. The situations incorporate arranged horticultural and metropolitan water use, culturing and editing examples and manure and creature squander the executives choices. The NOAA uses the model to gauge non-point source stacks in all U.S. beach front regions as a feature of the National Coastal Pollutant Disposal Inventory. Smack is currently being fused into the US EPA BASINS interface for the evaluation of water bodies with weaknesses.

SWAT uses the curve number method to predict runoff and has gotten a lot of critical assessments (e.g. Hjelmfelt et al., 1982; Bales and Betson, 1982). More study is required to establish the precise predictions of the method. Mishra and Singh (1999) show that, given the addition of two adjustment variables, their expanded version of the method yielded better results than the original formulation.

Hjelmfelt et al (1982) have not found a strong correlation between curve number and anterior condition for specific precipitation events, which means that the associations with the individual characteristics of the storm, labor, plant growth and temperature are sufficient to mask the effects of affecting precipitation. The Curve Number technology is

widely used in spite of its failures because it enables a rapid transition from soil and vegetation data sets (such as a GIS) to a rainfall-runoff model.

2.1 Recent developments in Hydrological Modelling

"Hydrological modelling has progressed considerably in the past three decades. The hydrological research community has significantly benefitted in the past three decades from fast developments in remote sensing, GIS, digital databases and computer technologies. Recently launched satellites like the PM-1 Earth Observing System, RADARSAT, LANDSAT 7 Enhanced Thematic Mapper, Space Imaging, Inc., which has 1-meter IKONOS satellite resolution, and others, allow the extraction of hydrologic data on various time and space scales, for example. Slope, aspect, drainage network and watershed flow direction are estimated using the Digital Elevation Model (DEM) datasets (Hornberger and Boyer 1995). Soil databases such as the National Soil Geographic Data Base of the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS), enable geographic variation of soil characteristics in hydrological models to be included (He et al. 1993; 2001)"[17].

Land cover datasets may be used to construct hydrological models utilising land use/cover related properties, such as a leaf area index, zero plane displacement height and the coefficient (n) values of Manning.

"Although a large number of digital datasets are available, it remains challenging to get input parameters for operational hydrological models, especially for geographically distributed models. For example, precipitation is an essential part of precipitation-runoff models. Because of a lack of spatial and temporal coverage of satellites and rain gauge stations, especially in rural areas, precipitation distribution estimates are still inadequate"[5].

Cloud indexing, thresholding and life history methods for prediction of precipitation by satellite remote sensing are still at the experimental stage (Engman, 1995).

"In sun-synchronous orbits, microwave satellites may provide precipitation estimates just twice daily because they pass anywhere in the earth's area twice a day. While

geosynchronous orbiting satellites such as the GOES can produce precipitation rates at a distance of 30 minutes in the same area of the globe in their field of views, they can only provide limited observations (Engman and Gurney 1991; Engman 1995). Ground-based radar is presently restricted to a measuring circle of up to 100 km and is utilised mainly in inhabited areas (Engman and Gurney 1991; Engman 1995). Estimates of precipitation of these radar stations still need to be calibrated against rain gauge data in the region. Consequently, operational hydrological models must continue to depend for precipitation estimates on poorly distributed precipitation gauges. Because errors in precipitation data provide greater uncertainty in parameter estimations than errors in runoff data (Borah and Haan 1991), it is important that countrywide observations on spatial and temporal precipitation distribution are increased in order to improve precipitation-runoff modelling"[11].

New ground-based radar stations in rural areas are being explored for a more comprehensive coverage of the United States. It is a long-term possibility to develop precise methods to estimate precipitation from visible, infrarot and microwave satellites. "In contrast to precipitation networks, there is virtually little systemic monitoring of solar radiation and surface temperature throughout the United States.

 While techniques are available to calculate solar energy and surface temperature from the visible and thermal bands of the satellites. A federal agency such as The USA, the US Geologic Survey or the National Oceanic and Atmospheric Administration (NOAA) should lead the way in collecting and analysing satellite data, extracting hydrologic metrics including net radiation, precipitation and surface temperature in order to help hydrologers overcome the obstacles to using remote sensing data for operational reasons"[10]. This will result in the increased use of remote sensing data in hydrological modelling and save enormous amounts of money both for space institutions and management agencies.

Chapter 3

SWAT MODEL

3.1 Definition

Dr. Jeff Arnold developed for the USDA Agricultural Research Service the Soil and Water Assessment Tool (SWAT) in 1985. It is a river basin or model in size. SWAT has been developed to predict the effect on water, sediment and agriculture chemical production of land management methods over long periods in large complex watersheds with changing soils, land use and managerial conditions. ArcSWAT (Winchell, 2007), a SWAT-connected version, enables the user to prepare the SWAT input and run the model inside the ArcGIS framework (Winchell, 2007)

.3.2 SWAT's Basic Features

- SWAT is a spatially discrete, time- and long-term model with a continuous yield. The model is not intended to carry out one-event floods. Compared to other modelling systems, SWAT provides many distinct features I have taken iv from the SWAT Manual, Neitsch, 2005):

- SWAT is an association based on methodology. Rather than using relapse models to describe the association among info and yield factors, SWAT requires explicit data about the climate, soil properties, geography, vegetation, and ground the board techniques in a watershed.

- SWAT benefits from information accessible to the public. While SWAT may be used to investigate more specialised processes such as bacterial migration, government entities are easily able to obtain minimal data needed to conduct a run, such as precipitation and temperature data.

- The cost of SWAT is cheap. Simulations of extremely large basins or a variety of management methods may be conducted without consuming too much time or money.

- SWAT enables users to examine long-term impacts. Many of the problems now faced by users involve the gradual buildup of pollutants and their impact on downstream water systems. Results from runs without output over many decades are necessary for this kind of problem to be examined. (Switzerland, 2005).

3.3 SWAT's basic modelling approach

Mass conservation is the fundamental assumption of hydrological modelling. The modelling of hydrology of a watershed may be split into two groups. The first segment of the hydrological cycle is the land phase. The water, sediment, nutrient and pesticide intake in each sub-bassin is regulated by the land phase of the hydrological cycle. The second stage of the hydrologic cycle is the routing phase, which is represented by the output channel system as the movement of water, sediments and other materials (Neitsch, 2005).

Watersheds in SWAT are separated into sub-bassins, each divided into many hydrological response units (HRU). The location of the sub-basin and its connection defines the sub-basin division. Soil types, land use conditions and plant and landscape variables are used to categorise HRU. The water produced by HURs helps to reach the highest point of the main river in the reservoir. River geographically reaches sub-basins. Each sub-water basin is then carried via the stream network.

The earth phase shows water cycles inside sub-bases, whereas the routing phase shows water movement between sub-bases.

3.4 The Hydrologic Cycle's Land Phase in SWAT

Note: This section is quoted and summarized from SWAT Manual

1. **Water Balance**

   SWAT simulates the land phase of the hydrologic cycle using the water balance equation 1 (ArcSWAT2005 Manual):

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \ldots..(1)$$

   Where t = time,

                     i= time index

                     SW_t = final soil water content on day i,

                     SW_o = initial soil water content on day i,

                     R_{day} = amount of precipitation on day i,

Q_{Surf} = amount of surface runoff on day i,

E_a = amount of evaporation on day i,

w_{seep} = amount of water entering the Vadose zone

from the soil profile on day i,

Q_{gw} = amount of return flow on day i

The dampness content of the dirt not really settled utilizing the accompanying condition. Since soil dampness stockpiling is the essential focal point of this examination, this proposition gives a short clarification of a few significant parts of the model. The following segments give more depictions of the various parts of the model (Neitsch et al., 2005). Soil water might move from numerous points of view, including upwards, downwards (permeations), upwards or along the side (plant assimilation) (adding to stream). As an outcome of plant retention, the most segment of water that enters the dirt profile is dispensed with through vertical development.

The dirt water volumes are commonly estimated as a level of the water volume or mass, or as the potential for soil water. In any case, the dirt water content relies extraordinarily upon the water balance esteems set out in condition 1. Precipitation is normally used as a wellspring of soil water, with overflow, genuine evapotranspiration, and precipitation ground water prompting soil water accessibility. The SWAT model hence estimated the dirt water content (SW) esteem as per the previously mentioned water balance information.

The content of water, on the other hand, does not necessarily represent the amount of water accessible to plants or how the soil profile flows. The water content gives simple information on the relative quantity of soil water. The soil water dynamics may be likened to sponge dynamics.

When a sponge is soaked in water, any excess water comes down when drawn from the water. This is the same as soil macro pores drainage. After it stopped leaking, the sponge has achieved field capacity.

The downstream water movement in the soil is called percolation. Percolation should be

estimated using SWAT for every soil layer in the profile. Water can only be percolated when the water content exceeds the field capacity of that layer (Neitsch et al., 2002).

Horizontal streams are normal in regions with a high pressure driven conductivity in surface layers and an impermeable or semi-porous layer at a shallow profundity. Precipitation permeates upward to the roosted table of water and is the wellspring of water for the horizontal floor stream. Smack joins a film stockpiling subsurface stream model (Neitsch et al., 2002).The most noteworthy volume stream rate through a particular spot during a tempest occasion is known as the pinnacle release or pinnacle surface spillover rate. Smack utilizes an adjusted reasonable procedure to decide the pinnacle spillover rate. The sane methodology accepts that a precipitation of force I starts at time t = 0 and proceeds always, with the pace of overflow expanding until t = t_conc.

The modified rational approach is represented mathematically as

$$Q_{peak} = \frac{a_{tc}*Area*Q_{surf}}{3.6*t_{conc}} \qquad \text{.......(2)}$$

Where, Q_{peak} = peak runoff rate (m3/s),

a_{tc} =fraction of daily precipitation that occurs during the time of concentration,

Q_{surf} = surface runoff (mm),

area = sub-basin area (km²),

t_{conc} = time of concentration (hr), and

3.6 = conversion factor.

Potential Evapotranspiration

"There are many techniques established to estimate potential evapotranspiration (PET). The technics Penman-Monteith (Monteith, 1965), Priestley-Taylor (Priestley and Taylor, 1972) and Hargreaves all form part of SWAT (Hargreaves et al., 1985). We selected the Hargreaves technique for this study due to lack of meteorological data such as wind

speed and sunlight hours for the other two methods"[8]. As a consequence, imputed temperature, precipitation and relative humidity weather data are utilised to generate such weather data as wind velocity and radiation during models that employ weather generators.

Surface Runoff

There are two ways for estimating surface runoff. The SCS curve number process and the Green [7] & Ampt infiltration method are both used by the USDA Soil Conservation Service (Green and Ampt, 1911). The SCS curve number technique will be utilised to estimate surface runoff in this investigation. Equation 3 describes the SCS curve number.

$$Q_{surf} = \frac{(R_{day}-I_a)^2}{(R_{day}-I_a+S)} \text{ for } R_{day} > I_a \dots\dots\dots\dots [3]$$

Where Q_{surf} = accumulated runoff (mm),

R_{day} = precipitation depth for the day(mm),

I_a = initial abstraction(mm),

S = retention parameter (mm).

$Q_{surf} = 0$, **for** $R_{day} \leq I_a$.

The initial abstraction is related to S by the equation.

$$I_a = fi * S$$

Where, fi = initial abstraction ratio.

The worth of fi shifts in the scope of 0.1 and 0.3, the worth of fi has been created for dark soil district for Indian conditions as 0.3 for AMC-I and 0.1 for AMC-II and III (Hand book of Hydrology, Ministry of Agri., 1972). By and by, the spillover Curve Number (CN) (Mishra and Singh, 2003) is utilized to register S in mm as,

$$S = \frac{25400}{CN} - 254 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots [4]$$

The permeability of the soil, landuse, and antecedent soil water conditions all influence the SCS curve number. Three antecedent moisture conditions are defined by SCS: 1 – dry, 2 – average moisture, and 3 – wet. In dry conditions, the moisture condition 1 curve number is the lowest value that the daily curve number can reach.

Equation is used to determine the curve numbers for Antecedent moisture conditions (AMC) 2 and 3

$$CN_1 for AMC - I = 0.39 * CN_2 * \exp(0.009 * CN_2)$$

$$CN_3 for MAC - III = 1.95 * CN_2 * \exp(-0.00663 * CN_2)$$

2. Modules

Each module represents a certain collection of processes, such as external forcing and system characteristics. Climate and land usage are examples of external forces. Parameters used to specify system characteristics are :

i. Climate

The watershed environment influences the general meaning of the various segments of the hydrological cycle by providing the water offset with dampness and energy input. The factors required for SWAT were day by day precipitation, greatest/least air temperature, sun radiation, wind speed and relative mugginess.

ii. Hydrology

Precipitation in plants may be intercepted and maintained or fall to the earth's surface as it falls. Water on the surface of the soil either flows into the profile of the soil or runs off the surface. Runoff flows quickly to the stream channel, adding in the short term to stream responsiveness. It may be held in the ground and subsequently evaporated or transpired, or it can be reached via subterranean paths to the surface water system resulting to delayed reaction or basic flows.

iii. Land Use\Land Cover

SWAT replicates all land cover types using a single plant growth model. The

model can identify annual and perennial plants. The plant growth model is used to estimate the amount of water and nutrients lost, the amount of transpiration and how much biomass/rend is generated from the root zone.

iv. **Erosion**

The Modified Universal Soil Loss Equation (MUSLE) for each hydrologic reaction unit is utilized for ascertaining disintegration and residue yields; (Willams, 1975). MUSLE utilizes the measure of spillover to impersonate disintegration and residue yield. The hydrology model gives the surge volume and pinnacle surge gauges, combined with the subbasin region to register the surge erosive energy variable.

v. **Management**

Smack empowers the client to foster administration rehearses at each HRU. The client might choose the beginning and end dates and the time and amount of manure, pesticide, water system and work. for the development season. Toward the finish of the developing season, biomass might be collected from the HRU for yield or left on a superficial level as a buildup.

Notwithstanding these essential administration methods, brushing, programmed compost and water applications and the fuse of the executives decisions for water use are additionally advertised. The combination of calculations to appraise metropolitan silt and supplement loads is the most recent improvement in land the board (Neitsch, 2005).

3.5 Hydrological cycle's routing phase in SWAT

The flows and loads are routed via the stream network once SWAT has determined the loading of water, silt, nutrients, and pesticides to the main channel. SWAT mimics the change of chemicals in the stream and streambed, in addition to keeping track of mass movement in the channel.

i. The Routing of the Main Channel

The four components of the main channel routing include waters, sediments, nutrients and organic substances.

The channel is directed using a variables storage coefficient technique or the "Muskingum routing method (Neitsch, 2005). SWAT estimates deposition/degradation by stream power, which controls sediment flow in the channel. The water quality component of the model controls the conversion of nutrients in the stream. The total pesticide load in the channel is broken down into dissolved and sediment associated components, transported by water and affected by the transport/deposition of sediments"[2].

ii. Reserviour Routing

The water balance of reservoirs includes input, outflow, surface precipitation, evaporation, water drainage and diversion from the bottom of the reservoir. The Shenandoah iSWAT model does not incorporate wetland/reservoirs.

3.6 SWAT Input and Output files

Input Files

The input of the SWAT may be specified at three different levels of detail: watershed, sub-basin and HRU. Data must be provided for each particular feature used in the modelling of watersheds, such as reservoirs or point sources.

Watershed level inputs are used for all watershed modelling procedures. When the input corresponds with a simulated process in the HRU, inputs at the level of the sub-basin are set to the same value for all HRUs. The HRU levels entries are inputs that may be

changed to a different value for each HRU in the watershed.

Additional files are required to manage all input and output files in addition to the files containing the particular data. Some of them are:

FILE.cio--- Input/output file for master control. This file specifies the simulation start and finish times, as well as input files for the whole basin that are read at various phases of execution. Model execution is directed to the weather input files and the model configuration file, *.fig, via File.cio. To run various models, separate versions of.cio are necessary. These are saved as modelname.cio, and the relevant one must be transferred to FILE.CIO before running ISWAT 2008c.

Runname.fig--- file of configuration The model topology (connectedness) of sub-basins and reaches is determined by this control file. It also defines which sub-basinlevel files will be called: *.sub, *.rte, and *.swq. The ArcSWAT pre-processor creates.fig files for each HUC, such as SFShen.fig, NFShen.fig, and LowerShen.fig (renamed).

Each sub-basin requires three needed input files, whereas each HRU requires four.

Level	File type	Descriptions
Watershed	file.cio	Master watershed file. This required file contains the names of watershed level files and parameters related to printing.
	.fig	Watershed configuration file. This required file defines the routing network in the watershed and listed input file names for different objects in the watershed.
	.bsn	Basin input file. This required file defines values or options used to model physical processes uniformly over the entire watershed.
	.pcp	Precipitation input file. This optional file contains daily measured precipitation for a measuring gage. Up to 18 precipitation files may be used in each simulation and each file can hold data for up to 300stations.
	.tem	Temperature input file. This optional file contains daily measured max and min temperature for a measuring gage. Up to 18 precipitation files may be used in each simulation and each file can hold data for up to 150 stations.
	.slr	Solar radiation input file. This optional file contains daily solar radiation for a measuring gage. The solar radiation file can hold data for up to 300 stations.

	.wnd	Wind speed input file. This optional file contains daily average wind speed for a measuring gage. The wind speed file can hold data for up to 30 stations.
	.hum	Relative humidity input file. This optional file contains daily relative humidity values for a measuring gage. This file can hold up to 300 stations
	.pet	Potential evapotranspiration input file. This optional file contains daily PET values for the watershed.
	.cst	Weather forecast input file. Optional
	.cal	Auto-calibration input file. Optional
	crop.dat	Land cover/plant growth database file. This required file contains plant growth parameters for all land covers simulated in the watershed.
	till.dat	Tillage database file. This required file contains information on the amount and depth of mixing caused by tillage operations simulated in the watershed.

	pest.dat	Pesticide database file. This required file contains information on mobility and degradation for all pesticides simulated in the watershed.
	fert.dat	Fertilizer database file. This required file contains information on the nutrient content of all fertilizers and manures simulated in the watershed.
	urban.dat	Urban database file. This required file contains information on the building-up/ wash-off of solids in urban areas simulated in the watershed.
Sub-basin	.sub	Subbasin input file. This required file for each subbasin defines climatic inputs, tributary channel attributes, and the number and types of HURs in the subbasin.
	.wgn	Weather generator input file. This required file contains the statistical data needed to generate representative daily climatic data for a subbasin.
	.pnd	Pond/wetland input file. Optional
	.wus	Water use input file. Optional
	.rte	Main channel input file. This required file contains parameters governing water and sediment movement in the main channel of a subbasin
	.wwq	Watershed water quality input file. Optional
	.swq	Stream water quality input file. Optional

Table 2: The above is a list of SWAT input files.

Output files

- An assortment of yield documents are made by each SWAT reproduction: rundown input record (input.std), synopsis yield record (output.std), HRU yield document (output.hru), yield sub-base record (output.sub), and principle channel or yield document (output.rch).

- In the synopsis input record, the rundown tables of the significant info information are printed. This document enables the client to twofold check input information. Albeit not all model sources of info are given, probably the main documents are incorporated.

- The yield synopsis record incorporates the normal watershed loads from the HRUs to the streams. There is likewise a table appearance yearly normal HRU and sub-bowl esteems for a couple of measures.

- The yield HRU document contains rundown information for each hydrological reaction unit in the watershed. The record incorporates the date, region, precipitation, stream conditions, vanishing, water quality and other variable components for each HRU.

- The yield sub-bowl document gives rundown information for each sub-bowl in the watershed. The aggregate or weighted normal number of all HRUs in the sub-base is given for the various factors.

- The principle channel yield record contains synopsis data for each steering region in the watershed. The records incorporate variable information, for example, normal day by day stream, evapotranspiration, conveyed dregs, moved nitrogen and the sky is the limit from there.

- The yield document for the HRU impoundment contains rundown data on lakes, lakes and depressional regions.

- The yield supply record contains rundown data on the repositories in the watershed. (2005, New York).

3.7 The Drainage System: An Overview

A drainage system is the region where waterfalls occur and the network via which they flow to an exit. The hydrologic cycle, which also includes precipitation, evapotranspiration, and groundwater flow, involves the movement of water through drainage systems.

A drainage basin is a body of water that drains to a shared exit. Watershed, basin, catchment, and contributing area are other words for drainage basins. The entire area flowing to a particular outlet or pour point is usually described as this area. The point at which water flows out of a space is referred to as the pour point.

The lowest point on the drainage basin's border is generally here. A drainage divide or watershed border is the line that separates two basins.
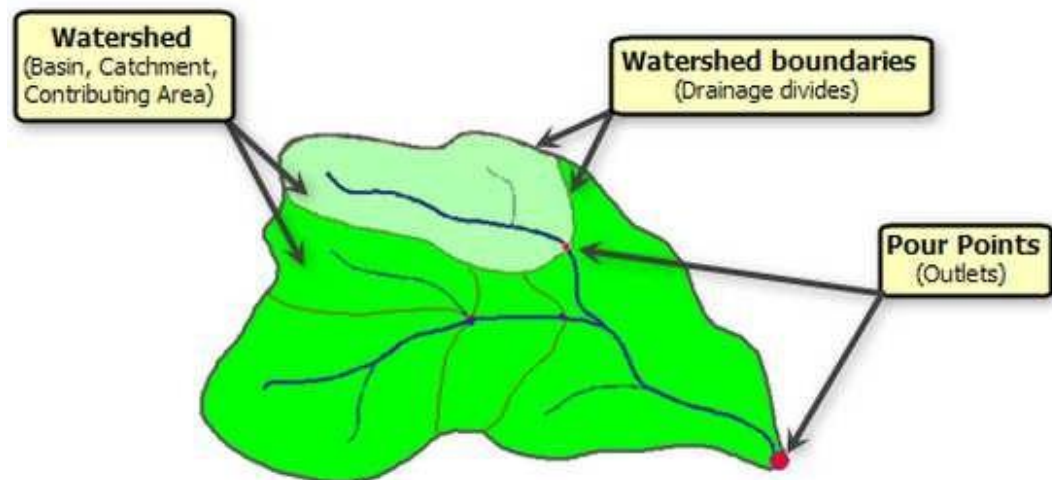
Figure 2: *Drainage System Components*

What is the process of flow accumulation?

The cumulative flow of all pixels in the output raster is computed using the flow accumulation tool. If no weight raster is provided, each cell has a weight of 1, and the number of cells in each cell is the same as the output raster value of cells.

