Hydrologic Response to Land Use/ Land Cover Change in Upper Narmada Basin

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List of Abbreviations

Abbreviation	Description
AQR	Aquifer Recharge
Cumec	Cubic meter per second
DEM	Digital Elevation Mode
ENS/NSE	Nash-Sutcliffe Efficiency
ET	Evapotranspiration
e.g.	For example
et al.	And others
ETM+	Enhanced Thematic Mapper plus(advance)
FCC	False Color Composite
Fig.	Figure
GIS	Geographical Information System
GPS	Geographical Positioning System
GWQ	Ground Water Flow
ha	Hectare
HBV	Hydrologisika Bayraans Vattenbalans avediling
HEC-HMS	Hydraulic Engineering Centre-Hydrologic Modeling System
HRU	Hydrological Response Unit
i.e.	That is
IGBP-IHDP	International Geosphere-Biosphere Program and the International Human Dimension Program
J.N.K.V.V.	Jawaharlal Nehru Krishi Vishwa Vidyalaya
LULC	Land Use / Land Cover
LUCID	Land-Use Change Impacts and Dynamics
Max	Maximum
Min	Minimum
M ha	Million Hectare
M.P.	Madhya Pradesh
MoA	Ministry of Agriculture

MoEWR	Ministry of Energy and Water Resources
MRS	Mean Relative Sensitivity
PBias	Percent of bias
R^2	Coefficient of Determination
RS	Remote Sensing
RSR	Root mean Square Error
SCS	Soil Conservation System
SURQ	Surface runoff
SWAT-CUP	Soil and Water Assessment Tool- Calibration and Uncertainty Programs
SUFI2	Sequential Uncertainty Fittings 2
SWAT	Soil and Water Assessment Tool
TM	Thematic Mapper
UTM	Universal Trans Mercator
USGS	United States Geographical Survey
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
Viz.	Videlicet or used as Namely or that is to say or as follows
WY	Water Yield
WGEN	Weather Generator

List of Symbol

Symbol	Stand for
%	Percentage
º	Degree
‘	Minute
“	Second
<	Lesser than
>	Greater Than
&	And
Q	Discharge
≤	Lesser than or equal
≥	Greater than or Equal
±	Plus -Minus

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1. INTRODUCTION

Land and water are the two most vital natural resources of the world and these resources must be conserved and maintained carefully for environmental protection and ecological balance. Prime soil resources of the world are finite, non-renewable over the human time frame, and prone to degradation through misuse and mismanagement. In India, out of a total geographical area of 328 M ha, an estimated 175 M ha of land, constituting an area of 53% suffers from deleterious effect of soil erosion and other forms of land degradation (Baishya, 2006). Due to increasing population pressure, exploitation of natural resources, faulty land and water management practices, the problem of land degradation will further aggravate. Land use change within a region has not only an impact on various hydrologic landscape functions but also affects the habitat quality and thus the biodiversity of a landscape. Water resources degradation is an issue of significant societal and environmental concern.

Information on land use/land cover (LULC) in the form of maps and statistical data is very vital for spatial planning, management and utilization of land for agriculture, forestry, pasture, urban-industrial, environmental studies, economic production etc. Today, with the growing population pressure, low man-land ration and increasing land degradation, the need for optimum of land assumes much greater relevance. The draft outline on the National Land Use Policy and strategy on optimum land Use planning and the creation of National land use conservation Board (NLUCB) in 1985 clearly indicate the serious concern of the government in this regard. Further, with the present thrust that the agricultural planning in the country should be based on agro-climatic zones, the prima-facie need is to have a comprehensive information on the spatial distribution pattern of land use/ land cover, particularly on the availability of agricultural land during Kharif and Rabi crop seasons, cropped area during both seasons and area under fallow, apart from other land use/land cover classes.

Water is the principal motivating and integrating factor in hydrologic response studies. The concept of a watershed inherently integrates the upstream with the downstream through the flow of this central resource as part of the general hydrological cycle. A number of villages in a watershed often share the same stream as their water source. However, stream flow usually has high seasonal variability, and seasonal local water scarcity is a problem faced by many farmers in small watersheds (Jamtsho and Gyamtsho 2003). Furthermore, variability in stream flow produced by complex interactions of land use, land management, and climate, combined with competing and increased demand, make management of water resources at watershed scales extremely challenging and requires a thorough understanding of these interactions. Given that impacts of LUCC on water resources are the result of complex interactions between diverse site specific factors and offsite conditions, standardized types of responses will rarely be adequate. General statements about land–water interactions need to be continuously questioned to determine whether they represent the best available information and whose interests they support in decision-making processes (FAO, 2000, 2002; Bewket and Sterk, 2005).

Understanding how LULC influence stream flow will enable planners to formulate policies towards minimizing the undesirable effects of future land use changes on stream flow pattern. Furthermore, future LULC together with climate change scenarios can cause significant impacts on water resources by resulting changes in the hydrological cycle. However, in order to predict the future effects of LULC on river flow, it is important to have an understanding of the effects on historic LULC have had on river flow. Besides, the knowledge of the types and impacts of land use and land cover and climate changes is essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable management of natural resources.

Nowadays there is a great need to detect spatial patterns of land use/land cover (LULC) change at local, regional and global scales (Doxani et al, 2012). Understanding LULC change is of fundamental importance for environmental monitoring, urban planning, and governmental decision-making around the world (Ji et al, 2006). One particular consequence of LULC change has considerable impacts on hydrological processes by affecting the nature of surface runoff and water quality, hence further impact on ecosystems, biotic systems, and even on human health (Gordon et al, 1992; Novotny and Olem, 1994; Rogers 1994; Paul and Meyer, 2001; Frumkin, 2002).