The top left image shows each cell's direction of passage, while the top right image shows each cell's number of cells. The cumulative flow of all pixels in the output raster is
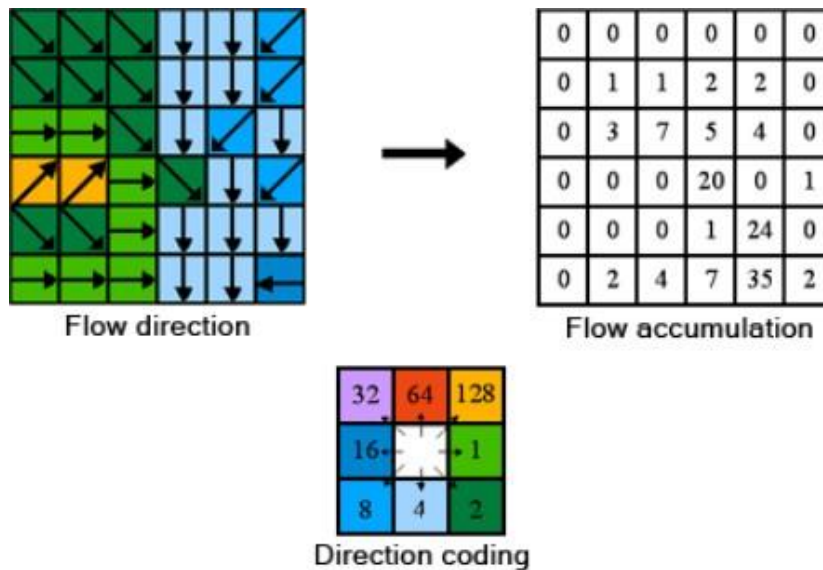
Flow direction

Flow accumulation

Direction coding

computed using the flow accumulation tool. If no weight raster is provided, each cell has a weight of 1, and the number of cells in each cell is the same as the output raster value of cells.

The top left image shows each cell's direction of passage, while the top right image shows each cell's number of cells.

Cells with high flux accumulation are locations with high flux and may be utilized to identify stream channels. Local topographic heights with 0 flow may be used to form ridges.

3.8 SWAT-CUP (Calibration and Uncertainty Program)

The SWAT-CUP interface was created specifically for SWAT. The goal of the SWAT-CUP is to:

- Combine several SWAT calibration/uncertainty analysis methods into a single user interface.

- Make it simple for students and professionals to apply the calibration method.

- Make it easy for newcomers to master the programs.

- Provide a quicker method for performing time-consuming calibration procedures

and standardize calibration stages, as well as.

- Add more features to calibration procedures like graphing calibrated results, data comparison, and so forth.

Calibration/Uncertainty Analysis Procedure

"In Sequential Uncertainty Fitting version 2, there is uncertainty in driving (e.g. precipitation), conceptual model, parameters, and observed data (SUFI-2). P-factor, the percentage of the observed data that is broken by the uncertainty of the 95% forecast, measures how effectively all the uncertainties are represented (95PPU)"[16]. The 95PPU is computed by means of the cumulative distribution of a Latin hypercube sample output variable at 2,5 percent and 97,5 percent. "The uncertainties of the parameter generating 95PPU take into consideration all uncertainties, because the data show all kinds of mistakes (e.g., discharge). Another method to evaluate the strength of a studies on calibration and uncertainty is to use the d-factor which is the average thickness of the 95PPU band divided by standard deviation of observed data"[1].

Chapter-4

Study Area and Data Used

4.1 Investigation Area

"The Narmada, also known as the Rewa, is the longest river in Central India and the sixth largest in the Indian subcontinent. It is the third longest river entirely in India after the Godavari and the Krishna. It is the historic boundary between northern and southern India, which flows 1,312 km westward via the Gulf of Khambhat and empties into the Arab Sea. Along with the Tapti River & Mahi River, it is one of just three major rivers running from East to West in the peninsula of India (longest west flowing river). It is one of the rivers of India which flows through a rift valley west of Satpura and Vindhya mountains.
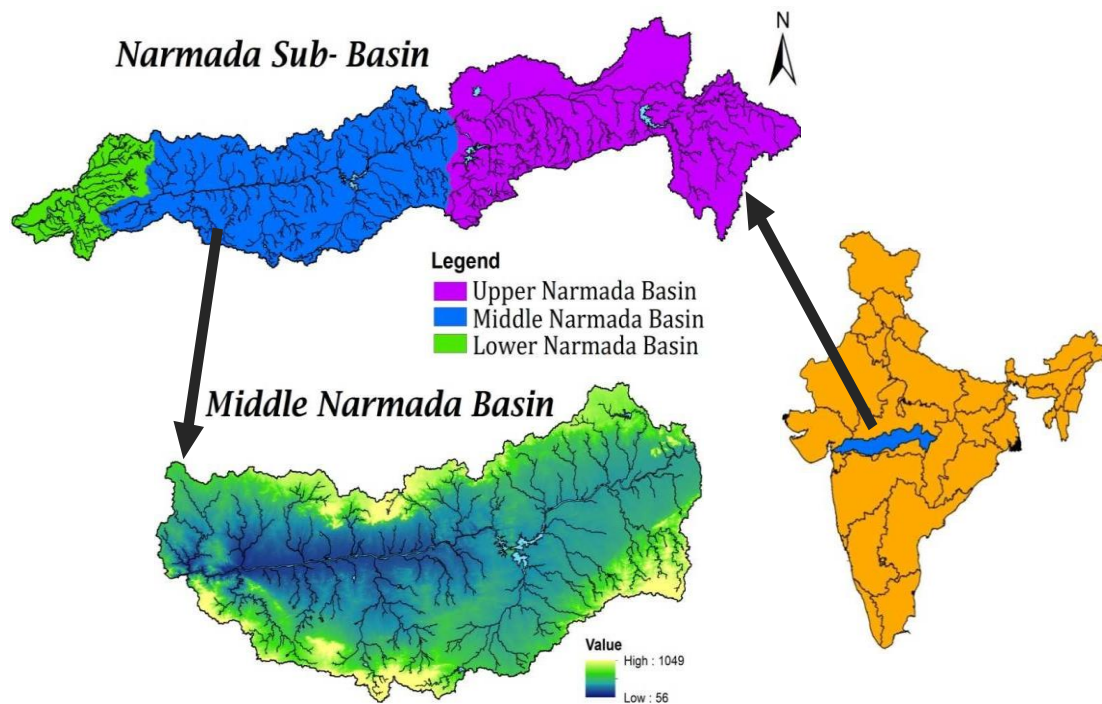
Figure 3: Narmada Basin is depicted on a map

At an altitude of 1068 metres above sea level on the Amarkantak plateau of the Maikala River in the Shahdol area of Madhya Pradesh, the river rises at 23°45' latitude north and 80°35' longitude east. The river runs 1,212 kilometers into the Arabian Sea in the

Cambayan Gulf near Bharuch, Gujarat. The first 1,085 kilometers of its trip are home to Madhya Pradesh. For the next 40 kilometers the river marks the boundary between the states of Madhya Pradesh and Maharashtra. It then defines for the next 42 kilometers the boundary between Maharashtra and Gujarat"[10]. The last 165 kilometers of the course are located in Gujarat.

The Middle Narmada basin has an area of 40,680 sq km, or roughly 1.38 percent of the country's entire geographical area, however we've chosen 40,608 sq km as our research region. Longitudes 75°18' 55" E to 78° 58' 29" E and latitudes 23° 25' 44" N to 25° 06' 19" N make up the basin.

4.2   Data Sources and Dataset Preparation

Below are the data used for model calibration and validation .

Data	Location	Period of Records	Supplying Agency
Digital Elevation Model	Basinwide (Middle Narmada Basin)	Unknown	ASTER DEM, Japan Space Systems
Soil Map (Hard Copy)	Madhya Pradesh	1996	NBSS & LUP, Nagpur
Land use/ Land Cover Map	Madhya Pradesh	2010-11	NRSA, Hyderabad
Rain-gauge	45 Stations	1995-2010	IMD, New Delhi
Ground Water	118 Wells	2007-2011	CGWB, New Delhi
River Discharge Data	2 stations	2000-2010	CWC, Bhopal
Max. Min. Temperature, Relative Humidity, Solar radiation, Wind Speed	45 Stations	1995-2010	Global Data (http://globalweather.tamu.edu/)

4.3 In order to execute the SWAT model, we'll need to use a timeline

Warm Up	**1995-1996**
Calibration	**1997-2008**
Validation	**2009-2010**

Chapter-5

Methodology

5.1   Flow Chart
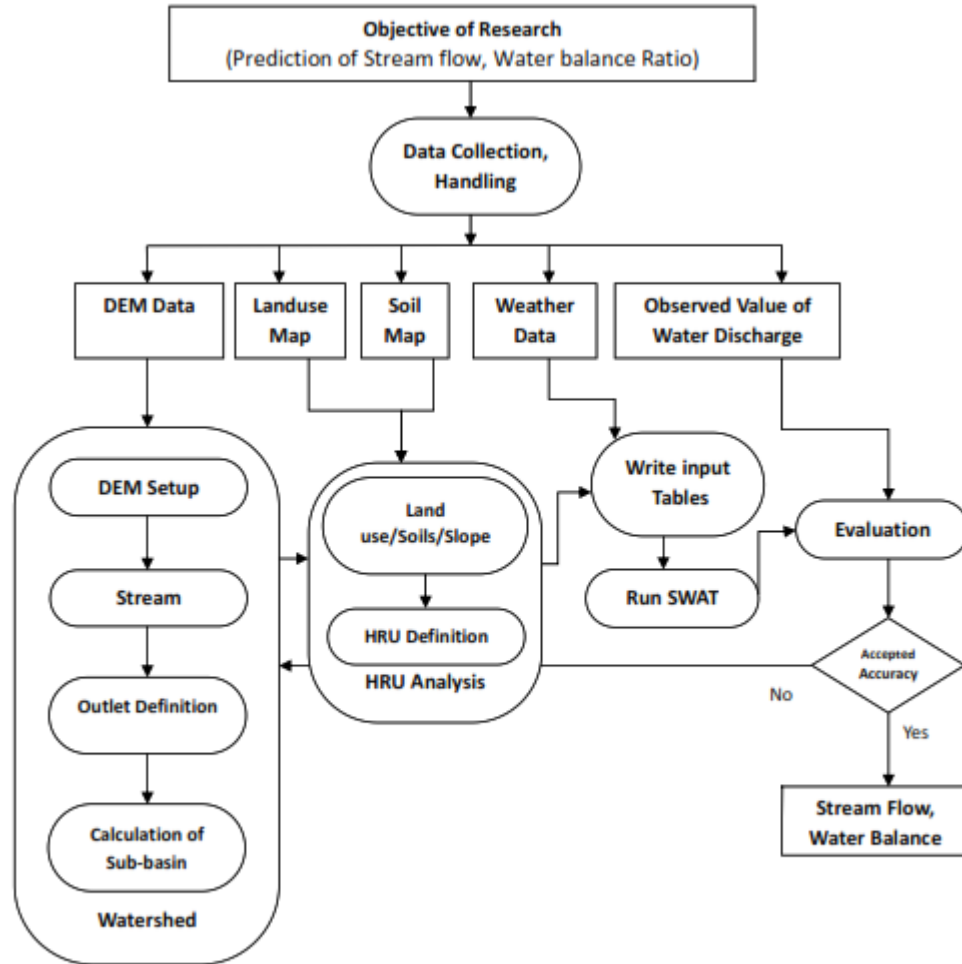
Figure 4: Flow Chart

The present research investigates the effect on stream flow in the Middle Narmada basin from topography, land use, soil and climatic variables, based on the SWAT2012 physical watershed model. Also studied were the effects of sub-basin discretization and the development of hydrologic reaction units (HRUs) on stream flow. Calibration, sensitivity, and uncertainty analysis were all part of the model's application. The SUFI-2 calibration and uncertainty analysis methods were utilized for this purpose. It took 55 iterations to achieve a converged solution.

5.2 Model Input

The ArcSWAT interface requires the Digital Elevation Model (DEM), soil data, land use, meteorological data, river flows and stream layers of the network. Data from the weather and river discharge were also used to calibrate the system and predict stream flow.

Figure 5*: 30m resolution ASTER DEM data (Image courtesy of Japan Space Systems)*

1. Digital Elevation Model Data

To describe the geography, a DEM which characterizes the rise of each point in a given district at a predefined spatial goal. A DEM of 29 m x 29 m goal was gained from the ASTER site (Fig. 11). The DEM was utilized to plan the tank and examinations the seepage examples of the geography of the land surfaces. DEM was used to gauge sub bowl measurements, including incline, length and width, for example, slant and stream network highlights. The worth changes from 58 to 1059 meters. Land Use/Land Cover Map
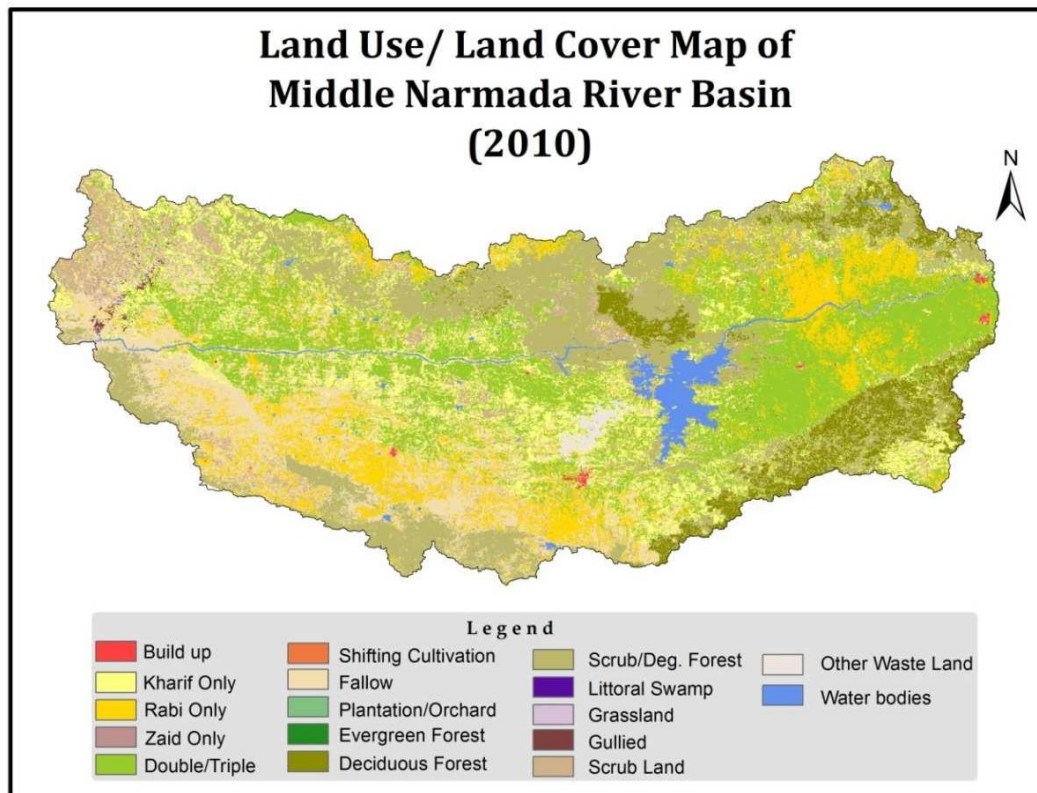
Figure 6: *Land use/Land Cover Map (Source: NRSA, Hyderabad)*

Land use is one of the most important factors affecting watershed surface erosion, runoff and evapotranspiration. The land use map for the study region was obtained by the Hyderabad National Remote Sensing Agency. More over half of the Middle Narmada basin, as shown in Fig. 12, is utilized in farming.

2. **Soil Data**

   For different layers of each soil type, the SWAT model requires distinct soil textural and physicochemical characteristics such as soil texture, accessible water content, hydraulic conductivity, bulk density, and organic carbon content. The NBSS & LUP, Nagpur provided the 1:50,000 scale soil map and soil characteristics data. Clayey, Loamy, and Loamy-Skeletal soils are the most common soil types in the basin.
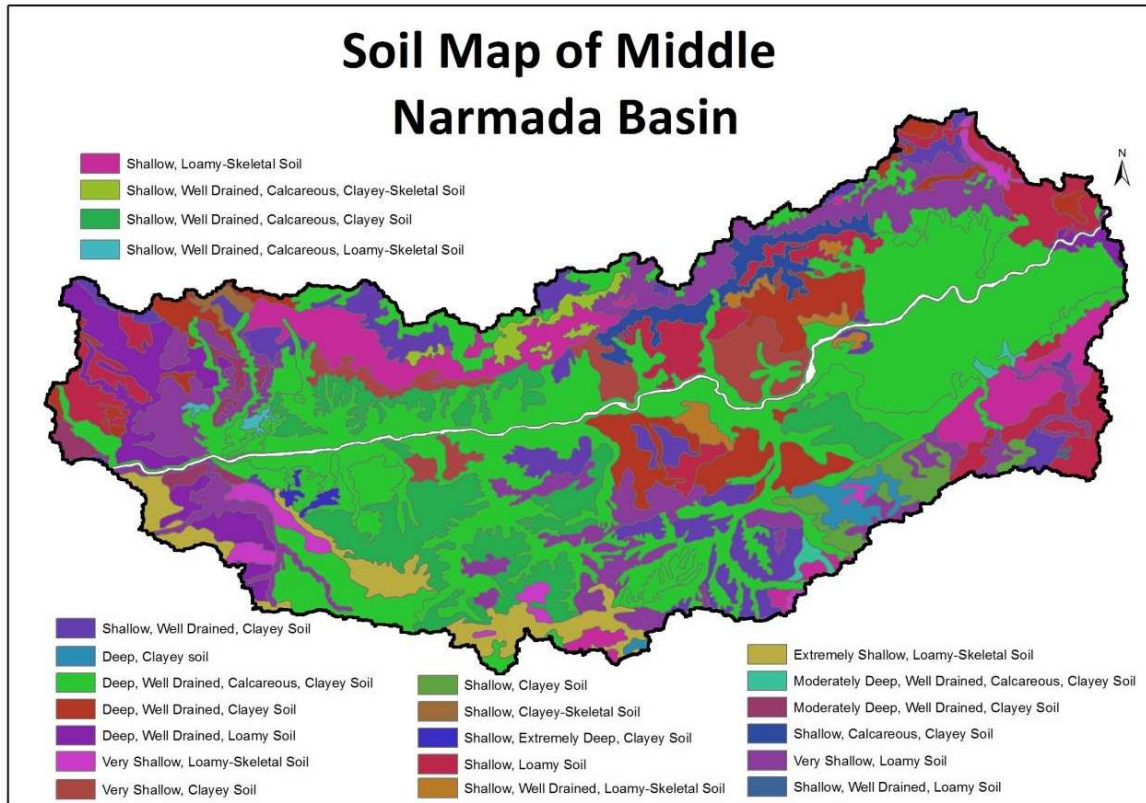
Figure 7: Soil Map (Source: NBSS & LUP, Nagpur)

3. Weather Data

Smack requires every day meteorological information, either from a deliberate information assortment or from a model for a meteorological generator. The climatic factors utilized in this exploration to accomplish the hydrological balance from 1995 to 2010, were day by day precipitation, least and greatest air temperatures. Precipitation insights were provided by the India Meteorological Department in New Delhi. Temperature, relative moistness, sunlight based radiation and wind speed information from the worldwide http://globalweather.tamu.edu/) information site were gotten. Figure 8: Rain-Gauge Location Map (Source: IMD, New Delhi).

4. River Discharge

The Narmada River at Hoshangabad and Rajghat supplied daily river flow values for CWC,Bhopal.
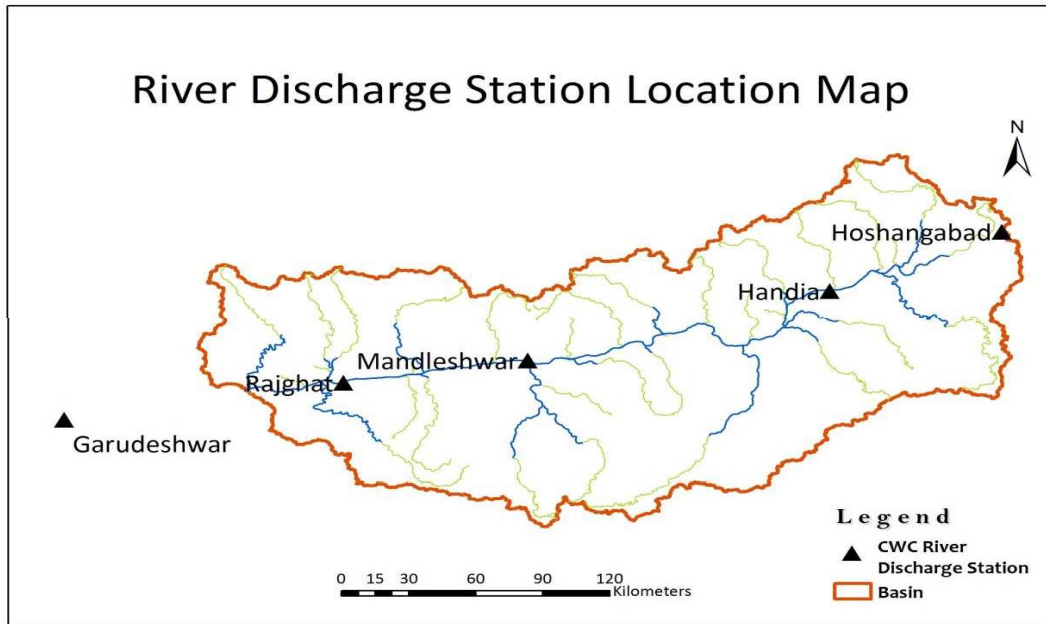
Figure 9: Location Map of River Discharge Stations (Source: CWC, Bhopal)

5. Groundwater Data

For 118 wells in the research region, the Central Water Ground Board in New Delhi collected groundwater data.   *:*
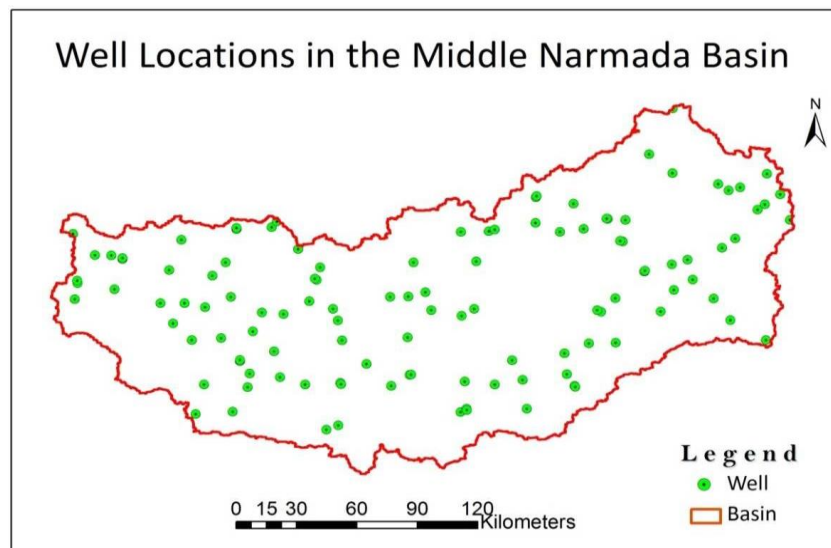
Figure 10: Locations of Wells in the Middle Narmada Basin (Source CGWB, New Delhi)

5.2　Model Setup

There were five steps to setting up the model:

(1) Data preparation;

(2) Sub-basin discretization;

(3) HRU definition;

(4) Parameter sensitivity analysis;

(5) Calibration and uncertainty analysis
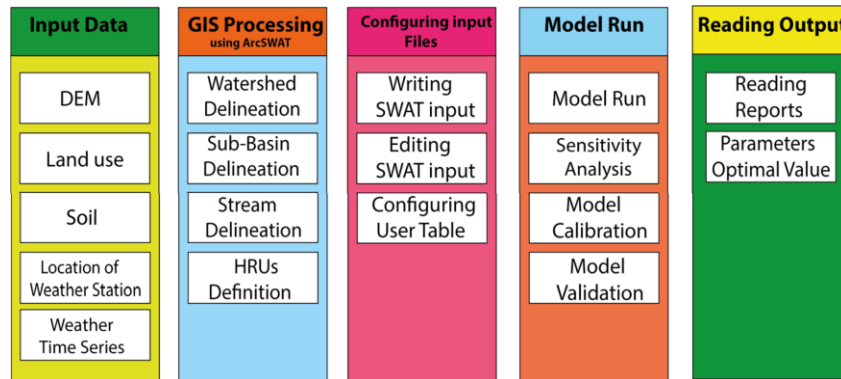
Figure 11: SWAT Model components and input/output data

5.1　Getting Started

Create an empty ArcMap document. "If the toolbar is not loaded in the map document by ArcSWAT, right-click on the menu bar to create a menu of all available tools and then choose ArcSWAT as shown below"[120].

Figure 12: Pop-up Menu

The ArcSWAT toolbar has now been added to the map document, as shown below. We have the option of leaving it floating or docking it in one of ArcMap's menu bars.
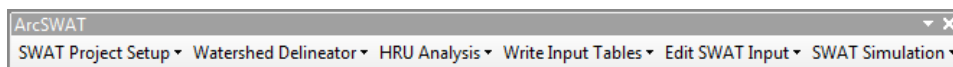
Figure 13: ArcSWAT Tool Menu

5.4.1 Project Setup

"The initial step in using ArcSWAT is to establish a project and generate all relevant folders and databases to store all data. Project Setup SWAT> New teams for the SWAT Project were established".
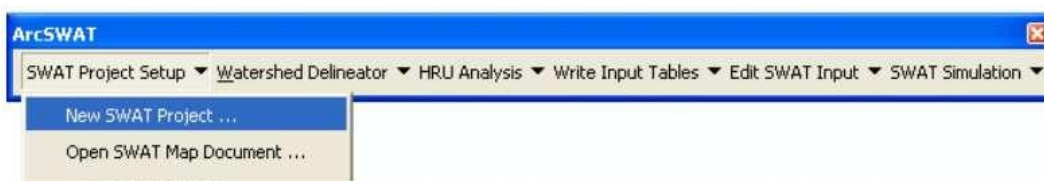
Figure 14: ArcSWAT Tool

If a warning comes that asks us to save the map document, choose No and proceed. The Project Setup window should appear within a few seconds, as seen below. Determine the project directory location. A name is automatically given to the geodatabase, the geodatabase for raster storage and the SWAT parameter. Click OK. Click OK. After a few seconds, we should be notified that the project is finished. Click Ok to continue.

If a warning comes that asks us to save the map document, choose No and proceed. The Project Setup window should appear within a few seconds, as seen below. Determine the project directory location. A name is automatically given to the geodatabase, the geodatabase for raster storage and the SWAT parameter. Click OK. Click OK. After a few seconds, we should be notified that the project is finished. Click Ok to continue.
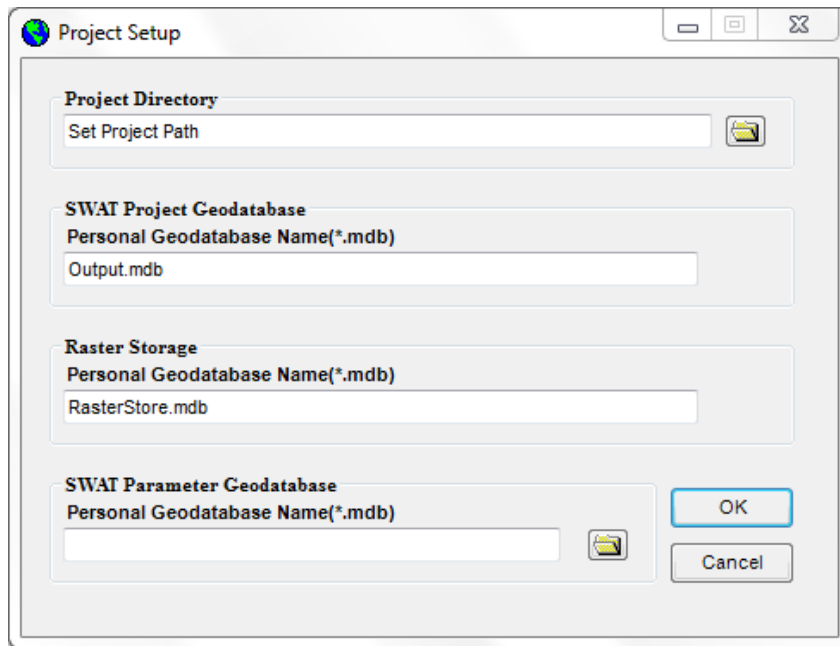
Figure 15: Project Setup Dialog box

ArcMap is now stored with the name of the directory we supplied. The directory is also created with project.mdb and RasterStore.mdb. After the project is finished, we start the process of delineating the watershed.

5.4.2 Watershed Delineation

As illustrated below, go to Watershed Delineator >> Automatic Watershed Delineation.
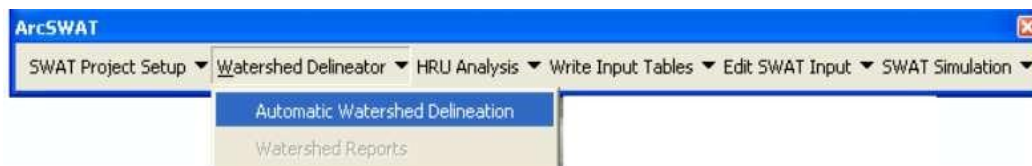
Figure 16: Watershed Delineator Menu

Once the watershed demarcation window has been opened, go to the DEM setup section and click on the open file button (#1 in the picture below), then choose from map, and then select your project DEM. Click the OK button. We'll see that the DEM's name has changed to Source DEM. Let's go through the mask and burn and work on the direction of the flows and the accumulation grids.
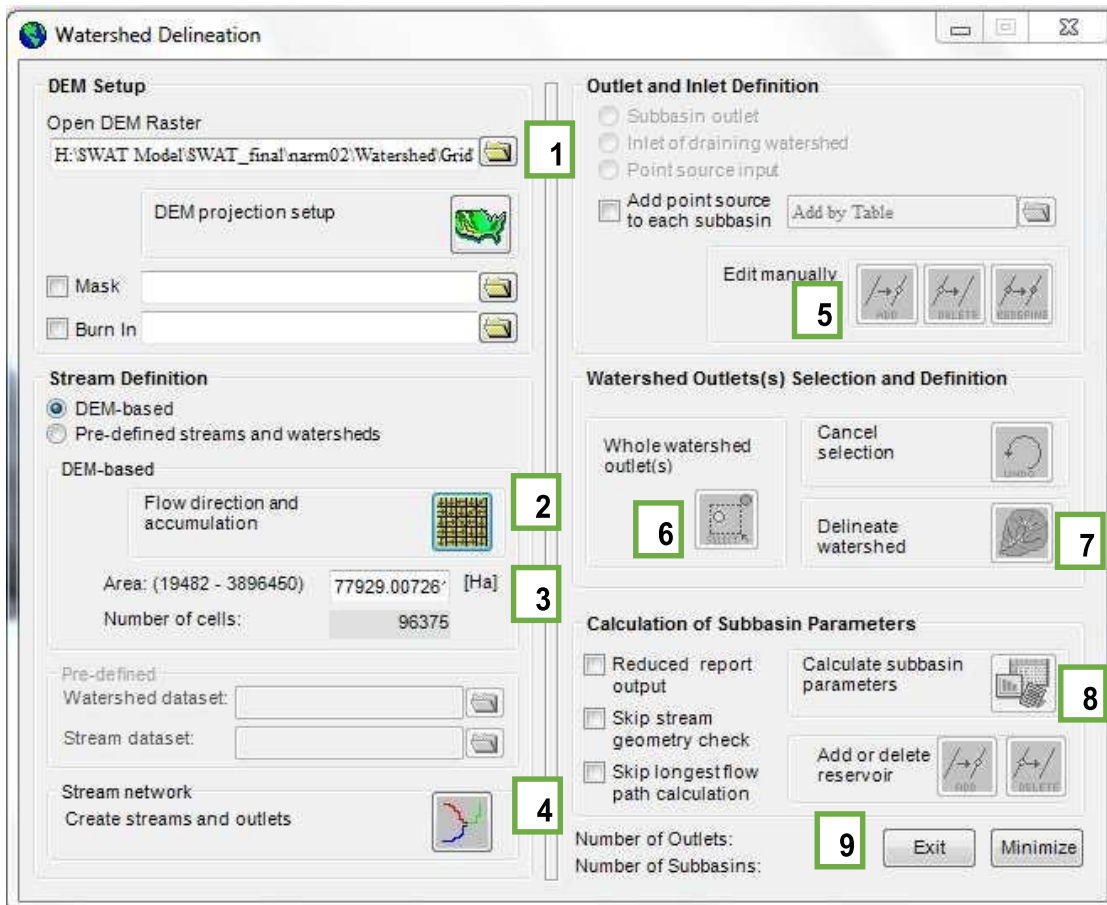
Figure17: Watershed Delineator Dialog box

When the flow direction and flow accumulation are finished, the area box is filled with a number. We will use this as the key stream area threshold (Diagram #3) to build the stream network. Then, click the Set stream and outlets (#4) button for each sub-basin to establish a stream network, sub-basins and outlets.

51

Next, under the Selection and Definition watershed outlets section, choose Whole watershed outlet button (#6) and then use the mouse to select our desired outlet location as shown below. If we make an error and choose the incorrect outlet, we may use the undo button.

Figure 18: Stream Network

When the outflow is chosen, the Delineate watershed button (#7) becomes green. To demarcate the shift, click on the Watershed demarcation button. Click OK after the delineation is finished. Once the watershed is defined, a polygon feature class with sub-basins has been added to the cartography document.
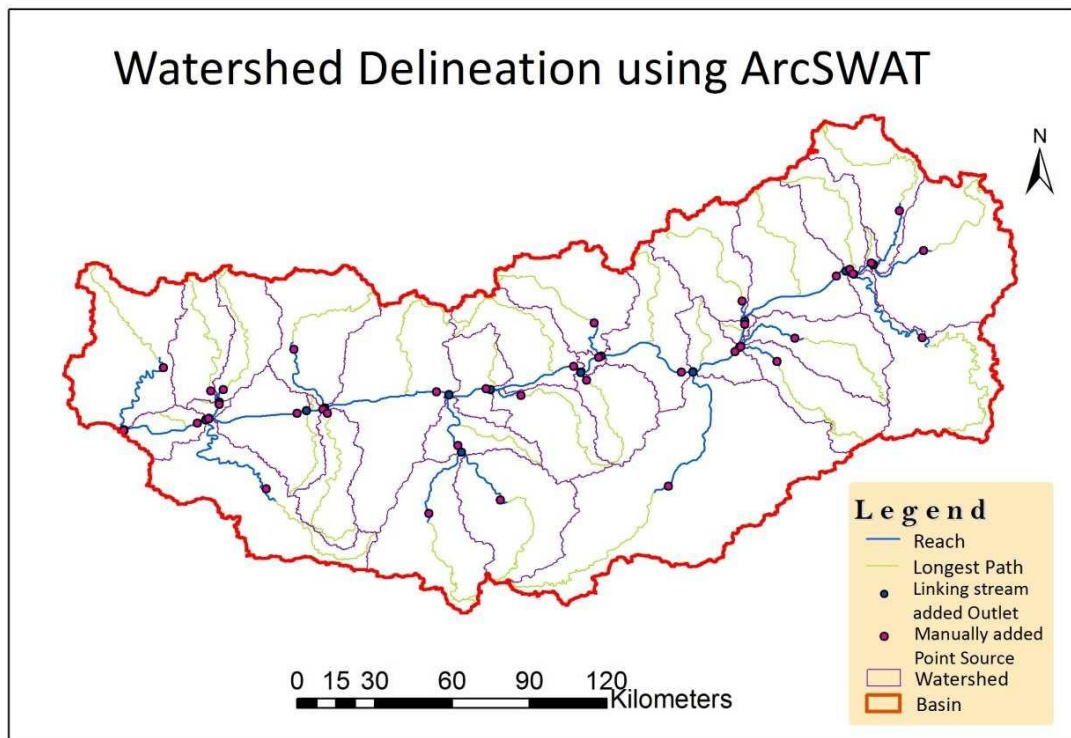
Figure 19: Watershed Delineation using ArcSWAT

The last step of watershed delineation is to generate parameters/attributes for all sub-bases. To add the key characteristics of the watershed feature class to the SWAT model, click on the Calculate Sub basin Parameters button (#8). It's going to take a while. After all attributes have been calculated, click OK on the final message box.

Figure 20: Sub-Watershed of Middle Narmada Basin

After delineating the watershed, the next stage is to generate HRUs using data on land use, soil, and slope (elevation).

5.4.3 HRU Analysis

Click HRU Analysis > Land Use\Soils\Slope Definition on the ArcSWAT toolbar, as illustrated below.

Figure 21: HRU Analysis Menu

In the landuse/soils/incline definition window, there are three tabs, one for each land use, soil and slant. Presently we're starting area use. Snap the open document button (#1) to stack the land use information. In the following window, we select land use information from the circle and snap to open it. By exploring the project, we now load the expected landuse raster.
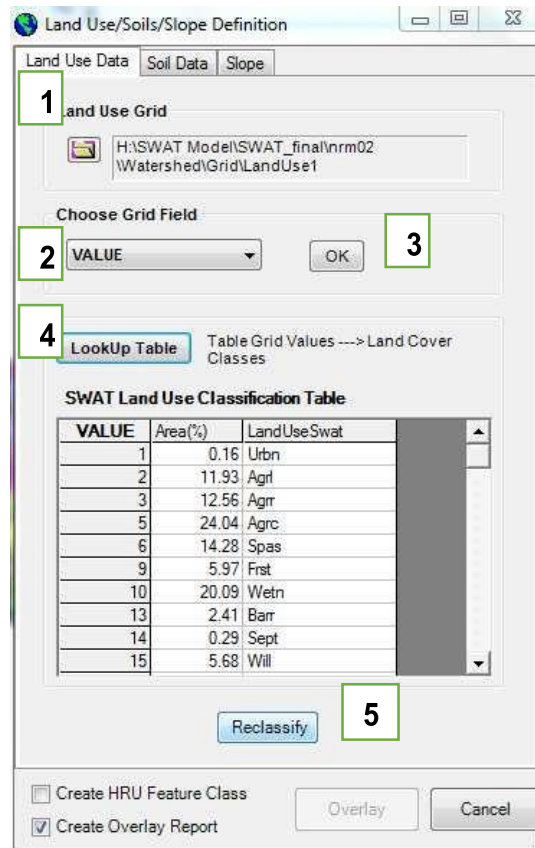
Figure 22: Land Use/Soils/Slope Definition dialog box

Before importing the data into the project, the software will clip it.
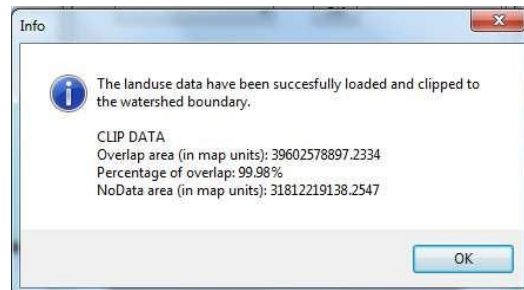
Figure 23: Land Use Clip info message

Presently, subsequent to picking Value for the network choice field (#2), we click OK (#3). Go to LookUP Table (#4) then, at that point pick the choice User Table to add another section. To complete the HRU investigation area ashore use information handling, click Reclassification (#5).

After the land use information has been prepared, snap to the Soil Data tab.

Snap Soils Grid (#1) to get to and investigate soil information, which stacks the dataset from the plates, and afterward picks it. This progression takes the information raster and slices it to the watershed. This cycle might take longer, contingent upon the size of the watershed. After the dirt information have been stacked, we pick Value (#2) as the framework field and snap Ok (#3). This will add all mathematical qualities from the land soil dataset to the SWAT soil classification table.

We will observe that for each value, each soil type has a linked region. The next stage is to link these numerical values to a particular kind of soil. To accomplish this, choose UserSoil(#5) from Soil Database options (#4). The classification table for SWAT soils will now include a user-defined field.
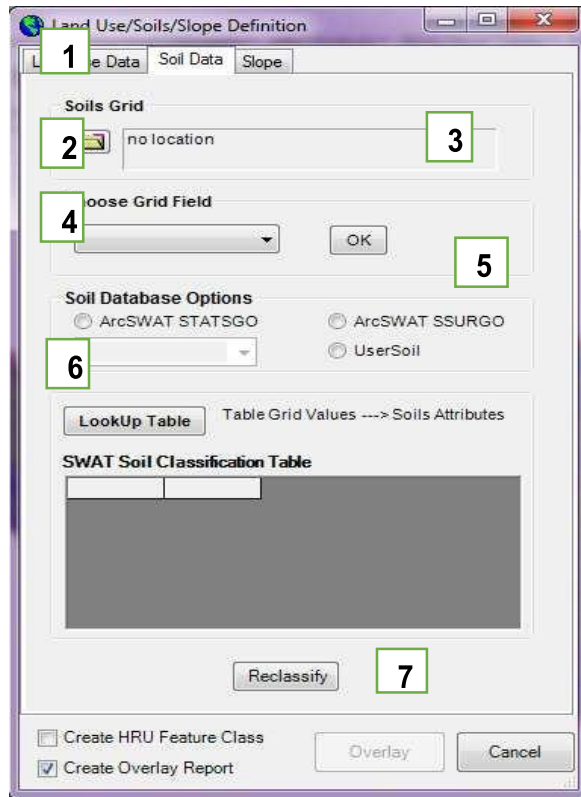
Figure 24: Soil data Definition Dialog box

When you select Lookup Table (#6), the relevant soil name will be added to the newly created field. To reclassify the soil data according to the swat model, click Reclassify (#7). The next step is to add slope characteristics to each HRU after the soil data has been processed. Select the Slope tab.
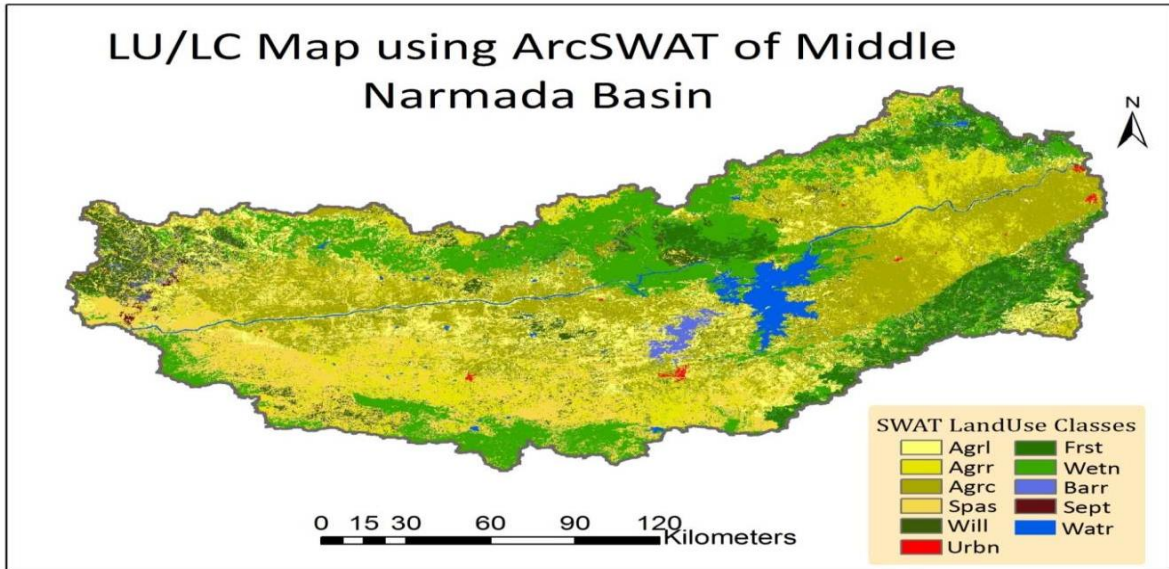
Figure 25: SWAT LU/LC Map
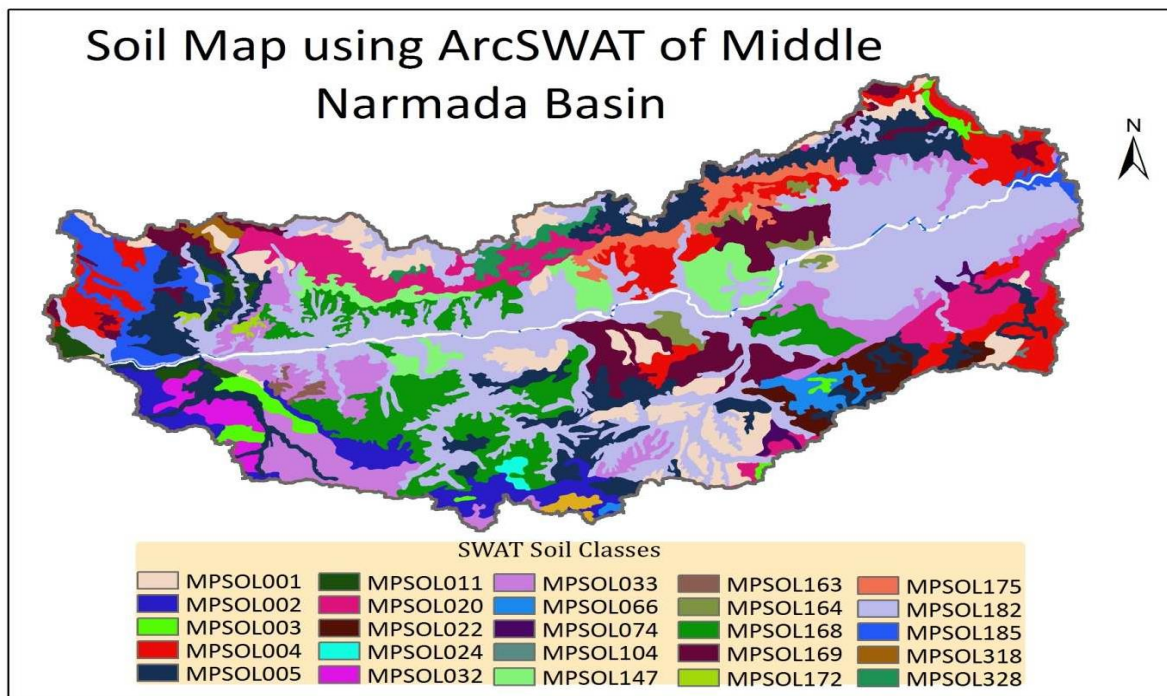
Figure 26: SWAT Soil Map
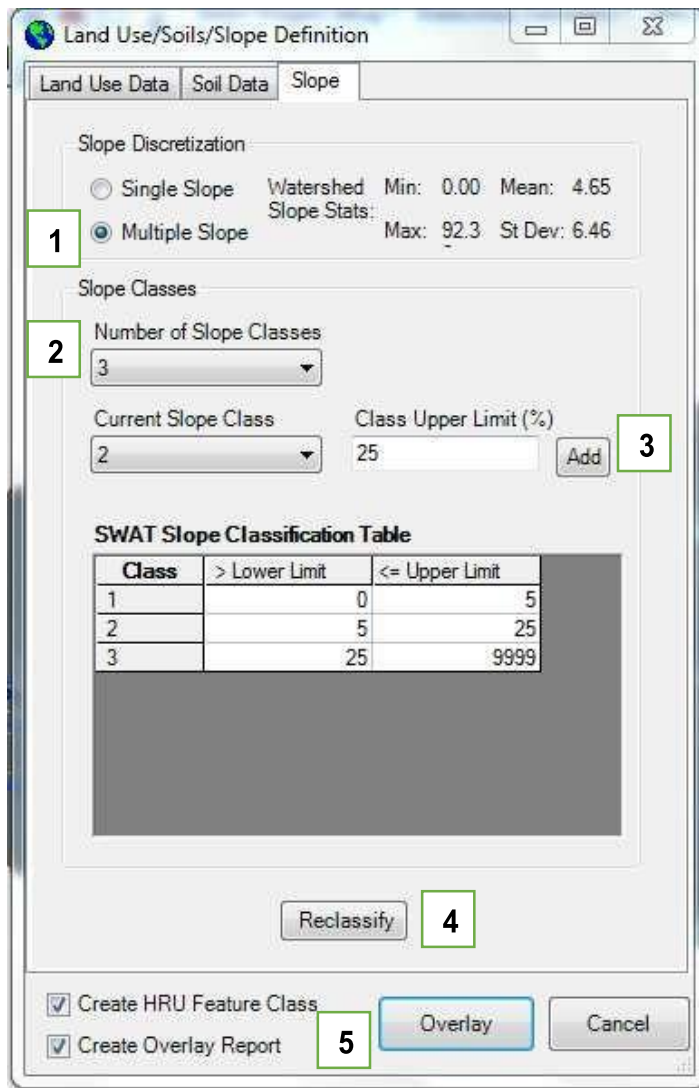
Figure 27: Slope Definition Dialog box