Increased stream flow can pick up large amount of soil contaminants (often containing fertilizers and pesticides) to the streams to contribute non-point source (NPS) pollution, which is also produced from fertilizers used for agriculture. NPS pollution has become the leading cause of degraded water quality in the U.S. (Bhaduri et al, 2000). For example, accumulated nutrient such as nitrogen (N) and phosphorus (P) in the water body can cause surface and ground water impairment such as nutrient enrichment. Eutrophication and algae blooms can greatly harm aquatic ecosystems by depleting oxygen and killing aquatic plant and animal species (Young, 1999; Danovi, 2011).Eroded sediment from agricultural land and construction sites is another NPS pollution source. It was carried to nearby streams where it may clog drainage ditches, because turbidity in water bodies, and increase water-treatment costs (USGS, 2011).

Thus, quantifying the relationship between LULC change and its impact on hydrology including both water quantity and quality would provide valuable information for land use. Temporal changes and spatial patterns are often studied by analyzing land use land cover changes using space borne images. LULC is an important factor, affecting runoff regime within watersheds through processes such as urbanization, agricultural activities, quarries and afforestation.

An understanding of hydrological processes is essential for investigating impacts of land use and land cover, and climate changes on water resources. Hydrologic response to changes in land use and land cover changes, land management practices and climate changes is an integrated indicator of watershed condition. Watersheds are generally considered as useful units of analysis and action because of several physical (Natural system, multiple scales, ideal for process studies, integrated framework, assist in addressing complexity) and social (decision-making tool, social organization, upstream and downstream links) characteristics (Schreier et al, 2003; Richard B, 2005).

Hydrologic modeling and water resources management studies are intrinsically related to the spatial processes of the hydrologic cycle. Land use and land cover influences watershed hydrological responses by partitioning rainfall between return flow to the atmosphere as evaporation and transpiration and flow to aquifers and rivers. However, techniques for the analysis of the impact of LU/LC on modeled hydrological responses are still very much at early stage. The prediction of the effect of future change (and validation of prediction) has hardly even started (Beven, 2001).

The land use / land cover change has significantly impacts on natural resources, socioeconomic and environmental systems. However, to assess the effects of land use and land cover change on stream flow, it is important to have an understanding of the land use / land cover patterns and the hydrological processes of the basin. Understanding the types and impacts of land use and land cover change is essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable management of natural resources in the country in general and at the study area in particular.

Moreover, the study presents a method to quantify land use and land cover change and their impact on hydrological regime. This has been achieved through a method that combines the hydrological model i.e. Soil Water Assessment Tool (SWAT) to simulate the hydrological processes, Geographical information system (GIS) and Remote sensing (RS) techniques to analysis the land use and land cover change.

Objective of the Study

The main objective of this study is to assess the hydrologic response to land use land cover change in upper Narmada basin using Remote Sensing and GIS Techniques, with Soil and Water Assessment Tool (SWAT model) for the past 23 years (1989-2011). The study has been carried out with the following specific objectives:

- **I.** To detect the land use /land cover (LULC) change from 1989 to 2011 using remotely sensed data.
- **II.** To assess the hydrological response to land use /land cover change of upper Narmada basin.
- **III.** To predict runoff with changing scenario of land use /land cover.

2. REVIEW OF LITERATURE

2.1 General

Land use and land cover change very often due to the growing population and economy. In human history, land, a fundamental factor of production has been coupled to economic growth (Richards, 1990). Land use affects land cover and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere (Riebsame et al, 1994). The main factor that causes LULC changes are human demand for physical resources, technological expansion and institutional capacity to produce and consume such resources. The rapidly increasing population pressure in many rural areas of developing countries has often led to changes in LULC in terms of deforestation, reclamation of wetlands, etc. mainly aiming at agricultural production. Neither population nor poverty alone constitute the sole and major underlying causes of land cover change world-wide (Lambin et al, 2001). Rather, responses of people to economic opportunities, as mediated by institutional factors, drive land cover changes. Opportunities and constraints for new land uses are created by local as well as national markets and policies. Global forces become the main determinants of land use change, as they amplify or attenuate local factors.

Monitoring of these changes and assessing the impacts are very critical for developmental plans (Krishna et al, 1999). LULC monitoring is an important aspect to determine the LULC change and likely impacts on the ecosystem (Eiumnoh et al, 1997) that often lead to several environmental impacts, such as soil erosion, soil moisture, soil nutrients, change in micro-climate and so forth. These impacts not only affect within the watershed boundary but also bring in several harmful effects downstream. Knowledge of LULC change is important for many planning and management activities (Lillesand and Kiefer, 1994). Technological, institutional and natural resource policy forces also play an important role in changing land use pattern (Rao and Pant, 2001). Therefore, knowledge of changes in LULC is becoming far more important from both ecological and economical point of view (Lucas and Molenaar, 1990). Limitations of hydrological measurement techniques and a limited range of measurements in space and time are the main reasons to model the rainfall-runoff processes in hydrology (Beven, 2001). Everything we want to know in the hydrological cycle cannot be measured. Hence, we require to extrapolate our requirements from the available measurements and then arrive at the likely impact of future hydrological change. The assessment of the effects of LULC changes on water resources, runoff generation and floods is one of the recent areas of importance in hydrological modeling and is one of the main research topics in the last decade.

2.2 Land use / land cover change: A remote sensing and GIS perspective

Land use and land cover change are perhaps the most prominent form of global environmental change since they occur at spatial and temporal scales immediately relevant to our daily existence (CCSP, 2003). Technically, land use and land cover change mean quantitative changes in areal extent (increase or decrease) of a given type of land use and land cover respectively. Land use and land cover change are a manifestation of forces both anthropogenic and environmental – climate driven factors (Liu et al, 2009). The changes in land use in various spatial and temporal domains are the material expressions, and also indicate environmental and human dynamics and their interactions mediated by land availability (Lambin et al, 2003).

Spatial data on land use and land cover in a region is a prerequisite to determining the qualitative and quantitative changes in land use and land cover. Advances in remote sensing over the past few decades now enable repeated observations of the earth's surface (NAP, 2008).With the increase in sensor capability in terms of spatial resolution, spectral variability and temporal frequency, the minute changes on the earth's surface can be estimated fairly accurately.