We choose the numerous Slope option in Slope Discretization (#1), then we select the Total number of slope classes (#2) and specify the class upper limit (in percent), then we click on Add (#3), and finally we click on Reclassify (#4). After entering all of the information for Land, Soil, and Slope, the Overlay (#5) button will be highlighted; click it to begin the Overlay procedure.

Now, utilizing the combined land use, soil, and slope data, we generate the HRU by clicking on HRUAnalysis > Definition of HRU.
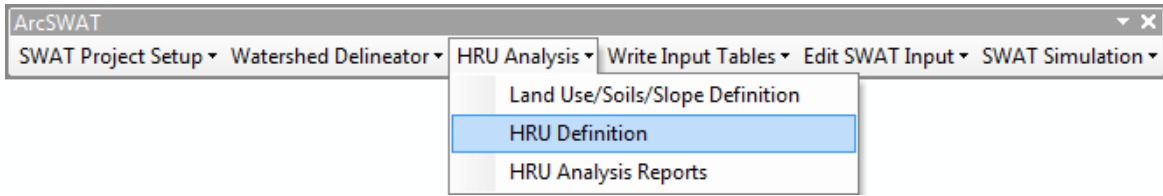
Figure 28: HRU Analysis Menu

In the HRU definition, we choose the Multiple HRU option and percent in the threshold frame. We build HRUs using a 22% threshold for land use, 22% for soil and 5% for slope..
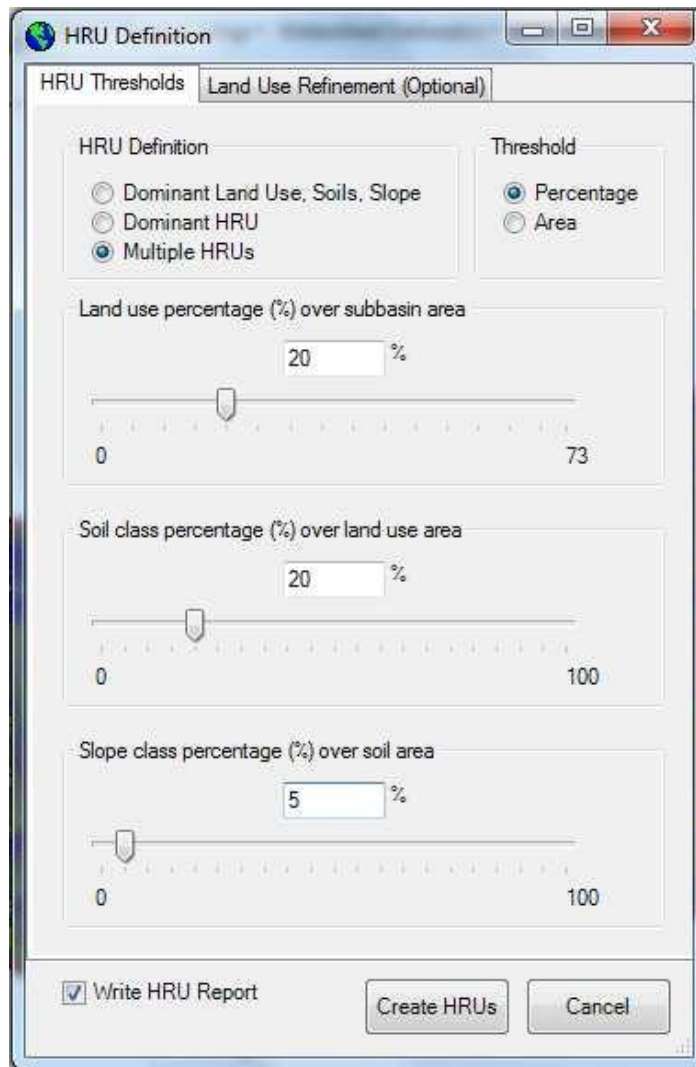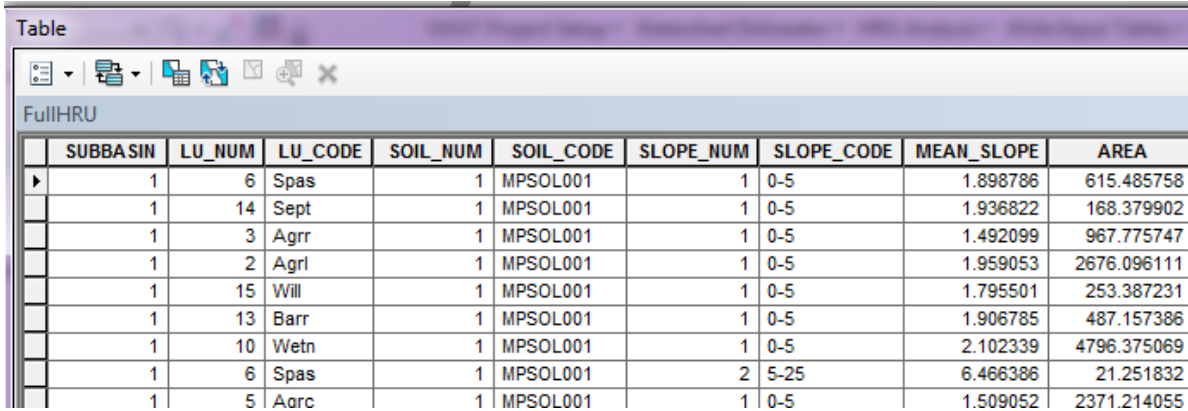
Figure 29: HRU Thresholds Definition Dialog box

A table named Fullhru will be added to the map document, and when we view it, we'll find that the UNIQUECOMB column contains numerous HRUs with unique combinations.

Figure 30: HRU Table

5.4.4   Creating Input Files/Tables

After the geoprocessing of DEM, Landuse and Slope information to make sub-bases and HRUs has been done, the following stage is to create input SWAT documents with meteorological information.

Weather Data

Write Input Tables > Generate Weather Input for SWAT to create weather input for SWAT. Stations of the Weather
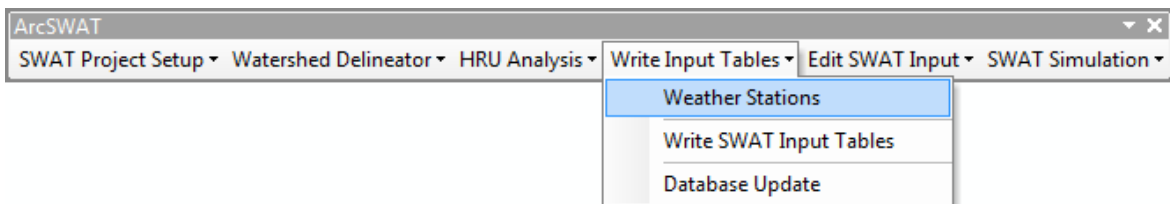
Figure 31: Write Input Tables Menu

Climate data might be submitted twoly. The first is to use the climate geodatabase of SWAT and the other is to utilize our very own data set. The customized information base (client of WGEN) is used.

60
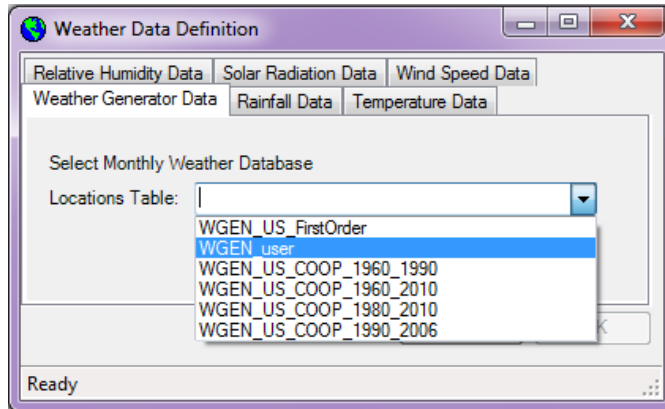
Figure 32: Weather data definition dialog box
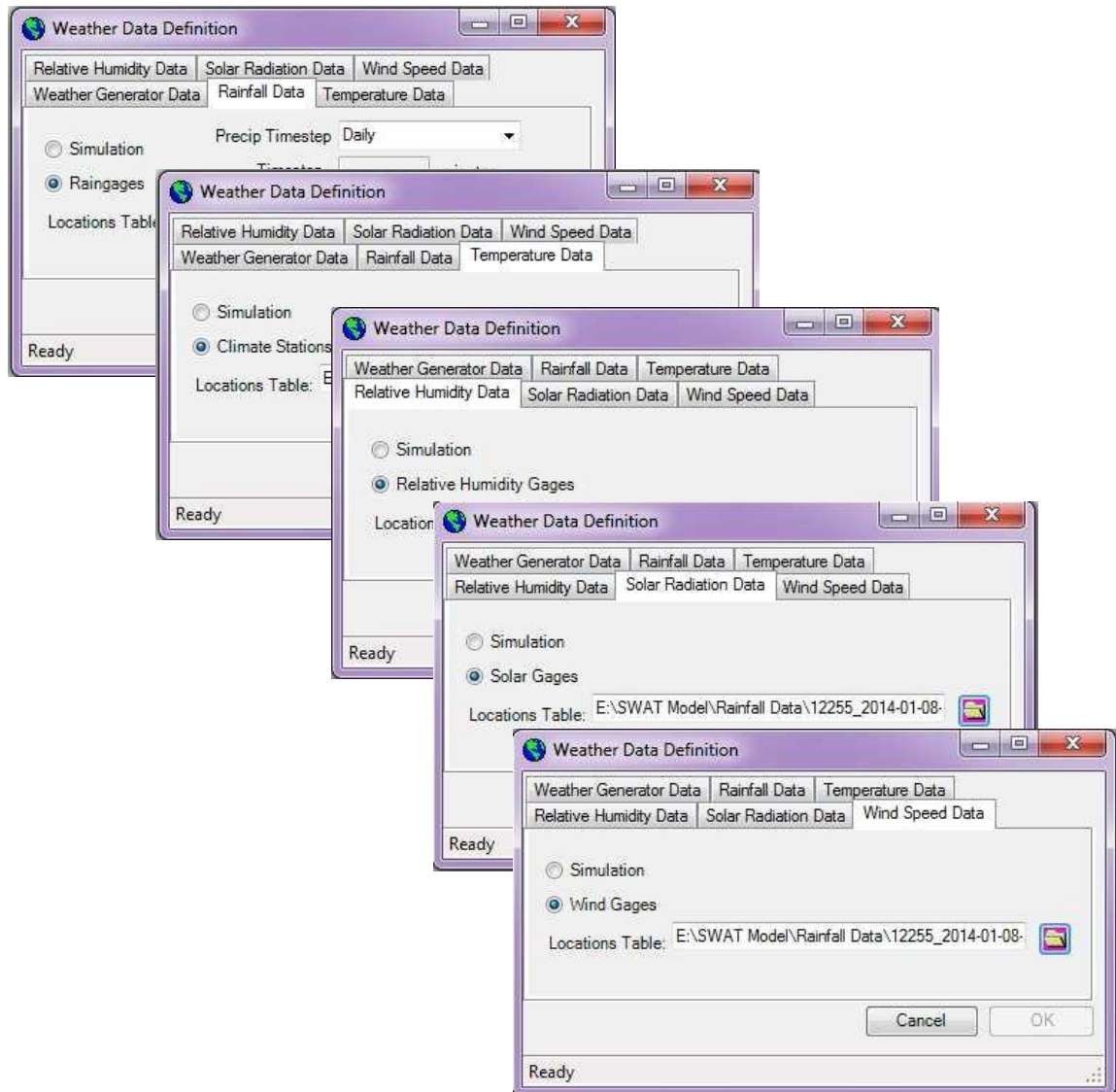
Figure 33: Weather data definition dialog box

Finally, press the OK button. This will result in the creation of a weather database for the research region.

Other Input Files

After creating the weather database, click Write Input Tables >> Write SWAT Input Tables to generate all additional input files.
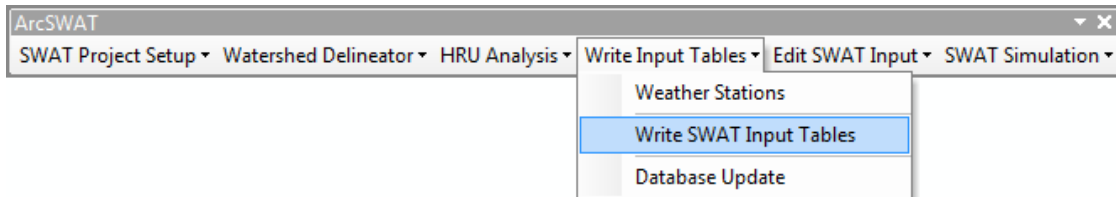

Figure 34: Menu of Write Input Tables

A new window titled "Write SWAT Database Tables" will appear. Select All is selected, and then Create Tables is selected.
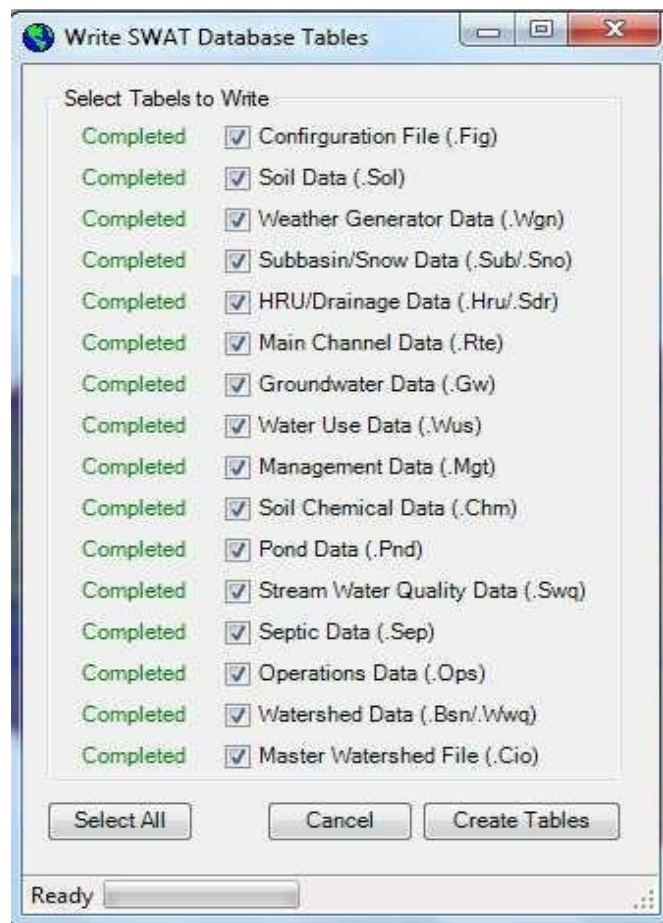
Figure 35: Write Input Tables Menu

We are now ready to conduct the simulation after receiving a final notification stating that all input tables have been prepared.

5.4.5   Running SWAT Simulation
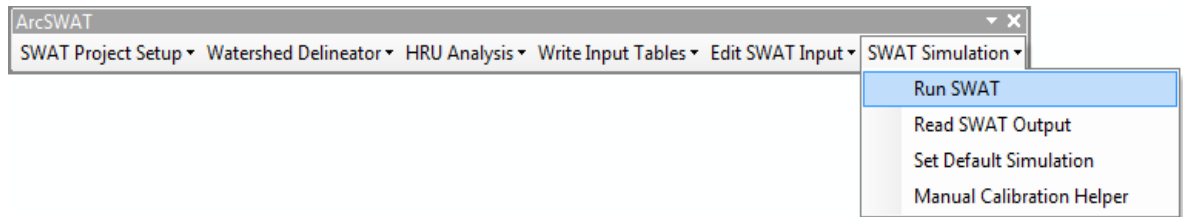
Click on SWAT Simulation >> Run SWAT

Figure 36: SWAT Simulation Menu

"Set the simulation period between 1 January 1995 and 31 December 2008 and change the output settings to daily, leaving the remaining default options alone. NYSKIP stands for model simulation warm-up, and in this session we will use NYSKIP = 2. We will now proceed and click Setup SWAT Run"[20]. Click Run SWAT after the SWAT setup notice is received.
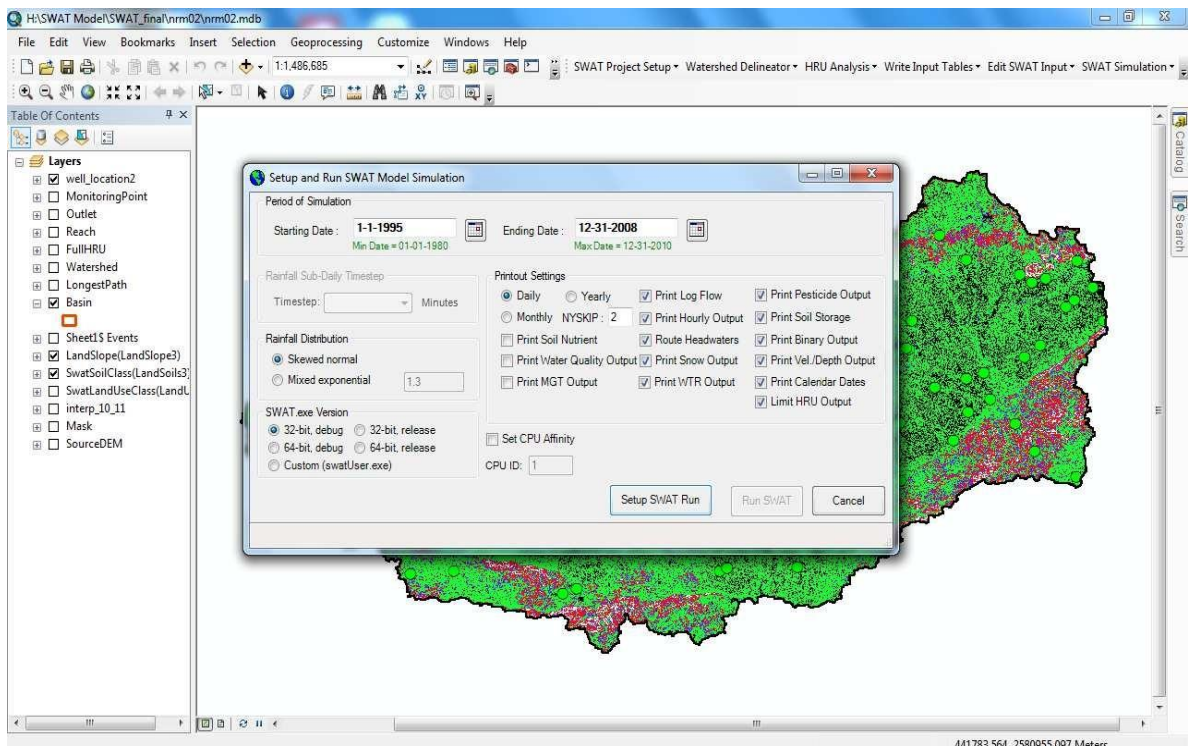