Land use and land cover changes, apart from changing the physical dimension of the spatial extent of the land use and land cover classes, also influence many of the secondary processes which lead to the eventual degradation of the ecosystems of the earth (Dregne and Chow, 1992). First and foremost, the impact of land use and land cover changes is the reduction of vegetation cover. The loss of a vegetation cover, in turn, leads to many other deleterious effects on the environment, namely, loss of biodiversity, climate change, changes in radiative forcing, pollution of other natural ecosystems with a reduction in their quality, changes in hydrological regimes, and the list continues (Niyogi et al, 2009). The secondary impact of land use and land cover changes initiates a cascade of effects on the environment and this works in a loop to further influence land use and land cover changes.

2.2.1 Causes and consequences

LULC can occur through the direct and indirect consequences of human activities to secure essential resources. This may first have occurred by means of burning of areas to develop the availability of wild game and it accelerated with the birth of agriculture, resulting in extensive clearing such as deforestation and earth’s terrestrial surface management that takes place today (Ellis and Pontius, 2006). Land use/ cover change is known as a complex process which is caused by the mutual interactions between environmental and social factors at different spatial and temporal scales (Valbuena et al, 2008; Rindfuss et al, 2004).

More recently, industrial activities and developments, the so-called industrialization, has encouraged the concentration of population within urban areas. This is called urbanization, which includes depopulation of rural regions along with intensive farming in the most productive lands and the abandonment of marginal lands (Ellis and Pontius, 2006). LULC changes are increasingly known as the consequence of actors and factors’ interactions (Bakker and van Doorn, 2009). These conversions and their consequences are obvious around the world and it has been becoming a disaster around the metropolitan areas in developing countries.

2.2.2 Driving force

Assessing the driving forces behind LULC is essential if previous patterns can explain and be utilized in forecasting future patterns. Land use /cover change can be caused by multiple driving forces that control some environmental, social and economic variables. These driving forces can contain any factor which influences human activities, including local culture, economic and financial matters, environmental circumstances (i.e. greenness, land quality, terrain situation, water availability and accessibility to recreation), current land policy and development plans, and also interactions between these factors. Therefore, these drivers have to be found to pursue these controlling variables. The driving forces will be utilized in order to manage land change. Investigation of interrelations between the drivers of land change needs a strong knowledge about methods and effective variables, as well as land policy (Ellis and Pontius, 2006). LULC is frequently addressed through mostly considered exogenous to the land use system (Verburg et al, 2004). Associations between driving forces and LULC could be addressed qualitatively and quantitatively by means of appropriate approaches.

2.3 Trends of land use /land cover change

Land use changes are complex processes that arise from modifications in land-cover to land conversion process (Noe, 2003). Despite this complexity, little is known about how human and environmental factors operate and how they interact to affect land-use patterns and hydrological processes (LUCID, 2004). According to Lambin (2001), land use /Land cover change is driven by the interaction in space and time between biophysical and human dimensions. There are also the potential impacts on physical and social dimensions.

According to the International Geosphere-Biospehre Program and The International Human Dimension Program (IGBP-IHDP, 1999), land cover refers to the physical and biophysical cover over the surface of earth, including distribution of vegetation, water, bare soil and artificial structures. Land use refers to the intended use or management of the land cover type by human beings such as agriculture, forestry and building construction.

Land use / land cover (LULC) change is commonly grouped in to two broad categories: conversion and modification (Meyer and Turner, 1994). Conversion refers to a change from one cover or use category to another (e.g. from forest to grassland). Modification, on the other hand, represents a change within one land use or land cover category (e.g. from rainfed cultivated area to irrigated cultivated area) due to changes in its physical or functional attributes. These changes in land use and land cover systems have important environmental consequences through their impacts on soil and water, biodiversity, and microclimate (Lambin et al, 2003).

Generally, knowing of the impacts of land use and land cover change on the natural resources like water resources depends on an understanding of the past land use practices, current land use and land cover patterns, and projection of future land use and land cover, as affected by population size and distribution, economic development, technology, and other factors. The land use and land cover change assessment is an important step in planning sustainable land management that can help to minimize agro-biodiversity losses and land degradation, especially in developing countries (Hadgu, 2008).

2.4 Land use / land cover changes and their impact on hydrology

Increased stress on the land due to population growth affects the hydrology of the area. The assessment of the effects of LULC changes on water resources, runoff generation and floods is often necessary in hydrological modeling and has gained considerable importance in the past decades. The hydrologic effects of land use changes have been described by Calder (1993). Land use change can have local, regional and global hydrologic consequences. On a global scale, the largest change in terms of land area and also in terms of hydrologic effects, is from afforestation and deforestation.

Afforestation can affect annual flow, seasonal flow and flood. It also improves water quality and reduces soil erosion. Agricultural intensification alters transpiration rates and affects runoff. The drainage of wetlands and urbanization are other land use changes with important hydrologic consequences. Urbanization increases impervious land uses, reduces infiltration and causes more runoff and higher peak discharges.

Fongers and Fulcher (2002) in their study stress the importance of detention/retention structures to reduce the increased flow rates, stream bank erosion and to improve the water quality caused by urbanization. A study conducted by Noorazuan et al (2003) concludes that the landscape diversity of Langat River Basin, Malaysia, were significantly changed after 1980s and as a result, the changes also altered the Langat's stream flow response. White and Greer (2002) from their studies infer that increasing urbanization in the sub watershed of Los Penasquitos Creek, California has been shown to be associated with the significant hydrologic changes in the stream, the most obvious of which are increasing peak flood flows and dry season runoff. If the continued watershed urbanization is projected to the future, the current hydrologic characteristics of the coastal streams will likely continue to change, and the aquatic and riparian-associated wildlife species that are favored under these modified conditions will continue to increase at the expense of those species better suited to historic conditions.

The influence of land use changes on runoff generation has been frequently studied in the last two decades using computer simulation models. Either distributed physically based rainfall-runoff models or conceptual rainfall-runoff models have been used by many researchers. Distributed physically based rainfall-runoff models use a large number of parameters, which are difficult to determine and the runoff generation processes are not described adequately. Conceptual rainfall-runoff models use less parameters but describe the rainfall-runoff processes with simple concepts. This simplification prevents to transfer measured physiographic properties and incorporate variables directly into the modelling parameters (Weiler et al, 2000).

Lorup et al (1998) adopted a methodology combining common statistical methods with conceptual hydrological modelling to distinguish between the effects of climate variability and the effects of land use for six semi-arid basins in Africa. Their analysis indicated a decrease in the low flow for most of the testing catchments located within communal land, where large increase in population and agricultural intensity have taken place. Nandakumar and Mein (1997) combined a Monte-Carlo simulation method with a conceptual rainfall-runoff model to examine the effects on random errors with conceptual model parameters on flood predictions.

Nobert and Jeremiah (2012) revealed that forest area reduced by 1.4%, 3.2% increase in agricultural area, 2.2% increase in urban and 0.48% decreases in waterbody area between 1987 and 2000. The results from SWAT (Soil and Water Assessment Tool) model simulation showed that the average river flows has decreased from 166.3 mm in 1987 to 165.3 mm in 2000. The surface runoff has increased from 59.4mm (35.7%) in 1987 to 65.9mm (39.9%) in 2000 and the base flow decreased from 106.8mm (64.3%) to 99.4mm (60.1%) in 1987 and 2000 respectively. This entails that the increase of surface runoff and decrease of base flows are associated with the land use /land cover change.

Wagner et al (2013) studied on past land use changes between 1989 and 2009 and their impacts on the water balance in the Mula and Mutha Rivers catchment upstream of Pune. Land use changes were identified from three Rivers catchment multi-temporal land use classifications for the cropping years 1989/1990, 2000/2001, and 2009/2010. The hydrologic model SWAT (Soil and Water Assessment Tool) was used to assess impacts on runoff and evapotranspiration. Two model runs were performed and compared using the land use classifications of 1989/1990 and 2009/2010. The main land use changes were identified as an increase of urban area from 5.1% to 10.1% and cropland from 9.7% to 13.5% of the catchment area during the 20 yr period. Urbanization was mainly observed in the eastern part and conversion to cropland in the mid-northern part of the catchment. At the catchment scale found that the impacts of these land use changes on the water balance cancel each other out. However, at the sub-basin scale urbanization led to an increase of the water yield by up to 7.6 %, and a similar decrease of evapotranspiration, whereas the increase of cropland resulted in an increase of evapotranspiration by up to 5.9 %.

Kulkarni et al (2014). Integrated model has been applied for hydrologic impact on changing land use in Poisar watershed of Mumbai, India. The land use/land cover maps from the satellite imageries for 1972, 1992 and 2009 indicated that the impervious area increased by 116% between 1972 and 2009.

The hydrologic impact studies for few rainfall events showed increase in peak discharge between 7 and 30%, decrease in time to peak discharge between 0 and 4% and increase in surface runoff between 14 and 48%, between 1972 and 2009. The hydrologic impact for rainfall with return periods of 25, 50 and 100 years indicated that the peak discharge increased between 6 and 9%, time to peak discharge reduced between 0 and 2% while the surface runoff increased between 11 and 16%. They found that the hydrologic impact of urbanization on this catchment is more visible for low and medium rainfall events than for high and extreme events for the catchment.

2.4.1 Effects on low flow

Land use changes and their associated effects are known to impact the hydrology of the catchment area (Foley et al, 2005; Bronstert et al, 2002; Ott and Uhlenbrook, 2004; Tang et al, 2005). The effect of land-use and land cover change on low flows during dry periods depends on competing processes, most notably changes in evapotranspiration and infiltration capacity (Calder, 1998). Each combination of both the dominating natural processes and the anthropogenic impacts has a different effect on the low flow regime (Smakhtin, 2001). Therefore, the relatively quantitative impacts of various anthropogenic processes and factors on the low flow regimes vary substantially in different river sub-catchments (Tu Min, 2006). However, vegetation cover plays an important role of increasing the capacity of catchments, conserving moisture and increasing water yield (Ngana, 2002; Lal, 1997; Pereira, 1989). Tu Min (2006) noted the same that, upland forested catchments are important recharge zones for aquifers, because forests are often situated in areas with high annual precipitation and are associated with soils that have high infiltration capacities. However, such occurrence would be rare and would be significant only where small catchments feed a localized groundwater aquifer (Brooks, 1997). While the decrease in water flow was obvious in many tributaries of Pangani River Basin; the exact mechanism leading to the decrease was somewhat unclear (Shaghude, 2006). The decrease had been attributed to population increase and water use practices (Mujwahuzi, 2001; Yanda and Shishira, 1999; Shechambo, 1999; Mwamfupe, 2002; Ngana, 2002; Shishira, 2002; Yanda, 2002) which also were the driving forces for land-use change. It is evident that the population has grown substantially in the sub-catchment (Mbonile, 1999; Yanda, 2002), and it would seem rational to attach the water problems to population increases, growing water demand and degradation of water sources. Nevertheless, the reasons may be manifold and land-use/cover change seems to form part of such an explanation (Brandon and Bottomley, 1998; Chen, 2000; Diouf and Lambin, 2001; Kuntz and Siegert, 1999). In urbanized catchments, low flows have a tendency to decrease due to the effects (for example, preventing the slow infiltration of water and in turn reducing groundwater recharge) of urban impervious surfaces upon direct runoff, infiltration and evapotranspiration. Yanda and Shishira (2001) observe that around Kilimanjaro mountain region, human encroachment on the forest land was driven by logging; agricultural expansion and settlements development that had been paralleled by significant changes of the land-use and land cover. While at least 41km^2 of natural forest was lost between 1952 and 1982 (Yanda and Shishira, 2001), other significant changes were also evident on the other land-cover types, such as woodlands, bush lands and grasslands. It was apparent that the Pangani river basin is currently under critical water stress, resulting from land-use/cover change (Shaghude, 2006). Little was known of the amount of water lost due to land-use changes as a result of demographic changes and deforestation. This had significant contribution to the current water stress in the basin (Shaghude, 2006) where Weruweru-Kiladeda sub-catchment belongs. Most studies of land-use/cover impacts have been concentrated on floods and mean flows, since the impact on low flows and droughts seems to be regarded as less important, but the current study successfully filled this gap.