Figure 37: SWAT Model Simulation Setup and Run Dialog Box

We'll see a DOS window showing the status of the simulation while it is running and we'll get a finalized message once the simulation is completed.
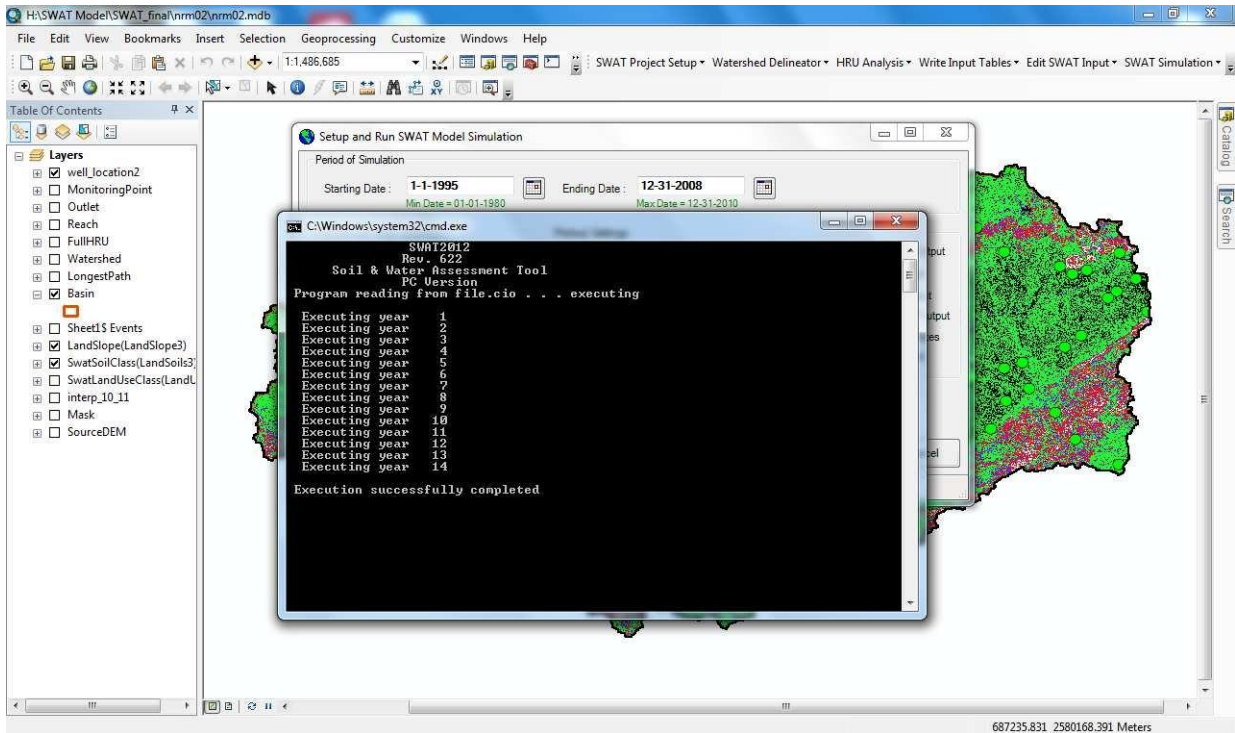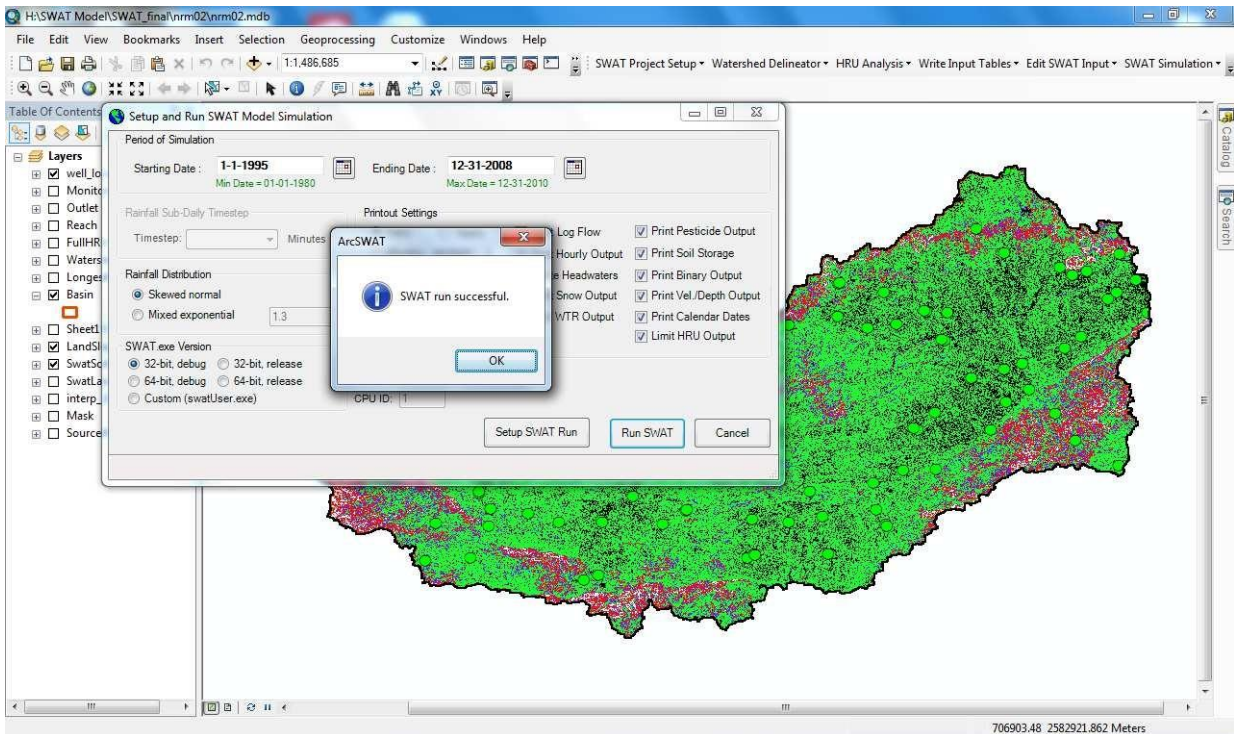

Figure 38: SWAT Executing in DOS Window

Figure 39: Final Simulation Done message

Subsequent to getting an effective reenactment message, we currently dispose of the SWAT recreation arrangement window.

Chapter : 6

Discussion of the Findings

6.1 Precipitation

The daily precipitation data from IMD have been converted into GIS format for the past 16 years. The monthly and yearly precipitation of the basin has been investigated. According to this statistics, precipitation varies across the basin temporarily and regionally. More than 85 percent of precipitation falls throughout the months of July to September. The yearly precipitation is between 778 mm and 1389 mm, the average annual precipitation for the last 16 years being 1035 mm. Some areas get 2000 mm of annual precipitation when account is taken of geographical variations.
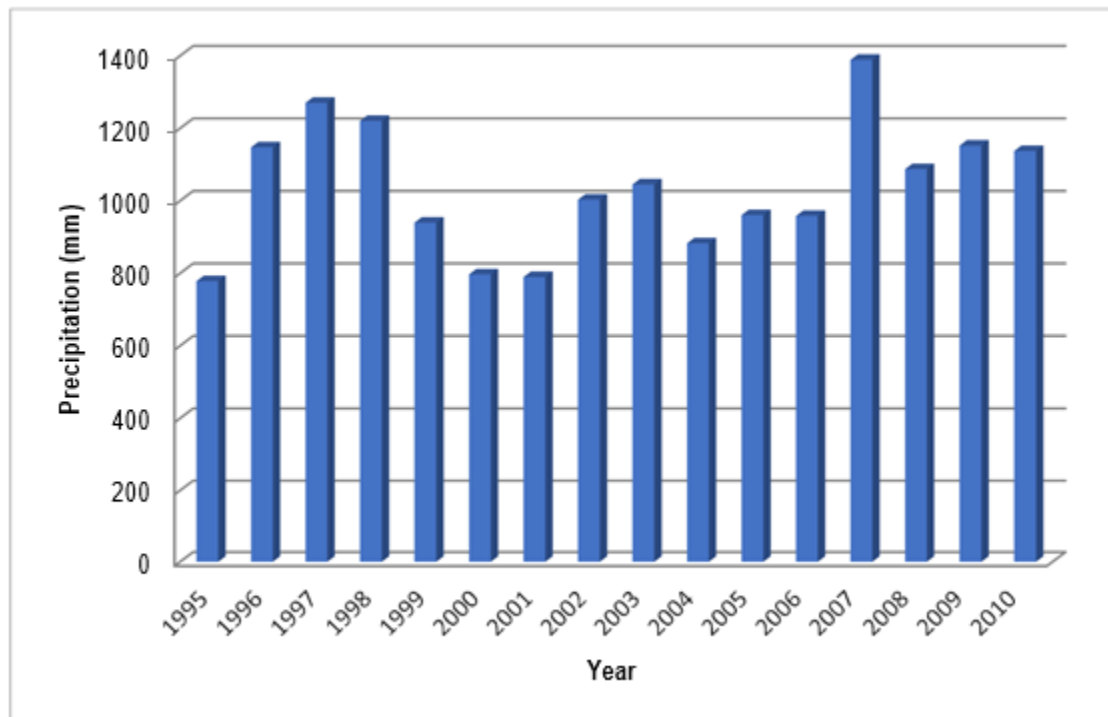

Figure 40: Annual Precipitation Variations in the Middle Narmada Basin

6.2 Temperature

A temperature addresses how hot or cold something is. The estimation depends on heat radiation, molecule speed, dynamic energy or, all the more regularly, the mass conduct of a thermometric material. Focal India has a monsoonal environment, with precipitation and temperature varieties because of the exceptional situation between the Satpura and the Vindhya mountains in the Narmada Basin. Temperature in the bowl is somewhere in the range of 12°C and 42°C consistently, with significant month to month evapotranspiration varieties.

The average maximum temperature rises between March and May, then falls until August and rises again until October.
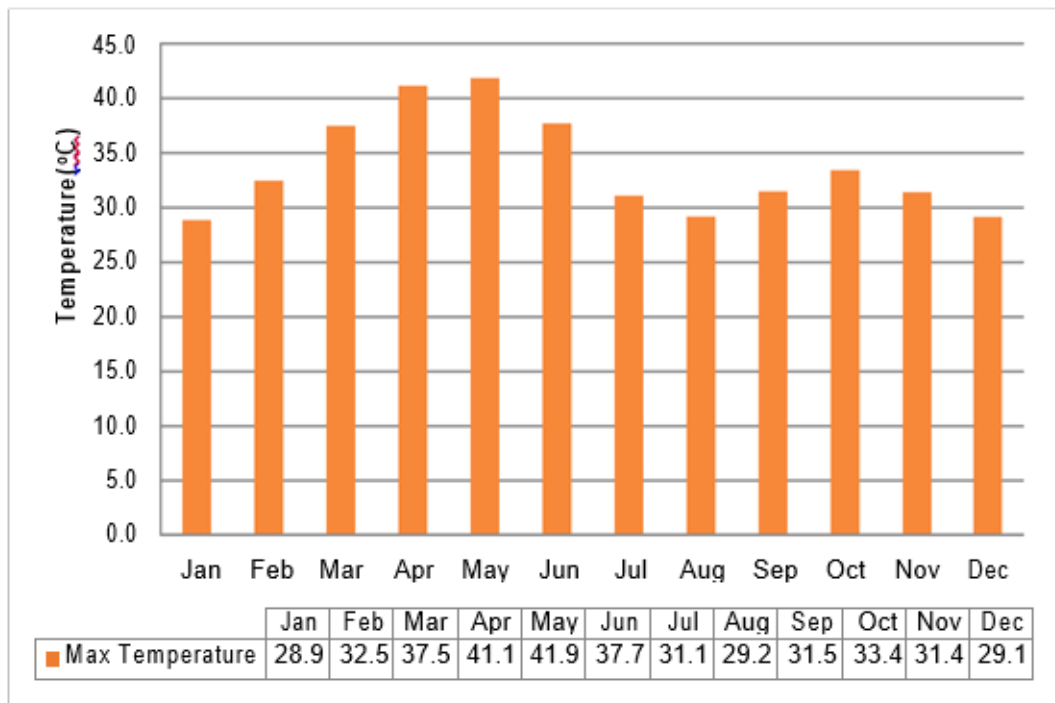

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Max Temperature	28.9	32.5	37.5	41.1	41.9	37.7	31.1	29.2	31.5	33.4	31.4	29.1

Figure 41: Month-wise Avg. The Middle Narmada Basin's Maximum Temperature
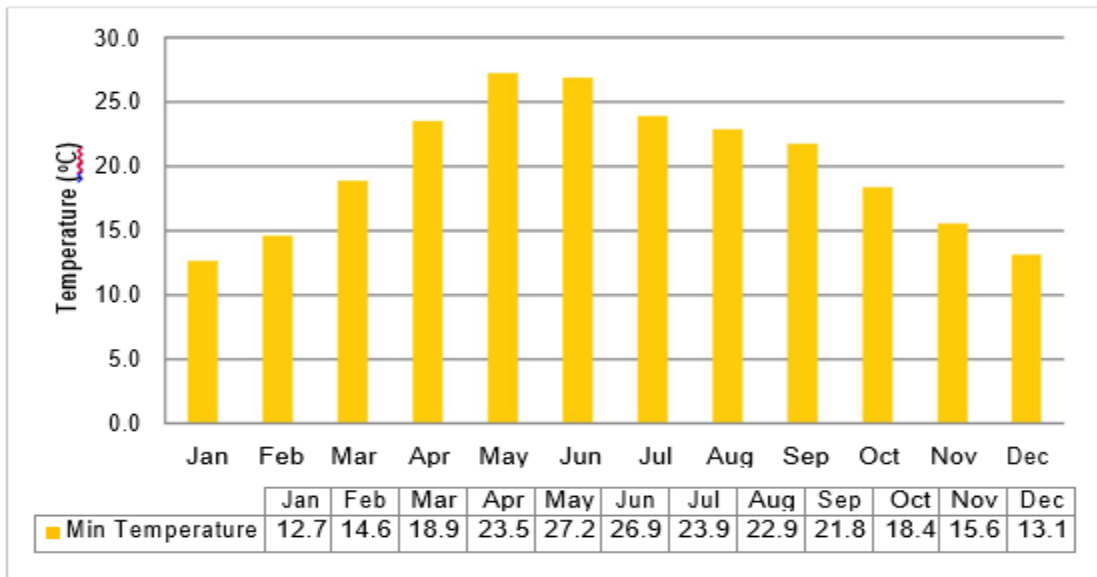
Figure 42: Month-wise Avg. Minimum Temp. of the Middle Narmada basin

6.3   Land Use/Land Cover Mapping

For the years 2010-2011, the LISS-III scenario, including the research area, was categorized. The table illustrates the geographical dimensions of various kinds of land use/land cover in the study area.

Landuse Distribution	Area (%)	SWAT Land use Class
Built-up	0.16	URBN
Kharif only	11.93	AGRL
Rabi only	12.56	AGRR
Double/Triple	24.04	AGRC
Fallow	14.28	PAST
Deciduous Forest	5.97	FRST
Scrub/Degraded forest	20.09	WETN
Wasteland	2.41	BARR
Gullied	0.29	SEPT
Scrubland	5.68	WETL
Waterbodies	2.61	WATR

Table 3: Landuse/ Land cover distribution in the study area and corresponding SWAT Landuse class

The landuse/land cover of the study region was calculated area by area and was then presented in a pie-graph in the figure to show the patterns of land use throughout the area.
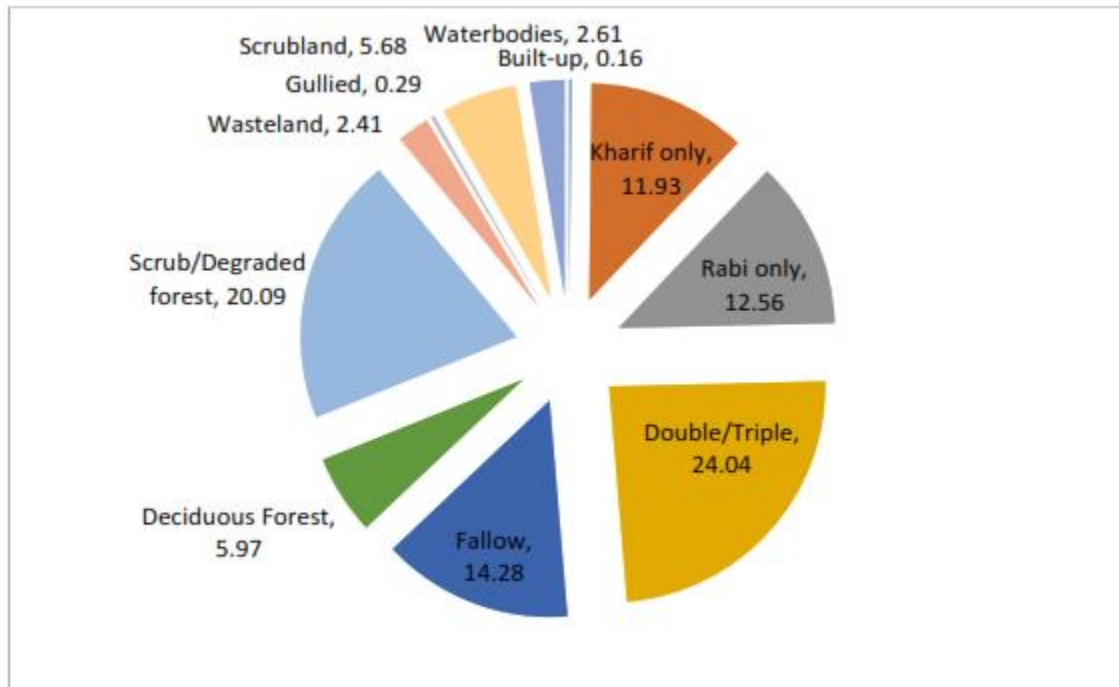

Figure 43: Landuse distribution (Area %)

With almost 24.04 percent of the total area under double/triple cropping, the bulk of the territory is under this method. The Kharif and Rabi crops are planted in about 11.93 percent and 12.56 percent of the land, respectively. A large portion of the land has been left fallow for the time being, ready to be cultivated. They are clearly visible in satellite data. Scrub/degraded forest covers almost 20.09 percent of the land, while deciduous forest covers 5.97 percent.
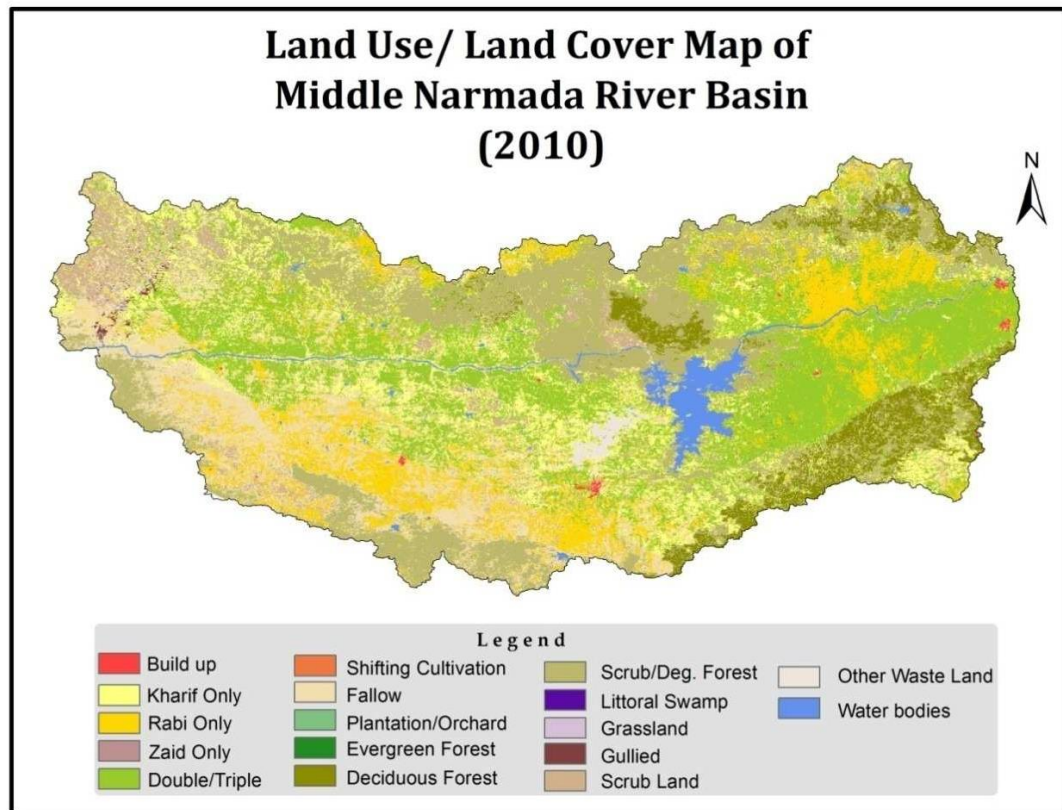
Figure 44: Land use /Land cover Map of Middle Narmada River Basin

6.4 Preparation of Digital Soil Map

ArcGIS 10 was used to generate the soil map vector coverage (NBSS & LUP). The soil map was scanned and georeferenced previously. In the field of research, there are soil mapping units.

Soil Texture	Area (%)	SWAT Land use Class
Shallow, Well Drained, Clayey Soil	6.27	MPSOL001
Extremely Shallow, Loamy-Skeletal Soil	3.42	MPSOL002
Very Shallow, Loamy-Skeletal Soil	1.19	MPSOL003
Shallow, Loamy Soil	6.93	MPSOL004
Very Shallow, Loamy Soil	10.94	MPSOL005
Moderately Deep, Well Drained, Clayey Soil	0.91	MPSOL011

Shallow, Loamy-Skeletal Soil	5.83	MPSOL020
Shallow, Clayey Soil	1.57	MPSOL022
Very Shallow, Loamy-Skeletal Soil	0.23	MPSOL024
Shallow, Loamy-Skeletal Soil	0.31	MPSOL025
Deep, Well Drained, Loamy Soil	1.11	MPSOL032
Deep, Well Drained, Calcareous, Clayey Soil	7.40	MPSOL033
Deep, Clayey soil	0.91	MPSOL066
Moderately Deep, Well Drained, Calcareous, Clayey Soil	0.35	MPSOL074
Shallow, Well Drained, Loamy Soil	0.03	MPSOL104
Very Shallow, Clayey Soil	3.07	MPSOL147
Shallow, Extremely Deep, Clayey Soil	0.23	MPSOL163
Shallow, Well Drained, Loamy-Skeletal Soil	0.88	MPSOL164
Shallow, Well Drained, Calcareous, Clayey Soil	7.58	MPSOL168
Deep, Well Drained, Clayey Soil	5.80	MPSOL169
Shallow, Well Drained, Calcareous, Loamy-Skeletal Soil	0.18	MPSOL172
Shallow, Calcareous, Clayey Soil	1.89	MPSOL175
Deep, Well Drained, Calcareous, Clayey Soil	29.01	MPSOL182
Deep, Well Drained, Loamy Soil	2.85	MPSOL185
Shallow, Clayey-Skeletal Soil	0.29	MPSOL318
Shallow, Well Drained, Calcareous, Clayey-Skeletal Soil	0.83	MPSOL328

Table 4: Distribution of Soil Texture

6.4 Groundwater

In assessing water resources, groundwater is quite important. A large portion of the agricultural region is also reliant on well irrigation. Groundwater is being utilized in the basin's metropolitan centers to fulfil residential and industrial requirements. The basin's annual groundwater flow ranges from +15 m to -25 m. These variations are more pronounced in certain packets. The Central Groundwater Board provided annual groundwater table data from 2007 to 2011 (only 5 years of data are available).