2.4.2 Effects on high flows

Land use / land cover change (LULC) play a significant role in modifying the hydrological flow regime of the river basins. According to Namrata (2010) there are many connections between the land surface characteristics and the hydrologic cycle. Changes in the vegetation cover tend to affect the degree of infiltration, run-off, and evaporation rate and precipitation pattern (Newson, 1995). LULC may have both immediate and long-lasting impacts on terrestrial hydrology, altering the balance between precipitation, evapotranspiration (ET) and the resultant run-off (Namrata, 2010). In the short-term, LULC may alter the hydrological cycle either through increasing high flows or through diminishing the low flow (Merritt et al., 2004). In the long-term, reduction in evapotranspiration and water recycling initiates a feedback mechanism that changes the climatic conditions of the area. The persistent Sahelian drought in Africa from the 1960s to the 1980s is attributable to human-induced climate change factors (Wang et al., 2004; Zeng et al., 1999). The hydrological effects of reservoirs are typically redistribution of the river flow within the year and increased evaporation from water surfaces. To respond adequately to land-use/cover change in water management practices and optimize the river functions in relation to each other, a good understanding of the hydrology of the Weruweru-Kiladeda Sub-catchment was essential. The discharge regime is an important aspect, particularly in case of high flows. High flows determine the boundaries of safety and extreme low discharges provide the thresholds for water supply. For nature conservation, the range of the discharges and the fluctuation is of importance. Regarding the regional water balance, annual average discharges are fundamental. The present study successfully filled this gap on how the high and low discharge regime of Weruweru and Kiladeda Rivers react to the changing land-use/cover for the period of study.

2.5 Climate and land use /land cover change impact on hydrological regime

The rainfall and temperature drives the hydrological cycle, influencing hydrological processes in a direct or indirect way. A large number of studies have been carried out to analyze the trends of variation in these parameters over India/Indian Sub- continent. The projections indicate that the warming would vary from region to region, accompanied by increase and decrease in precipitation (Sahai et al, 2003; Gadgil et al, 2004; Goswami et al, 2006; Ghosh et al, 2009, Aggarwal et al, 2012). In addition, there would be change in the variability of climate, and changes in frequency and intensity of some extreme climatic phenomenon. Flood magnitude and frequency are likely to increase in most regions, and low flows are likely to decrease in many regions. However, there have been very few studies addressing the issue directly, largely due to difficulties in defining credible scenarios for changes in flood producing climatic events. As it may be observed from these findings, studies using hydrological model with assumed plausible hypothetical climatic inputs would be useful for assessing impacts of climate change on water resources. In India several studies have been carried out to determine the changes in temperature and rainfall and its association with climate change. However, investigators used different data length and now studies have been reported using more than a century data.

2.5.1 Temperature trend in India

A study by Pant and Kumar (1997) on the seasonal and annual air temperature of India from 1881 to 1997 shows that there has been an increasing trend of mean annual temperature by the rate of 0.57^0C per 100 years. The trend of all India mean annual surface air temperature anomalies is shown in Fig. 2.1. An analysis of temperature data of 125 stations distributed all over India shows an increase of 0.42^0C, 0.92^0C and 0.09^0C in annual mean temperature, mean maximum temperature and mean minimum temperature respectively over the last 100 years (CWC and NIH, 2008). In a similar study, Hingane et al (1985) analyzed long term temperature records (1901 - 1982) of 73 stations and again found increasing trend of mean annual surface air temperature over India. It was observed that about 0.4^0C warming has taken place on country scale during the period of eight decades. It has been observed that the changes in temperature in India/Indian-Subcontinent over last century are broadly consistent with global trend of increase in temperature. However, the studies carried out on regional basis show varying trends. Hingane et al (1985) observed that trend of increase in mean annual temperature over the entire country was a result of rise in the maximum temperature; but later studies carried out by Sinha Ray et al (1997) have shown that the changes in mean annual temperature are partly due to rise in the minimum temperature related to enhanced extent of urbanization. Thereafter findings by Mukhopadhyay et al (1999) have confirmed that there is clear signal of urbanization in these warming, i.e. that there is a steeper rise in the minimum temperature in urban locations.

Further, examination of long- term variation in the annual mean temperature of highly industrial and densely populated cities like Mumbai and

Kolkata has shown increasing trend in annual mean temperature by 0.84^0C and 1.39^0C per 100 years, respectively (Hingane, 1995). These warming rates are much higher than the values reported for the country as a whole.

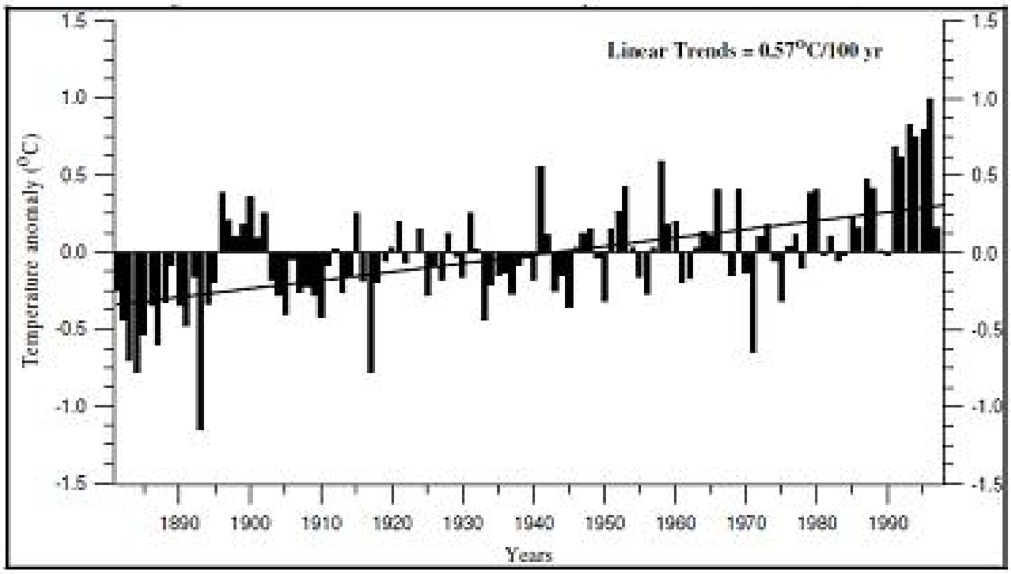

Fig. 2.1: All India mean annual surface air temperature anomalies (1881 - 1997) [Source: Pant and Kumar (1997)]

2.5.2 Rainfall trend in India

Studies related to change in rainfall over India have shown that there is no clear trend of increase or decrease in average annual rainfall over the country (Mooley and Parthasarathy, 1984; Sarkar and Thapliyal, 1988; Thapliyal and Kulshrestha, 1991; Lal, 2001). The examination of trend of annual rainfall over India has indicated that 5 year running mean has fluctuated from normal rainfall within ± one standard deviation (Thapliyal and Kulshrestha, 1991). Summer monsoon rainfall anomalies for all India are shown in Fig. 2.2. Though the monsoon rainfall in India is found to be trendless over a long period of time, particularly on the all India scale (Mooley and Parthasarathy, 1984), but there are pockets of significant long- term rainfall changes (Koteswaram and Alvi, 1969; Jagannathan and Parthasarathy, 1973; Raghavendra, 1974; Chaudhary and Abhyankar, 1979).

A comprehensive study using the monthly rainfall data for 306 stations distributed over India was attempted by Rupa Kumar et al (1992). It was noticed that areas of north-east peninsula, north-east India and north-west peninsula indicate widespread decreasing trend in the Indian summer monsoon rainfall. On the other hand, a widespread increasing trend in monsoon rainfall over the west coast, central peninsula and north-west India. The decreasing trend ranges between -6 to -8% of the normal per 100 years while the increasing trend is about 10 to 12%.

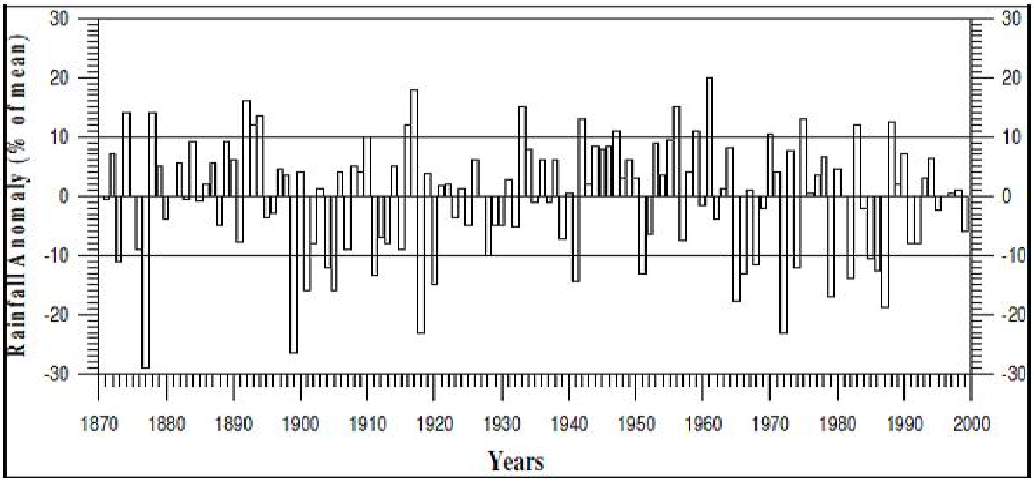

Fig. 2.2: All India summer monsoon rainfall anomalies (1871 - 1999)

[Source: Lal (2001)]

Ghosh et al (2012) reported how rainfall over India have changed in space and time over the past half century as well as on whether the changes observed are due to global warming or regional urbanization. Although a uniform and consistent decrease in moderate rainfall trends in heavy rainfall may be due in part to differences in the characterization and spatial averaging of extremes. Trends in Indian rainfall over the past half century in the context of long-term, low-frequency variability. Which shows that when generalized extreme value is applied to annual maximum rainfall over India, no statistically significant spatially uniform trends are observed, in agreement with previous studies using different approaches. Systematic examination of global versus regional drivers of trends in Indian rainfall extremes, and may help to inform flood hazard preparedness and water resource management in the region.

2.6 Land use/ land cover change scenario development

Several investigations of land Use/ land Cover change impacts on hydrology have been carried out in India. Chauhan and Nayak (2005) reported that industrial development and population pressure in Hazira, Gujarat, led to an increase of built-up area and a decrease in forest and agricultural areas between 1970 and 2002. Jayakumar and Arockiasamy (2003) have found an increase of cropland and a decree se of grassland and shrubland in a study on a part of the Eastern Ghats in South India. Deforestation between 1973 and 1995 was reported in a study on the southern part of the Western Ghats by Jha et al (2000). Similarly, a study about Indian Himalayan catchments by Sharma et al (2007) found a decrease of natural forest and an increase of agricultural land.

Impacts of land use change on the water resources in India were mainly assessed by using scenario analysis. Particularly, agricultural management practices are a focus of the research in India. Garg et al (2012a, b) found that agricultural water interventions had a pronounced impact on water resources. Sharma et al (2001) employed land use and land management measures that decreased the water yield significantly, and Behera and Panda (2006) identified critical sub watersheds and tested best management practices to minimize sediment and nutrient loads. Mishra et al (2007) analyzed the effects of land use on runoff and sediment yield to prioritize the construction of structural water management measures. Wilk and Hughes (2002) conducted a study in South India employing several land use scenarios, and found that only the extreme and very unlikely scenarios had a pronounced impact on runoff. The largest increases of runoff were found when converting forest and savanna to agriculture, whereas the largest decrease of runoff resulted from a conversion to forest in this study. Indian studies also focus on the impact of land use change on groundwater (Khan et al, 2011; Ramesh, 2001; Singh, 2001).