Wells with unusual variations in comparison to nearby wells are disregarded. Nearly 118 wells were discovered and plotted in a GIS system, as seen in the image. The data on wells in the research region is found to be sparse. The Inverse Distance Weight interpolation method was used to calculate annual groundwater flow grids throughout the time period given. The validation of these interpolated grids is done at random. The image depicts an annual groundwater flow grid from 2007-08 to 2010-11.
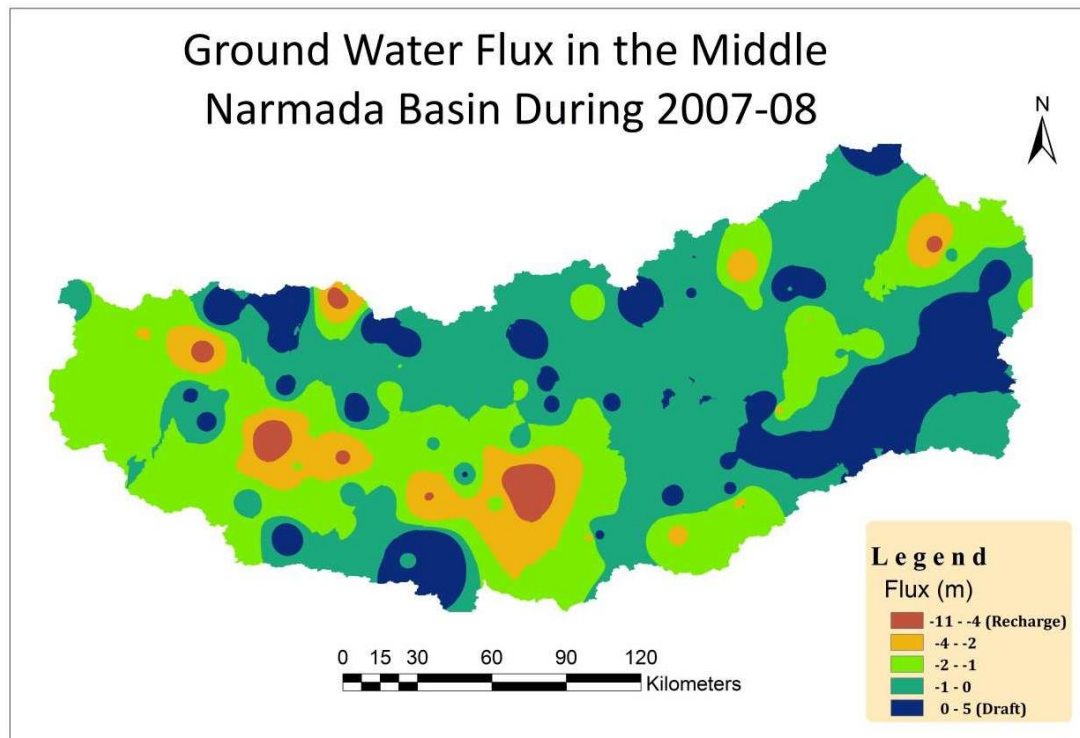

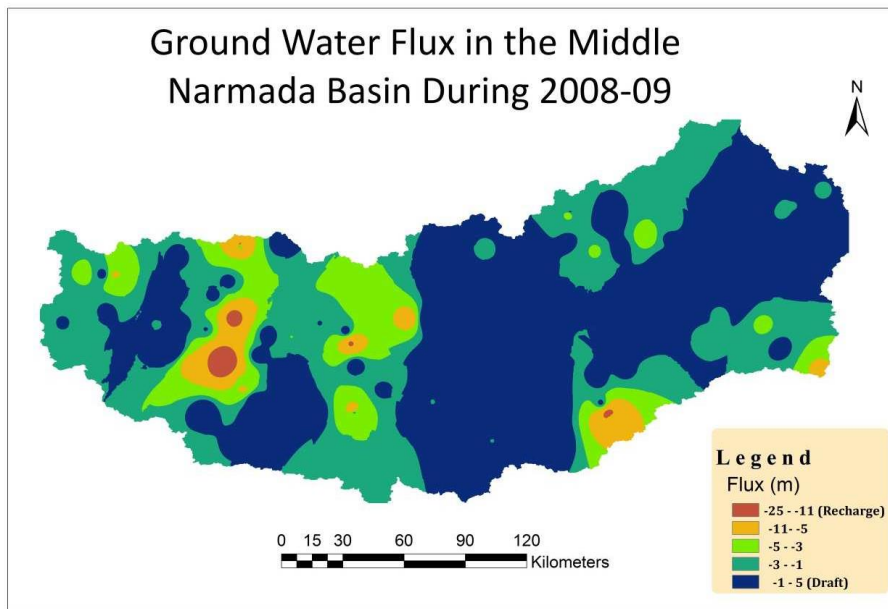*Figure 45:* Flux of groundwater in the middle Narmada basin in 2007-08.

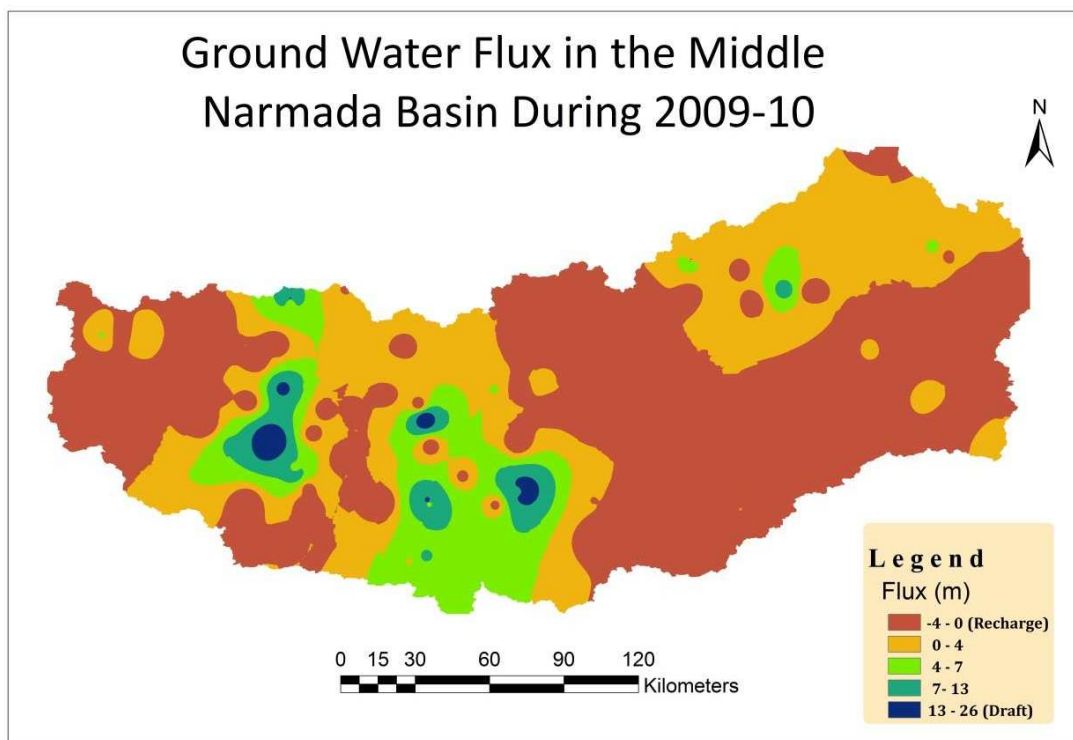*Figure 46:* Flux of groundwater in the middle Narmada basin in 2008-09

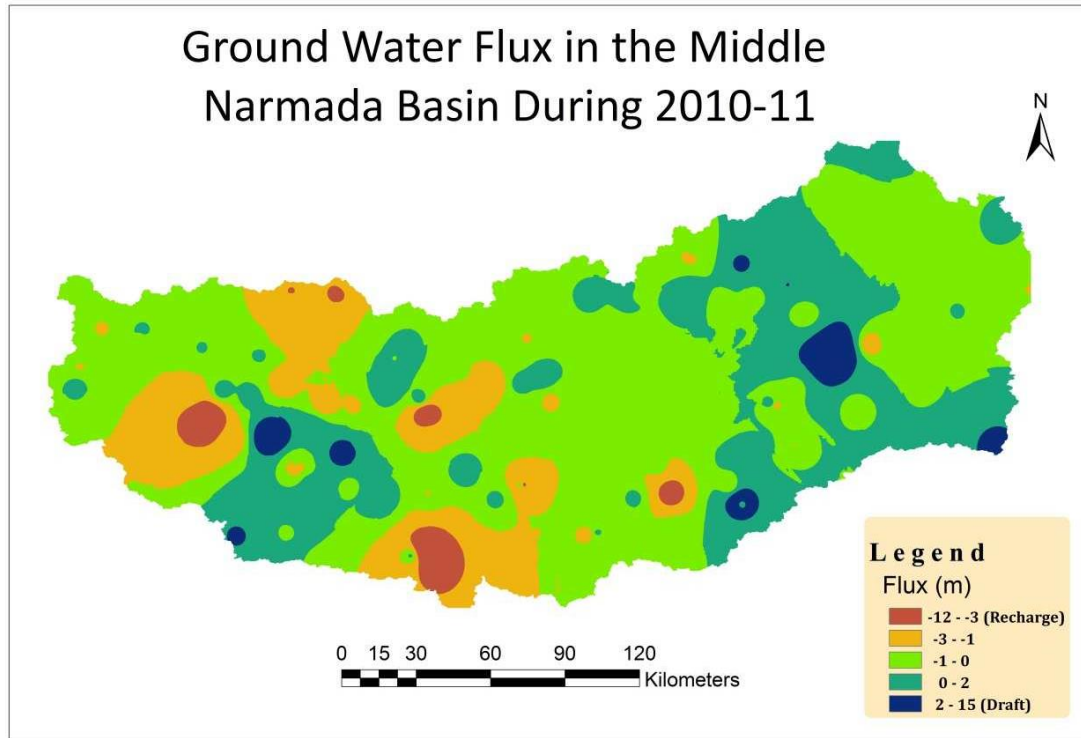*Figure 47: Groundwater flow in the Narmada basin in the middle of 2009-10.*

Figure 48: Groundwater flow in 2010-11 in the Narmada Middle Basin

6.6 Surface Runoff

The model productivity was assessed utilizing the default reproduction result and the noticed stream information. The edge space of 39,608 km2 brought about 37 sub-bowls, addressing the fundamental seepage lines of the watershed. This came about to a more exact portrayal of the hydrological measures just as a more productive stream yield than the genuine motion. The stream reproduction has not changed a lot of when the quantity of sub bowls arrives at this limit.

Various elements, including meteorological, water and physiographic impacts, influence the spillover. The SWAT model uses the SCS bend number strategy to figure the precipitation surface and the maintenance boundary (i.e., condition 2). The bend number worth is utilized to compute the last boundary (i.e., condition 3). The quantity of bends is for the most part affected by the sort of soil, land use and incline. The CN gauge in the bowl has been adapted to slants more prominent than 5%. Overflow will hence be less subject to discretization in the sub-bowl.

74

As indicated by the HRU definition research for each sub-structure, the prevailing sort of HRU definition was established on the predominant land use, soil and incline of each sub-surface. This single HRU in each sub-bowl was important for reflecting exactly the attributes of the sub-bowl. As an outcome, the recreated stream creates an inacceptable outcome contrasted with the noticed stream streams in the investigation region.

Various situations including 20% land use, 20% soil and an assortment of 5% incline limits give a more exact assessment of water stream in the bowl. As a result, there were 214 HRUs all through the entire bowl. The present circumstance brought about a thorough land use, tendency and soil data set with numerous HRUs that show the assortment of the examination field. The anticipated fluvial stream is fundamentally impacted by the circulation in each HRU of land use, soil and slant highlights. The genuine evapotranspiration ascends with the increment in the level of land use, pitch and soil limit. As an outcome, the qualities of HRUs impact stream.
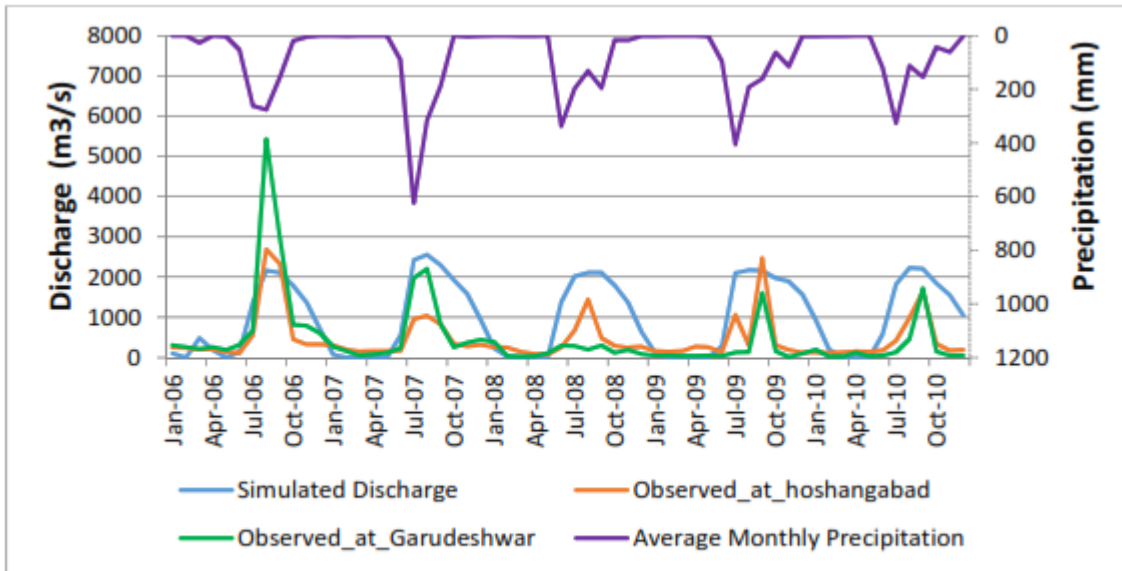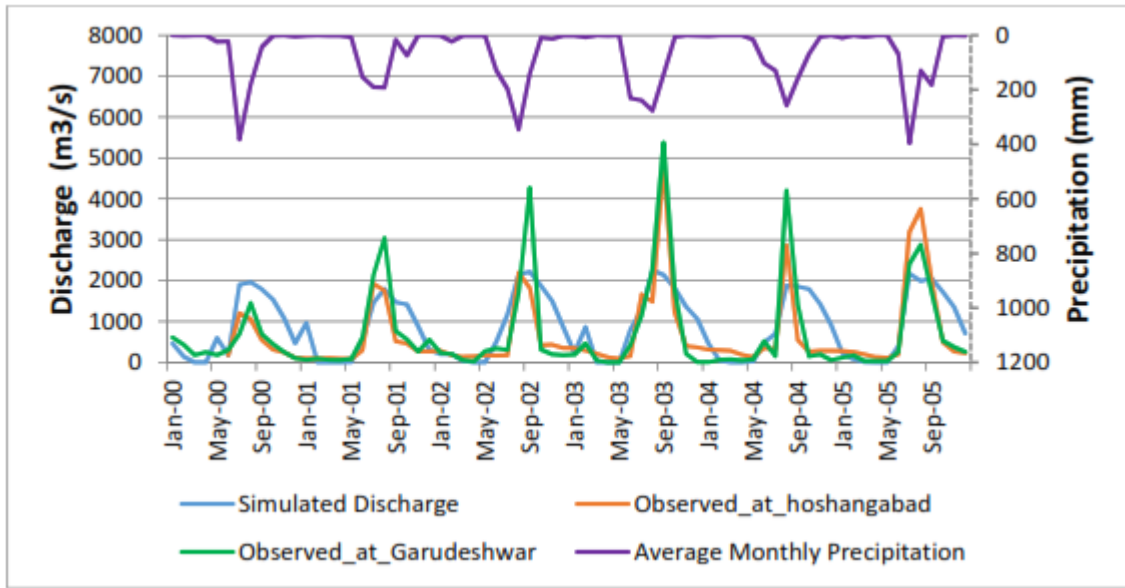
Figure 49: Comparison of Observed (at Hoshangabad and Garudeshwar) and simulated runoff (Q) on the middle Narmada basin

The anticipated worth incorrectness because of error in input information like precipitation and temperature, and other perilous sources like water system, water supply and other obscure exercises in sub bowls like the upstream dam (Indira Sagar). In any

case, extra factors other than precipitation and temperature might influence vulnerability. Information vulnerability and the improvement of foundation upstream of the watershed are accepted to be connected to show deficiencies in the examination region. Nonetheless, we can't preclude the likelihood that the dirt kind and its connected soil properties aren't right nearby. This might prompt some vulnerability in the reproduced result. Another issue is soil disintegration, which influences the construction of the dirt, its invasion and different properties. The forecasts are not precise since the model doesn't think about the impact of soil disintegration on the spillover. Different alignment (1997-2008) and approval (2009 and 2010) a long time execution information are remembered for the table.

We might gather that, based on the previously mentioned results, the model can more readily foresee the surface overflow than the ground-water commitment to stream. One issue might be the bad quality of soil information and the assessed number of bends during dry dampness. Since the SCS number is a component of soil penetrability, land use and the precursor conditions in soil water, it could be ineffectual to appraise the quantity of bends at dry dampness levels.

Parameters	Calibrated value (mm) 1997-2008	Validated Value (mm)	
		2009	2010
Precipitation	938	1034	873
Surface Runoff	245	354	162
Lateral Flow	28	38	37
Return Flow	105	112	96
Percolation to shallow Aquifer	149	158	138
Recharge to Deep Aquifer	7	8	7
Revap. From Shallow Aquifer	40	47	47
Evapotranspiration (ET)	532	442	518
Average Curve Number	80.54	79.54	79.54
Water Yield	378	504	295

Table 5: Different hydrological components for Middle Narmada basin

The last qualities for the still up in the air utilizing the SUFI-2 procedure following the adjustment interaction (Table). The changed sum during manual alignment is joined in the last CN2, Soil AWC esteem. The last fitted boundary esteems were fused into the SWAT2012 model for approval and future applications.

6.7   Parameter Sensitivity Analysis

In this exploration, the overall affectability esteems found in the boundary gauge measure were assessed. Treteen boundaries were discovered to be delicate: the ESCO, the underlying SCS Curve Number II (CN2), the alpha base stream (Alpha BF) [days], the water limit in the heavy spring for "revap" event (GW Revip), the powerful pressure driven conductivity (Ch k2) [mm/h] and the water edge of an edge in the flabber for "fire" spring (GWQMN). These delicate factors have been thought about for model adjustment. Different boundaries had little impact on stream reenactments. Changes in their qualities clearly affect the yield of the model.

Sl. No.	Sensitive Parameters	Parameters Description	Lower and Upper Bound	Final Fitted Value
1.	CN2	Curve Number	± 20%	-0.05
2.	ALPHA_BF	Base flow alpha factor	0 –1	0.19
3.	ESCO	Soil evaporation compensation factor	0.8 –1	0.82
4.	GW_DELAY	Ground water Delay (days)	30 – 450	133
5.	SOL_AWC	Water capacity of soil layer	-0.2 – 0.4	0.29
6.	GW_REVAP	Ground water revapcoefficient	0 – 0.2	0.07
7.	CH_K2	Hydraulic conductivity	5 –130	126.5
8.	GWQMN	Threshold depth of water	0 – 2	0.74
9.	SOL_BD	Soil Bulk Density	-0.5 – 0.6	0.41

Table 6: SWAT Flow Sensitive Parameters and Fitted Values after Calibration using SUFI-2

6.8   Water Balance Ratio

Table 8 shows the simulated water balance components for the Middle Narmada basin on an annual average basis for the calibration and validation period. "During the calibration period, evapotranspiration lost 46 percent of the annual precipitation in the basin, compared to 48 percent during the validation period. During the calibration and validation periods, surface runoff accounts for 65 percent and 69 percent of the water output, respectively. During the calibration and validation periods, ground water provides 28 percent and 26 percent of the water output, respectively"[6].

Period	Year		Precipitation	ET	Sur_Q	Lat_Q	GW_Q	WYLD	PERC
Calibration	1997-2008	mm	938	532	245	28	105	378	149
		%	100	57	26	3	11	40	16

Validation	2009	mm	1034	442	354	38	112	504	158
		%	100	43	34	4	11	49	15
	2010	mm	873	518	162	37	96	295	138
		%	100	59	19	4	11	34	16

Table 7: Water Balance Components on an Annual Average Basis over the Calibration and Validation Periods for Middle Narmada Basin

Water Balance Ratio

	Streamflow/Precipitation	Baseflow/Total Flow	Surface Runoff/Total Flow	Percolation/Percipitation	ET/Preciptation
Calibration (1997-2008)	0.4	0.35	0.65	0.16	0.57
Validation (2009)	0.49	0.3	0.7	0.15	0.43
Validation (2010)	0.34	0.45	0.55	0.16	0.59
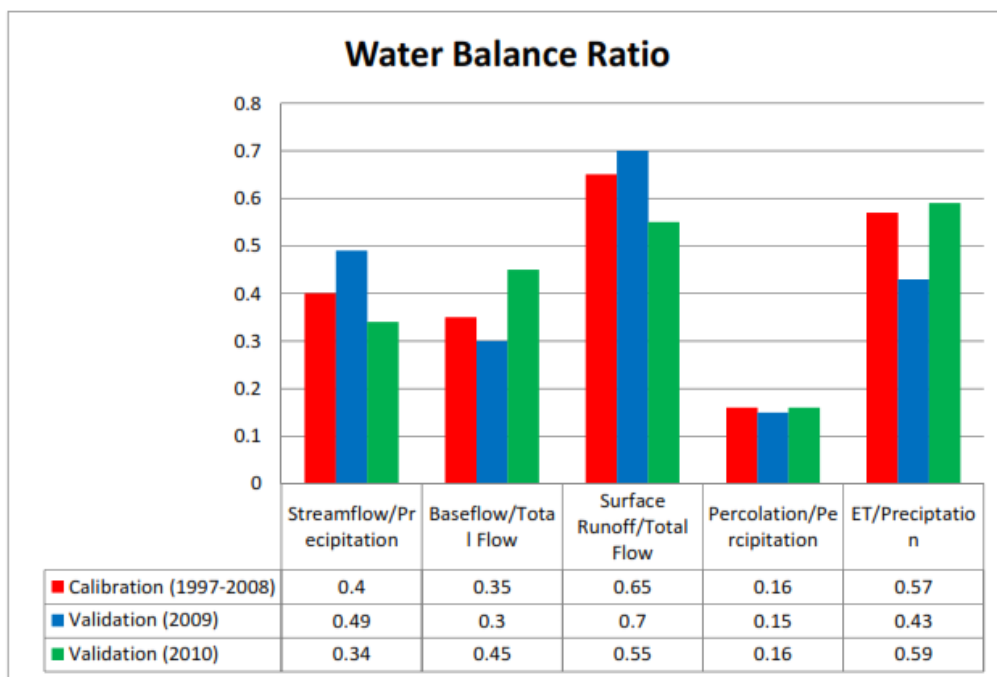
Figure 50: Water Balance Ratio on an Annual Average Basis over the Calibration and Validation Periods for Middle Narmada Basin

Conclusion

The SWAT2012 model has been effectively adjusted and checked utilizing the SUFI-2 strategy in the Middle Narmada Basin. The hydrological water equilibrium and surface overflow is assessed in the bowl. The model's affectability study to sub bowl depiction and HRU definition limits uncovered that the stream is more delicate to the HRU definition edges than the sub bowl discretization impact. The SUFI-2 technique is useful, yet requires extra emphasess and changes to the boundary ranges. The examinations of the hydrological water balance showed that the base stream adds to add up to squander in the explored region more than the surface overflow. Evapotranspiration represents about 45% of bowl misfortunes. Notwithstanding information weakness, the SWAT model delivered incredible recreation results for every day and month to month time stages. The aligned model might be utilized to survey the impact on future motion and soil disintegration of environment and land use and other administration situations.