Menzel et al (2009) designed two intermediate land use/cover change scenarios, with projected developments ranging between optimistic and pessimistic futures (with regard to social and economic conditions in the region) (shown in Table 2.1) and climate conditions remaining unchanged, the simulation results showed both increases and decreases of water availability depended on the future pattern of natural and agricultural vegetation and the related dominance of hydrological processes. In terms of scenario generation, as a first test, two extreme limiting scenarios were considered – total deforestation and total afforestation. The modelling process was carried out to assess influences on run-off components and total water yield in response to these bounding conditions.

Table 2.1: Hypothetical scenarios of land cover

Scenario	Description
Business as usual (baseline)	Forest are reduced in the lower and upper escarpments within the catchment in favour of transitional woodland-shrubs; there is transformation of savanna shrubland areas into cultivated and grazing land; and there are major increase in grassland areas.
Land degradation (pessimistic)	Assume accelerated land cover change with extensive deforestation, significant fraction of forest and savanna shrubland areas are transformed into the category agricultural land, which includes subsistence agricultural areas, transitional woodlands and sparsely vegetated areas.
Land conservation (optimistic)	Assumes creation of greener environment through management and reforestation, involves the conversion of potentially vulnerable areas (e.g. substance agricultural land and lower escarpments) into forest and savanna woodlands.

[Source: Palamuleni and Annegarnal (2011)]

In order to assess impacts of land use change on water resources hydrologic models typically employed are HBV (Bergstrom and Forsman, 1973; Ashagrie et al, 2006), MIKE-SHE (Refsgaard and Storm, 1995; Im et al, 2009), and SWAT (Arnold et al, 1998; Fohrer et al, 2001). Models are particularly useful, as they can assess past as well as possible future impacts (using land use scenarios). Huisman et al (2009) employed an ensemble of ten hydrologic models (the three previously named and six other models) to assess the impact of land use change scenarios, which resulted in a range of predictions that were generally in agreement with respect to the direction of the impact on hydrology.

2.7 Hydrological models

Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to meet one of the two primary objectives. The one objective of the watershed hydrologic modeling is to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena. The other objective is for hydrologic prediction (Tadele, 2007). They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate. Cunderlik (2003) classified hydrologic models into three main categories based on the process description.

2.7.1 Lumped models.

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models.

2.7.2 Distributed models.

Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amount of (often unavailable) data. However, the governing physical processes are modelled in detail, and if properly applied, they can provide the highest degree of accuracy.

2.7.3 Semi-distributed models.

Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models. SWAT (Arnold et al, 1993), HEC-HMS (US-ACE, 2001), HBV (Bergstrom, 1995), are considered as semi-distributed models.

Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events. Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield (Cunderlik, 2003).

For this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models. Therefore, three selected semi-distributed models were reviewed (Table 2.2).

Table 2.2: Description of three selected semi-distributed hydrological models

Description	**SWAT**	**HEC-HMS**	**HBV**
Model type	Semi-distributed Physically-based Long term	Semi-distributed Physically-based	Semi-distributed Conceptual based
Model objective	Predict the impact of Land management practices and sediment	Simulated rainfall-runoff process of watershed	Simulated rainfall-runoff process of flood
Temporal Scale	Day	Day	Day
Spatial Scale	Medium	Flexible	Flexible
Process Modeled	Continuous	Continuous and event	Continuous and event
Cost	Public Domain	Public Domain	Public Domain

2.8 Soil and Water Assessment Tool (SWAT model)

The Soil and Water Assessment Tool (SWAT) watershed model is one of the most recent models developed at the USDA-ARS (Arnold et al., 1998) during the early 1970's. SWAT model is semi-distributed physically based simulation model and can predict the impacts of land use change and management practices on hydrological regimes in watersheds with varying soils, land use and management conditions over long periods and primarily as a strategic planning tool (Neitsch et al, 2005).

The interface of SWAT model is compatible with ArcGIS that can integrate numerous available geospatial data to accurately represent the characteristics of the watershed. In SWAT model, the impacts of spatial heterogeneity in topography, land use, soil and other watershed characteristics on hydrology are described in subdivisions. There are two scale levels of subdivisions; the first is that the watershed is divided into a number of sub-watersheds based upon drainage areas of the attributes, and the other one is that each sub-watershed is further divided in to a number of Hydrologic Response Units (HRUs) based on land use and land cover, soil and slope characteristics.

The SWAT model simulates eight major components: hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, and agricultural management (Neitsch et al, 2005). Major hydrologic processes that can be simulated by the this model include evapotranspiration, surface runoff, infiltration, percolation, shallow aquifer and deep aquifer flow, and channel routing (Arnold et al, 1998). Stream flow is determined by its components (surface runoff and ground water flow from shallow aquifer).

The SWAT, which is used in this work, has also been used with good results for assessing land cover impacts on hydrology in several studies (e.g. Hernandez et al, 2000; Miller et al, 2002; Heuvelmans et al, 2005; Nelson et al, 2005; Santhi et al, 2001,2005; Kaur et al, 2004; Tripathi et al, 2003; Vache et al, 2003; Bracmort et al, 2006; Chaplot et al, 2004; Fohrer and Frede 2002; Fohrer et al, 2005). SWAT is a basin-scale continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in ungauged watersheds (Gassman et al, 2007). Hernandez et al (2000) found that SWAT could accurately predict the relative impacts of hypothetical land use change in the 8.2 km^2 experimental sub watershed within the San Pedro watershed. Miller et al. (2002) describe simulated stream flow impacts with SWAT in response to historical land use shifts in the 3,150 km^2 San Pedro watershed in southern Arizona and the Cannons Ville watershed in south central New York. Stream flows were predicted to increase in the San Pedro watershed due to increased urban and agricultural land use, while a shift from agricultural to forest land use was predicted to result in a 4% stream flow decrease in the Cannonsville watershed. Increased stream flow was predicted with SWAT for the 59.8 km^2 Aar watershed in the German state of Hessen, in response to a grassland incentive scenario in which the grassland area increased from 20% to 41% while the extent of forest coverage decreased by about 70% (Weber et al., 2001). Heuvelmans et al (2005) report that SWAT produced reasonable stream flow and erosion estimates for hypothetical land use shifts, which were performed as part of a life cycle assessment (LCA) of CO_2 emission reduction scenarios for the 29.2 km^2 Meerdaal watershed and the 12.1 km^2 Latem watersheds in northern Belgium.