Appendix

Appendix A: Avg. Monthly Basin Values
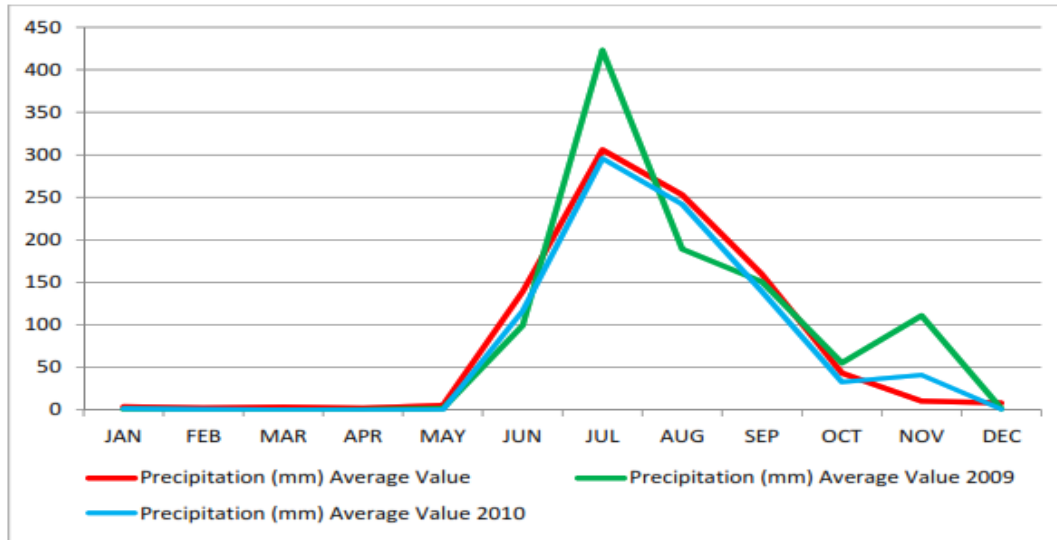
Figure 51: Comparison of Precipitation on a Monthly Average Basis for the year 2009 and 2010 Periods with Average Value of Middle Narmada Basin
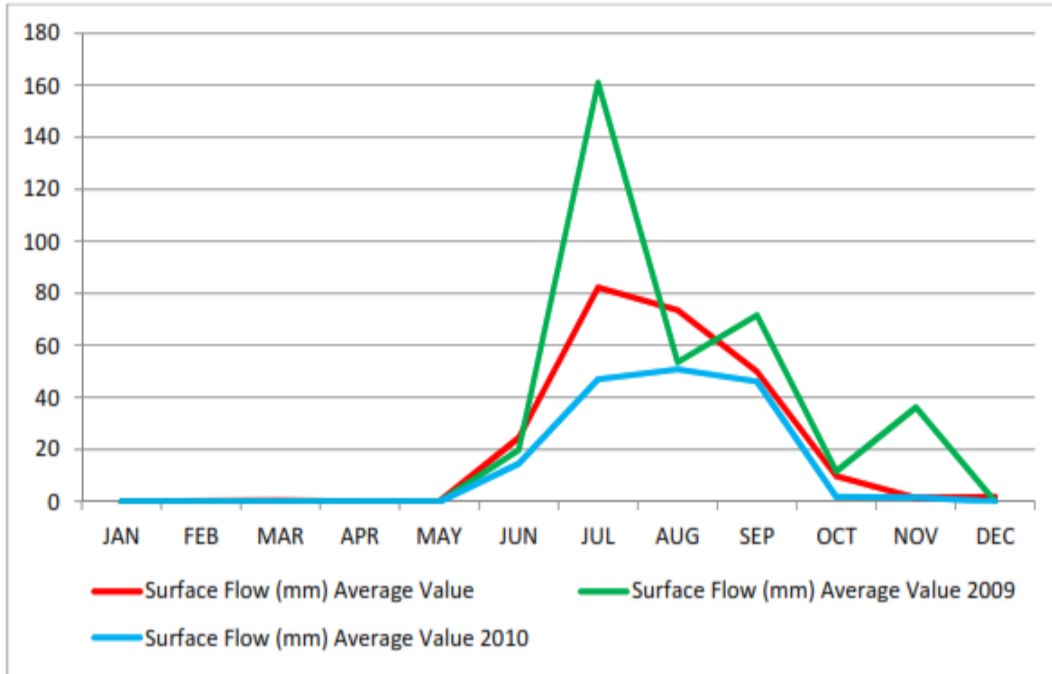
Figure 52: Comparison of Surface Flow on a Monthly Average Basis for the year 2009 and 2010 Periods with Average Valueof Middle Narmada Basin
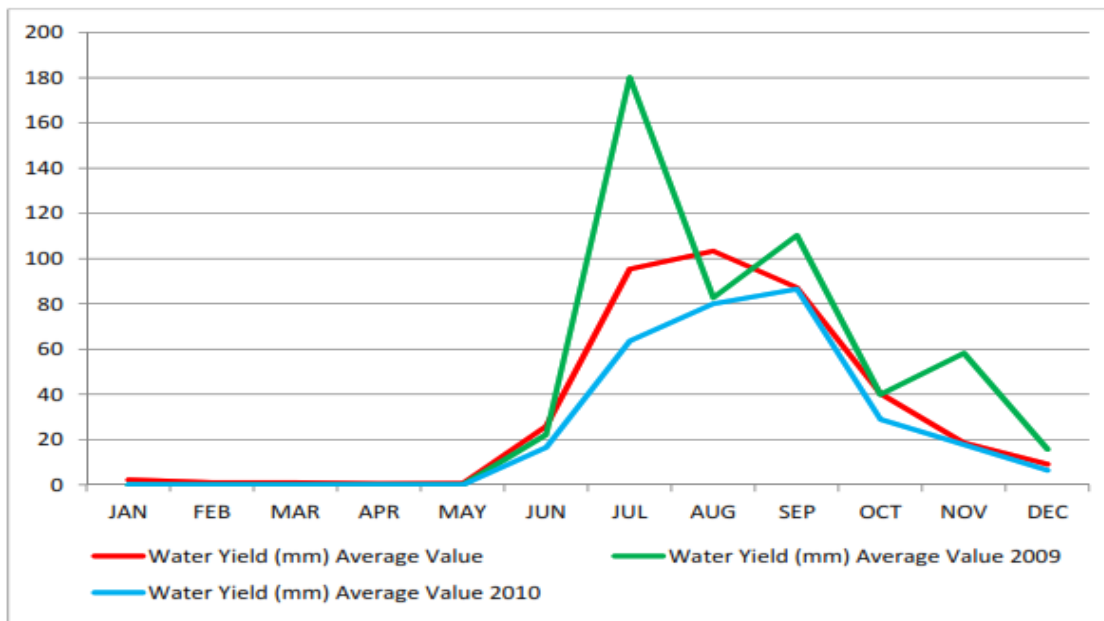
Figure 54: Comparison of Water Yield on a Monthly Average Basis for the year 2009 and 2010 Periods with Average Valueof Middle Narmada Basin
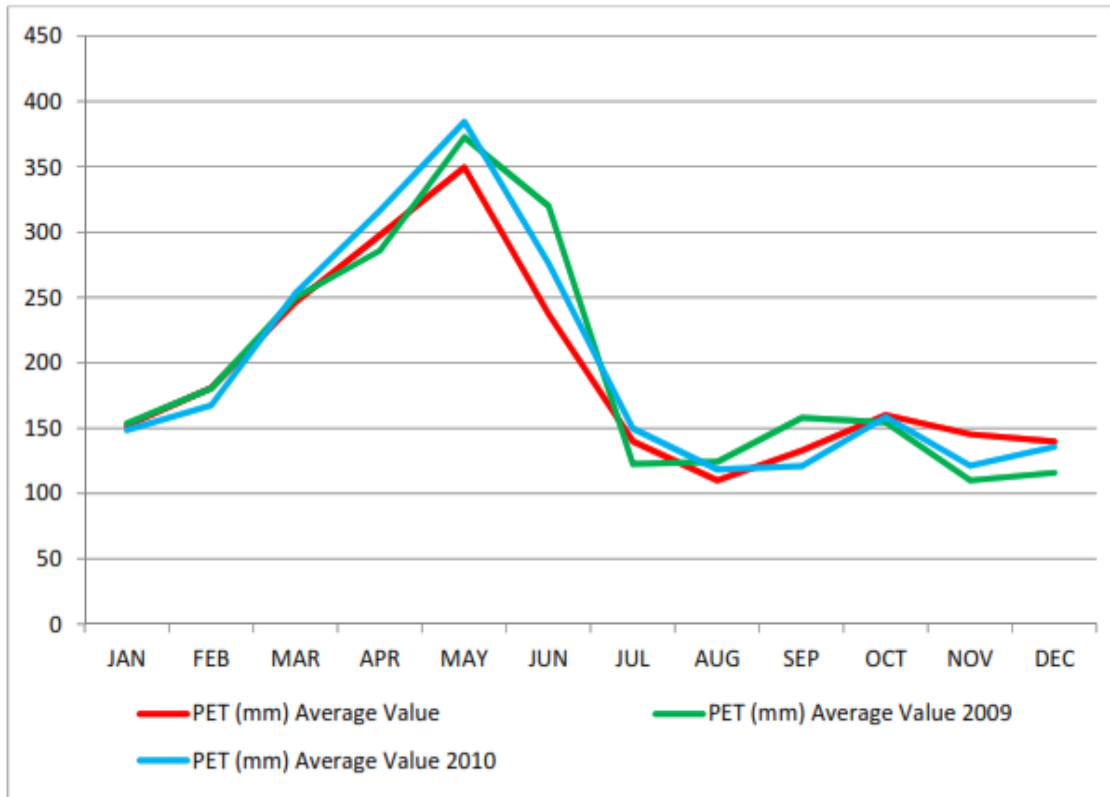
Figure 56: Comparison of Potential Evapotranspiration on a Monthly Average Basis for the year 2009 and 2010 Periods with Average Valueof Middle Narmada Basin

Appendix B: SWAT Error Checker Output
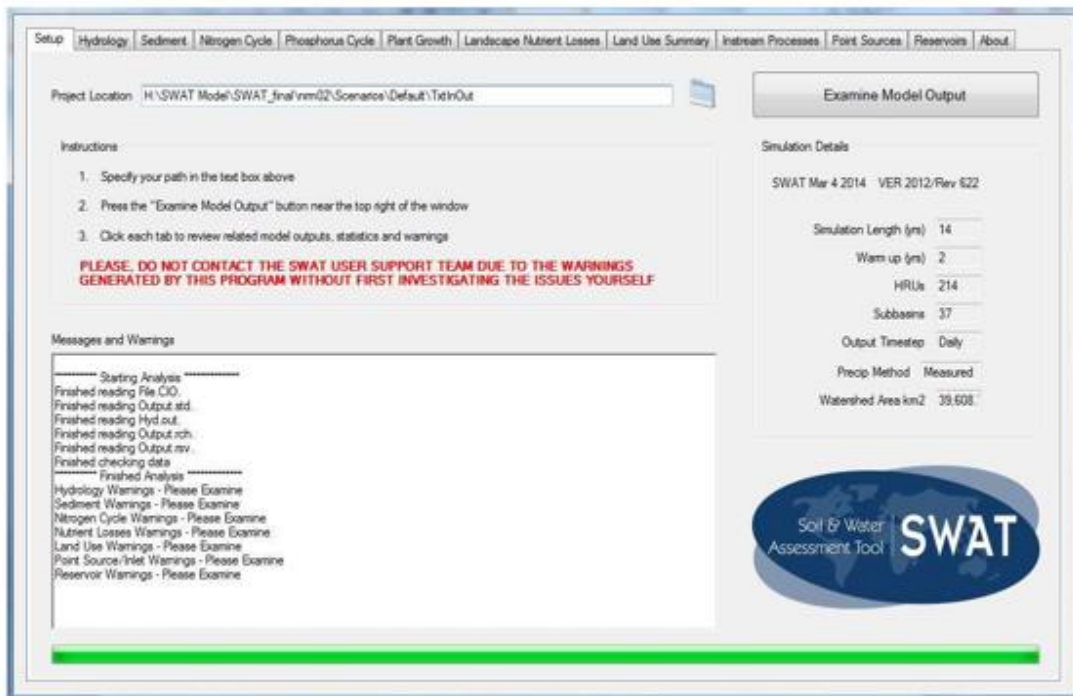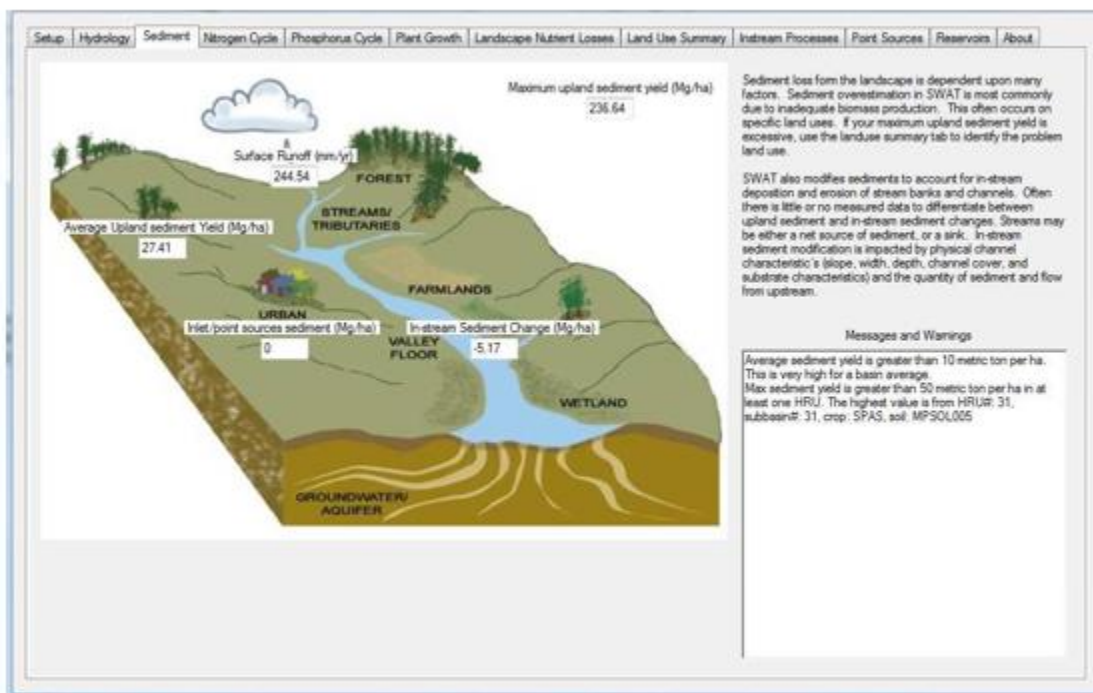

Figure 57: Setup Tab of SWAT Error Checker for the Middle Narmada Basin
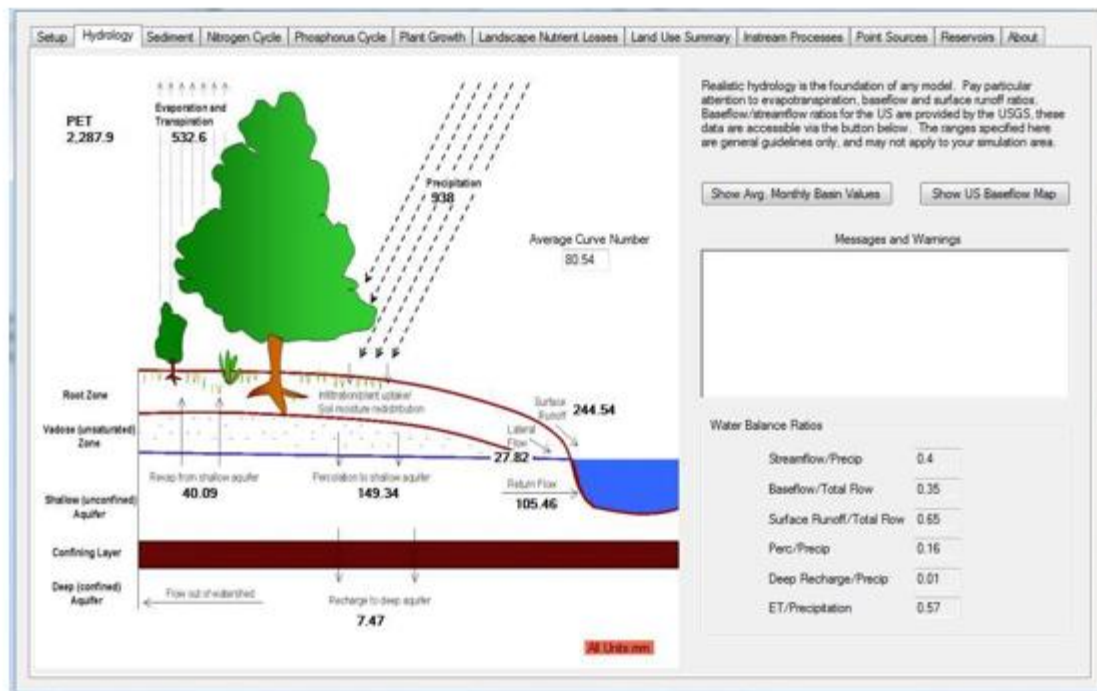
Figure 58: Hydrology Tab of SWAT Error Checker for the Middle Narmada Basin

Figure 59: Avg. Monthly Basin Value of SWAT Error Checker for the Middle Narmada Basin

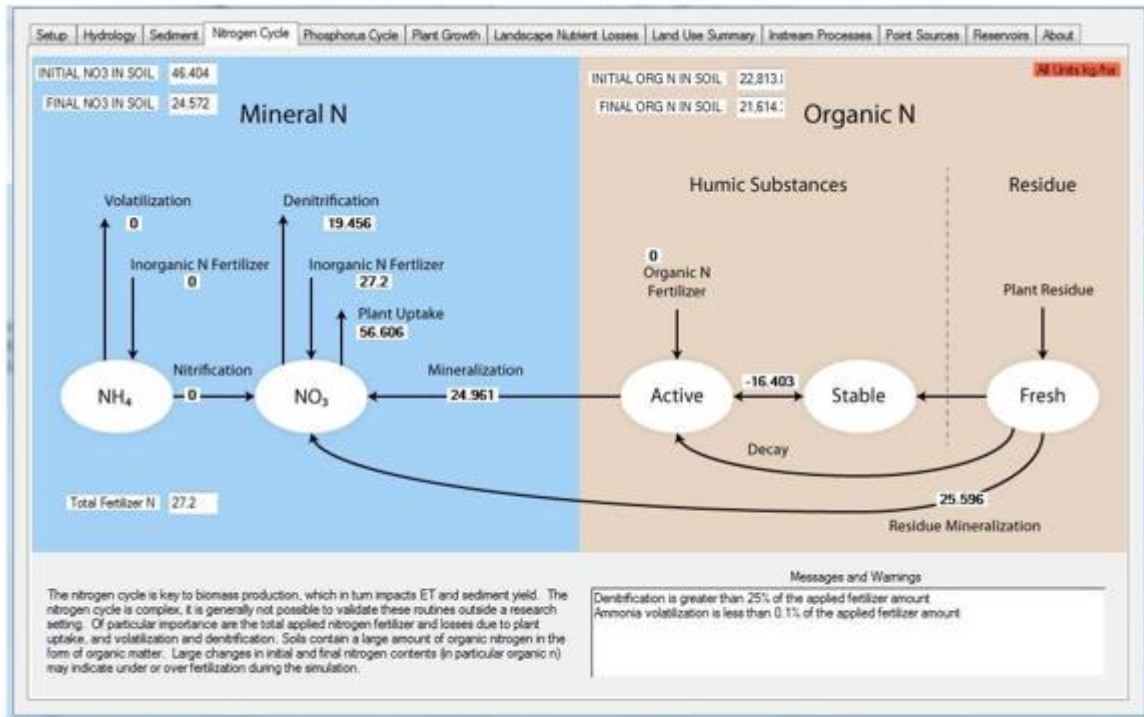Figure 60: Sediment Tab of SWAT Error Checker for the Middle Narmada Basin

Figure 61: Nitrogen Cycle Tab of SWAT Error Checker for the Middle Narmada Basin
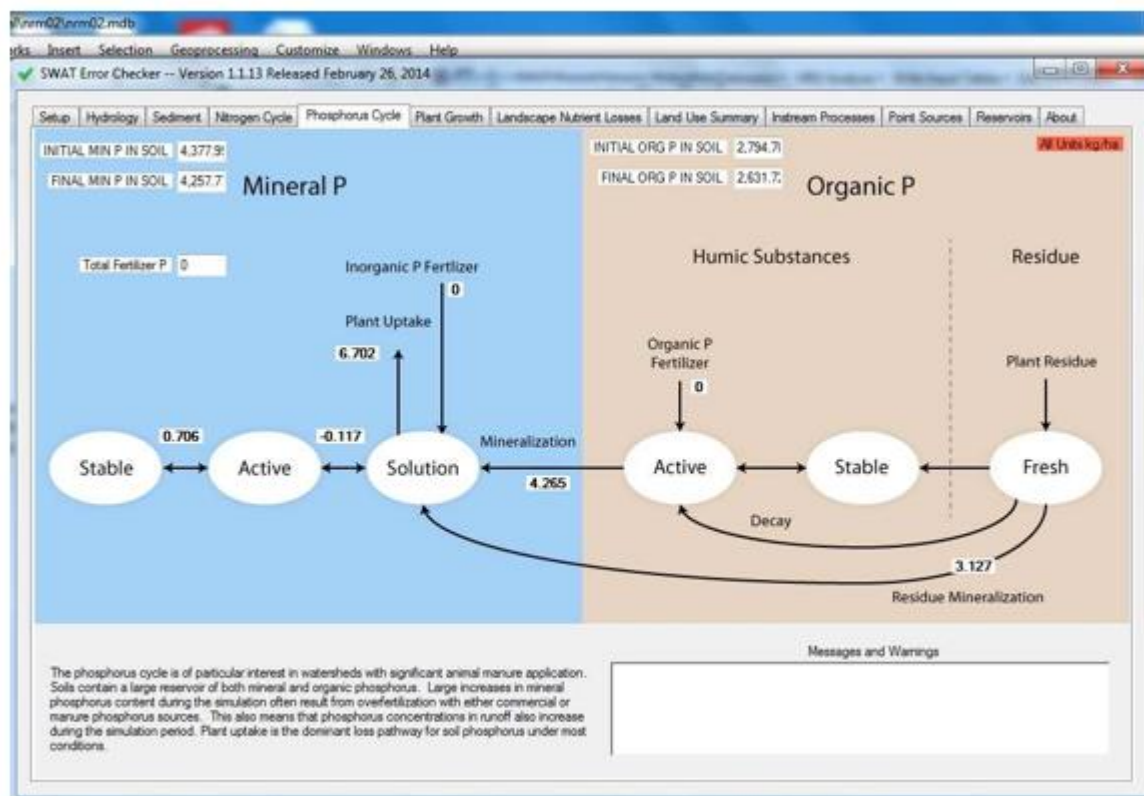

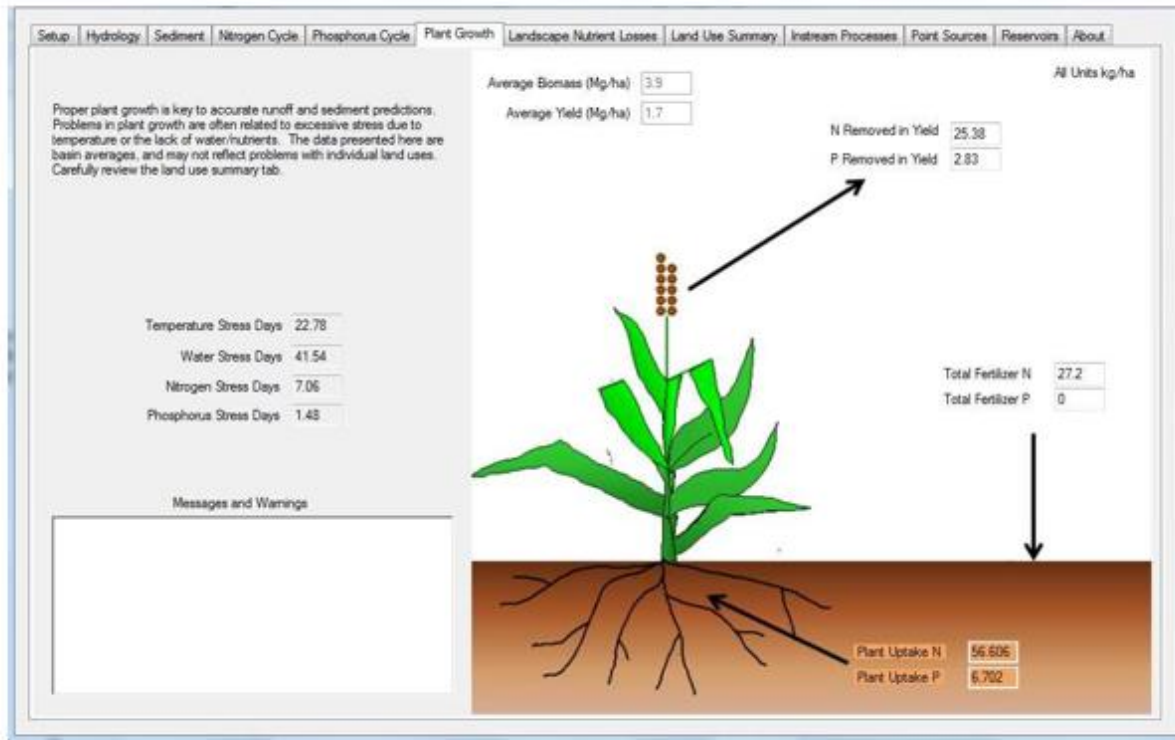*Figure 62: Phosphorus Tab of SWAT Error Checker for the Middle Narmada Basin*

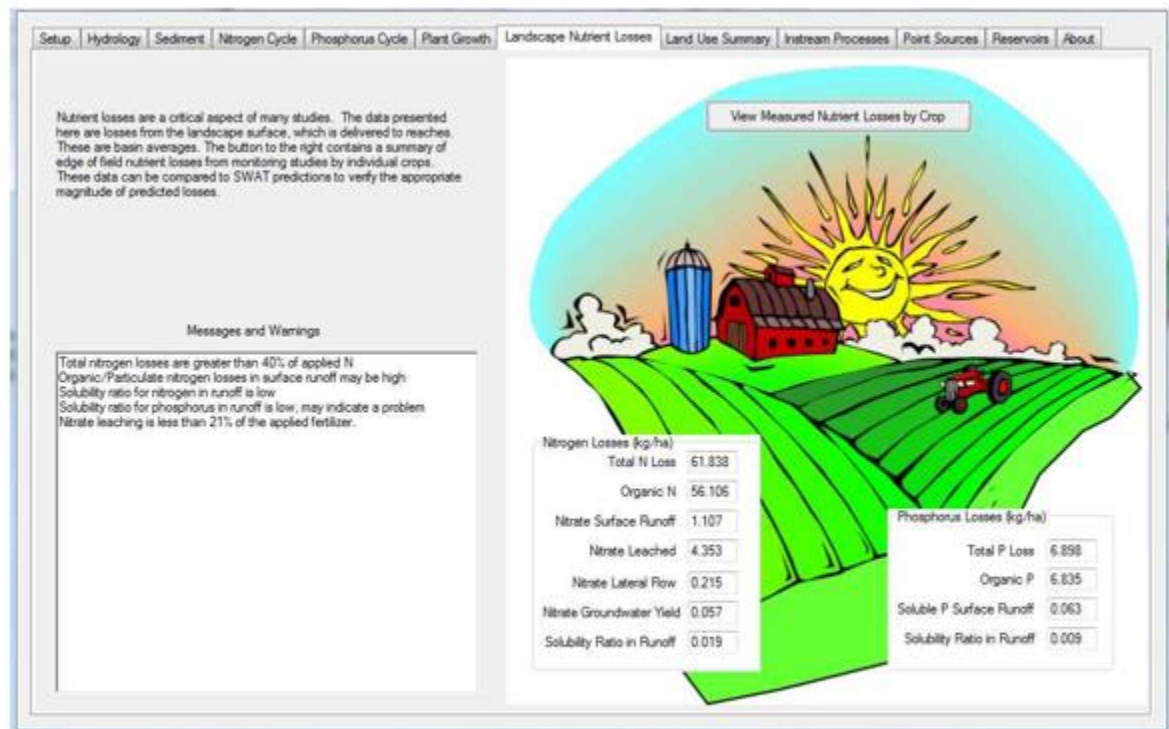Figure 63: Plant Growth Tab of SWAT Error Checker for the Middle Narmada Basin

Figure 64: Landscape Nutrient Losses Tab of SWAT Error Checker for the Middle Narmada Basin
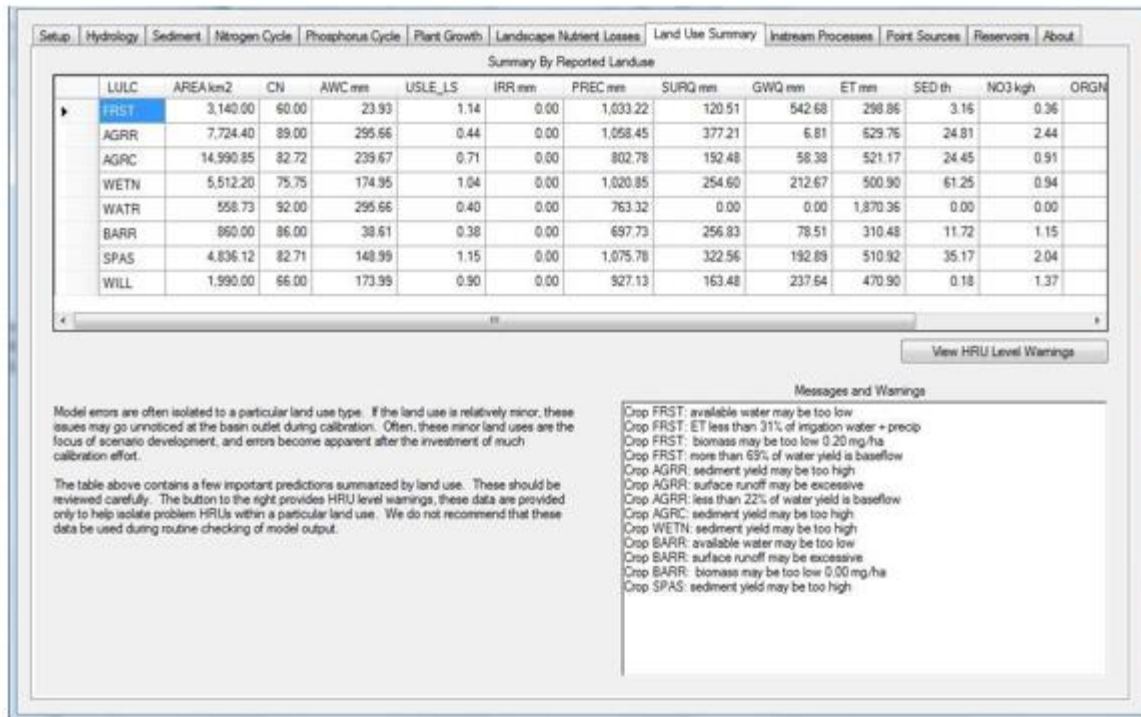
Figure 65: Land Use Summary 1 Tab of SWAT Error Checker for the Middle Narmada Basin
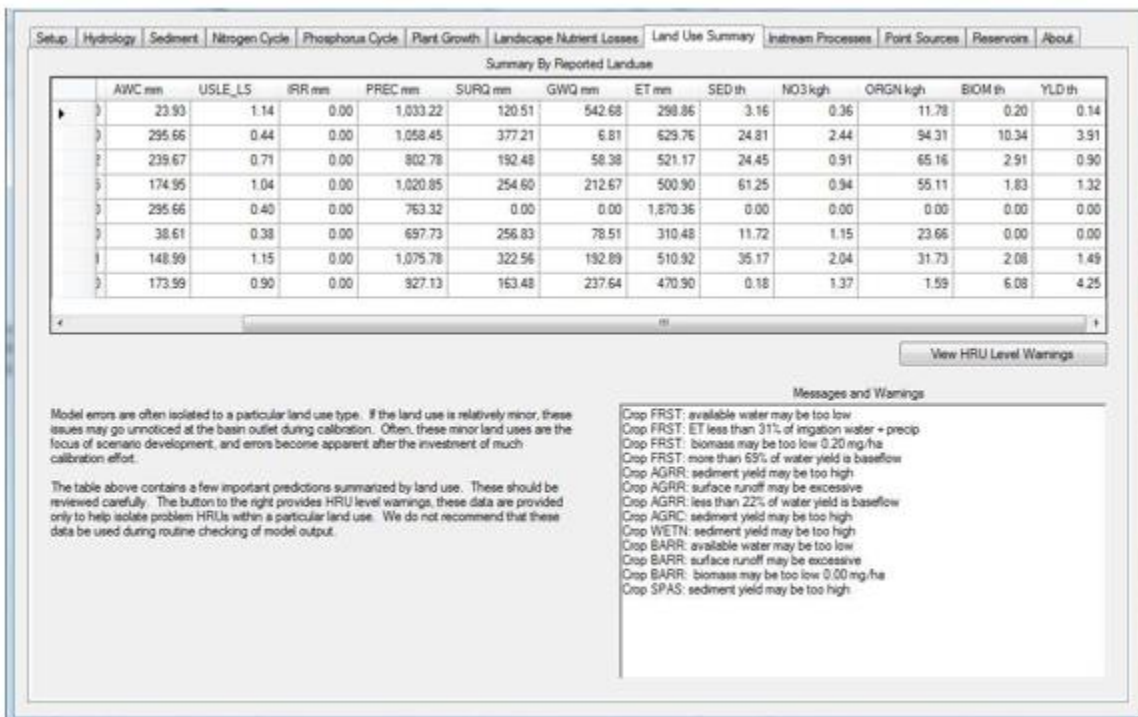

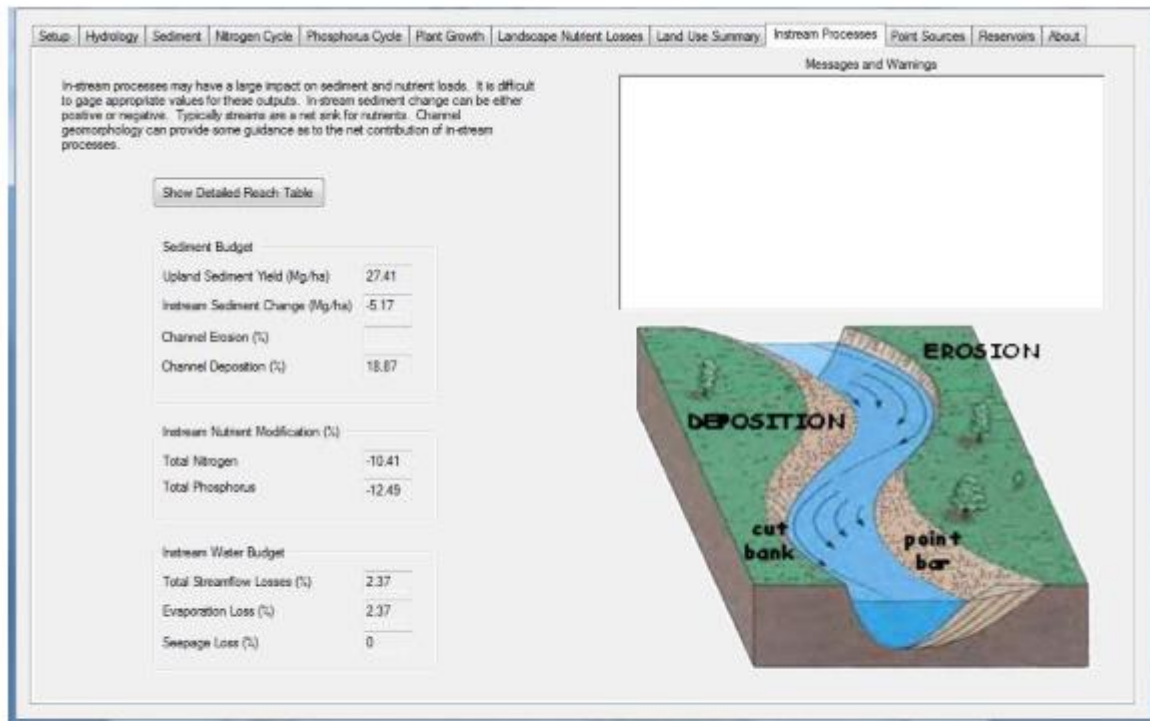*Figure 66: Land Use Summary 2 Tab of SWAT Error Checker for the Middle Narmada Basin*

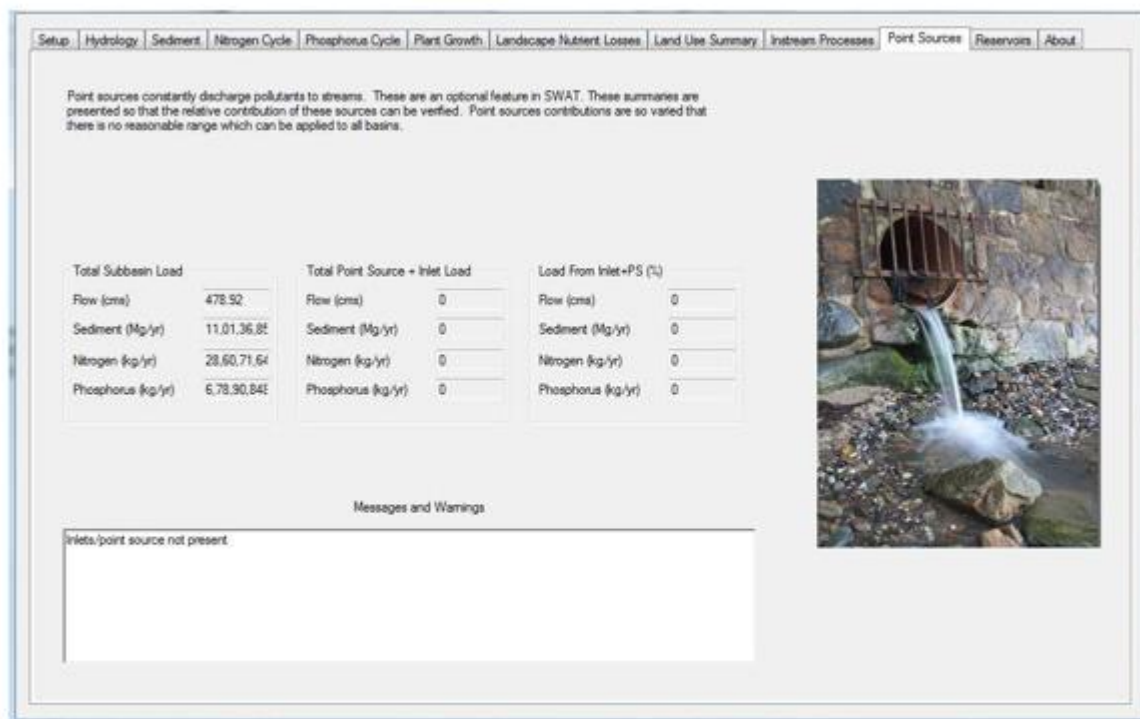Figure 67: Instream Processes Tab of SWAT Error Checker for the Middle Narmada Basin

Figure 68: Point Sources Tab of SWAT Error Checker for the Middle Narmada Basin

Appendix C: Sensitivity analysis

Sensitivity Analysis of Different Parameters used for Surface Flow

| Parameter Name	t-Stat	P-Value
3:V__GW_DELAY.gw	-8.354909466	0.000000000
12:R__SOL_BD(..).sol	-3.590008114	0.000549290
4:V__GWQMN.gw	-2.176908974	0.032227552
11:R__SOL_K(..).sol	-1.827125232	0.071149727
10:R__SOL_AWC(..).sol	-1.736366214	0.086080094
2:V__ALPHA_BF.gw	-1.242249953	0.217521211
1:R__CN2.mgt	-1.041923372	0.300367417
5:V__GW_REVAP.gw	-0.552891866	0.581771800
9:V__ALPHA_BNK.rte	-0.113266808	0.910083022
13:V__SFTMP.bsn	0.085425780	0.932121462
6:V__ESCO.hru	0.121224720	0.903795838
8:V__CH_K2.rte	0.331338506	0.741194848
7:V__CH_N2.rte	0.673214000	0.502616305
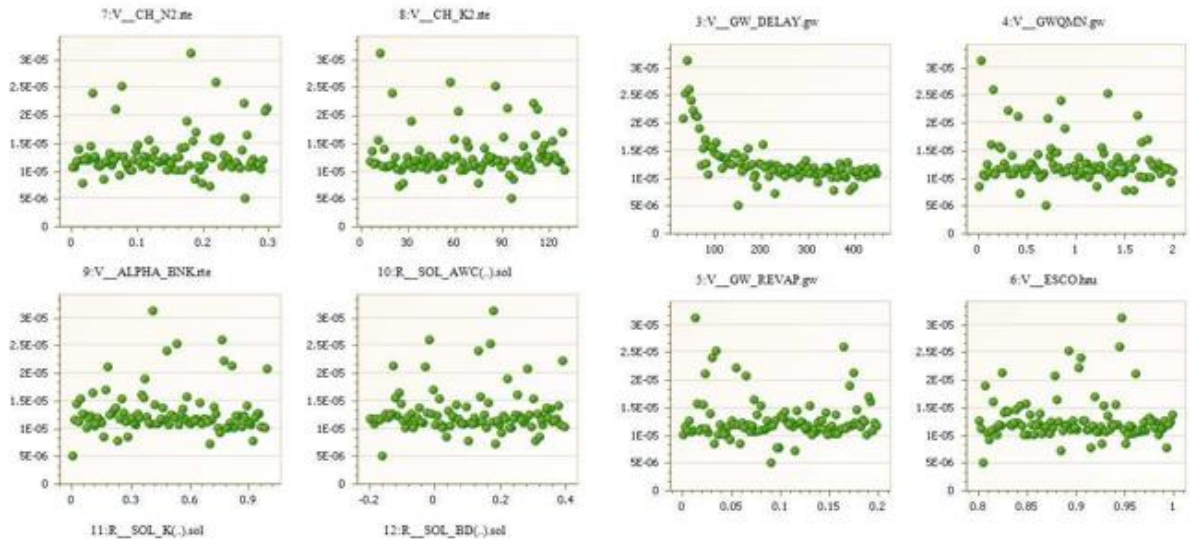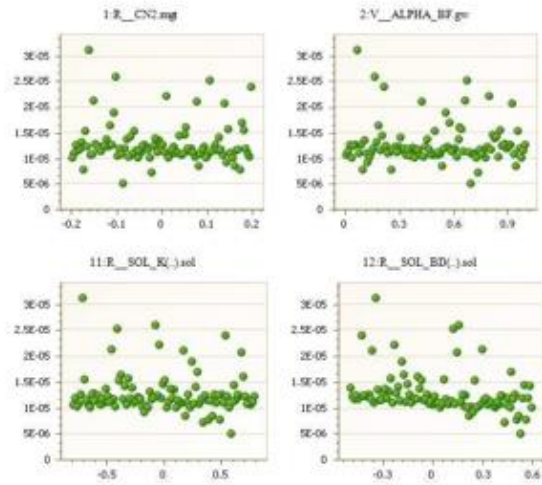
Figure 69: Dotty Plots of Different Parameters used in Surface Flow Calculation for the Middle Narmada Basin

Dotty plots illustrate the connection between the values of parameters and the function goal.

The primary purpose of these graphs is to show the distribution of sample points and to provide a sense of parameter sensitivity.

The t-stat sensitivity measures (higher absolute values show more sensitivity) and p-values reflect sensitivity significance. Near zero values are of higher significance.

GW DELAY, R SOL BD and V GWQMN are the most important parameters in the above.

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