However, they state that an expansion of vegetation the SWAT parameter data set is needed in order to fully support LCA analyses. The impacts of hypothetical forest and other land use changes on total runoff using SWAT are presented by Lorz et al (2007) in the context of comparisons with three other models.

Muttiah and Wurbs (2002) used SWAT to simulate the impacts of historical climate trends versus a 2040-2059 climate change projection for the 7,300 km^2 San Jacinto river basin in Texas. They report that the climate change scenario resulted in a higher mean stream flow due to greater flooding and other high flow increases, but that normal and low stream flows decreased.

Gosain et al (2006) simulated the impacts of a 2041-2060 climate change scenario on the stream flows of 12 major river basins in India, ranging in size from 1,668 to 87,180 km^2. Surface runoff was found to decrease, and the severity of both floods and droughts increased, in response to the climate change projection. An analysis of the impacts of 12 climate change scenarios on the water resources of the 18 major water resources regions in the U.S. was performed by Thomson et al (2005) using the HUMUS approach, as part of a broader study that comprised the entire issue of volume 69 (number 1) of Climatic Change. Water yield shifts exceeding 50% were predicted for portions of Midwest and Southwest U.S., relative to the present water yield levels. Rosenberg et al (1999) found that driving SWAT with a different set of 12 climate projections resulted in decrease in Ogallala Aquifer recharge of up to 77% within the Missouri and Arkansas-White-Red major water resources regions of the U.S.

Wu et al (2014) evaluated hydrological impacts of potential climate and land use changes in Heihe River Basin of Northwest China. In 2006–2030, land uses in the basin will experience a significant change with a prominent increase in urban areas, a moderate increase in grassland, and a great decrease in unused land. Besides, the simulation results showed that in comparison to those during 1981–2005 the temperature and precipitation during 2006–2030 will change by +0.8°C and +10.8%, respectively. The land use change and climate change will jointly make the water yield change by +8.5%, while they will separately make the water yield change by −1.8% and +9.8%, respectively. The predicted large increase in future precipitation and the corresponding decrease in unused land will have substantial impacts on the watershed hydrology, especially on the surface runoff and streamflow.

According to Kumar (2005) large scale LULC changes are taking place in Kerala State, which has an area of 38,863 km^2 and density of population of 819 per square kilometer. This change is mainly due to conversion of forests, mixed crop areas and also rice fields to plantation crops and urban areas. Therefore, the need to study the consequences of these LULC changes on the hydrology of this area was recognized. Not only in Kerala State but also in the entire humid tropical areas in south and south-east Asia these trends in change in LULC are noticed. It is in this background, the present study has been taken up in the Meenachil river basin of this humid tropical area, for which basin reliable hydrologic data for a few years are available and also data on LULC changes. Some of the existing mathematical tools and models have been attempted to achieve the objective of this study. The results of this study are expected to be of use to those involved in planning the development projects in this area.

The review indicated that Soil and Water Assessment Tool (SWAT, Arnold et al, 1998) has proven its suitability for hydrologic impact studies (Gassman et al, 2007) and furthermore under conditions of limited data availability (Ndomba et al, 2008; Stehr et al, 2008). However, it is evident from that not much work has been carried out in the study area. Hence, SWAT model has been to study the impact of LULC changes on hydrological behavior of upper Narmada basin.

3. MATERIAL AND METHODS

3.1 General

This section describes the materials and methods employed to derive the objective of the study. This study aimed at determine the hydrologic response to land use /land cover (LULC) changes on the Upper Narmada Basin. Different approaches or a combination of techniques were employed during this study to establish relationships between land use / land cover change and basin hydrology responses. Remote sensing and GIS analysis was used to establish changes that have occurred in the sub basin of Narmada. Collective information gave the historical perspectives of the LULC and hydrology in the areas. Fig. 3.1 presents Index map of the Narmada Basin.

3.2 Description of Study area:

This study has been conducted in the upper Narmada basin. The Narmada river, rises in the *Amarkantak Pleatue* of Maikal range in the Shahdol district of Madhya Pradesh at an elevation of 1057 meters above mean sea level at a latitude 22^{o}40' North and longitude of 81^{o} 45' East. The river travels a distance of 1312 km before it falls into *Gulf of Cambay* in the Arabian Sea near Bharuch in Gujarat. The first 1079 km of its run is in Madhya Pradesh. In the next length of 35 km, the river from the boundary between the states of Madhya Pradesh and Maharashtra. Again the next length of 39 km, it forms the boundary between Maharashtra and Gujrat. The last length of 159 km lies in Gujrat. The Narmada river has 41 tributaries, of these, 22 are on the left bank and 19 on the right bank. The important tributaries /sub-basin of the Narmada are Barna, Ganjal, Chhota Tawa, Hiren, Jamtara, Kolar, Orsang, Sher, and Tawa rivres.

The Narmada basin extends over an area of 98796 sq. km lying in the northern extremely of the deccan pleatue.The basin covers large areas in the Madhya Pradesh and Gujarat and a comparatively smaller area in Maharashtra (Fig.3.2).It is bounded on the north by the Vindhya, on the east by the Maikala range, on the south by the Satpura and on the west by the Arabian Sea.

Fig. 3.1: Narmada basin Index map (source: Anonymous 2014)

Narmada is the largest west flowing river of the Indian peninsula. Narmada basin lies in the central and western parts of the state in the form of lenticular river valley stretching in east-west direction.

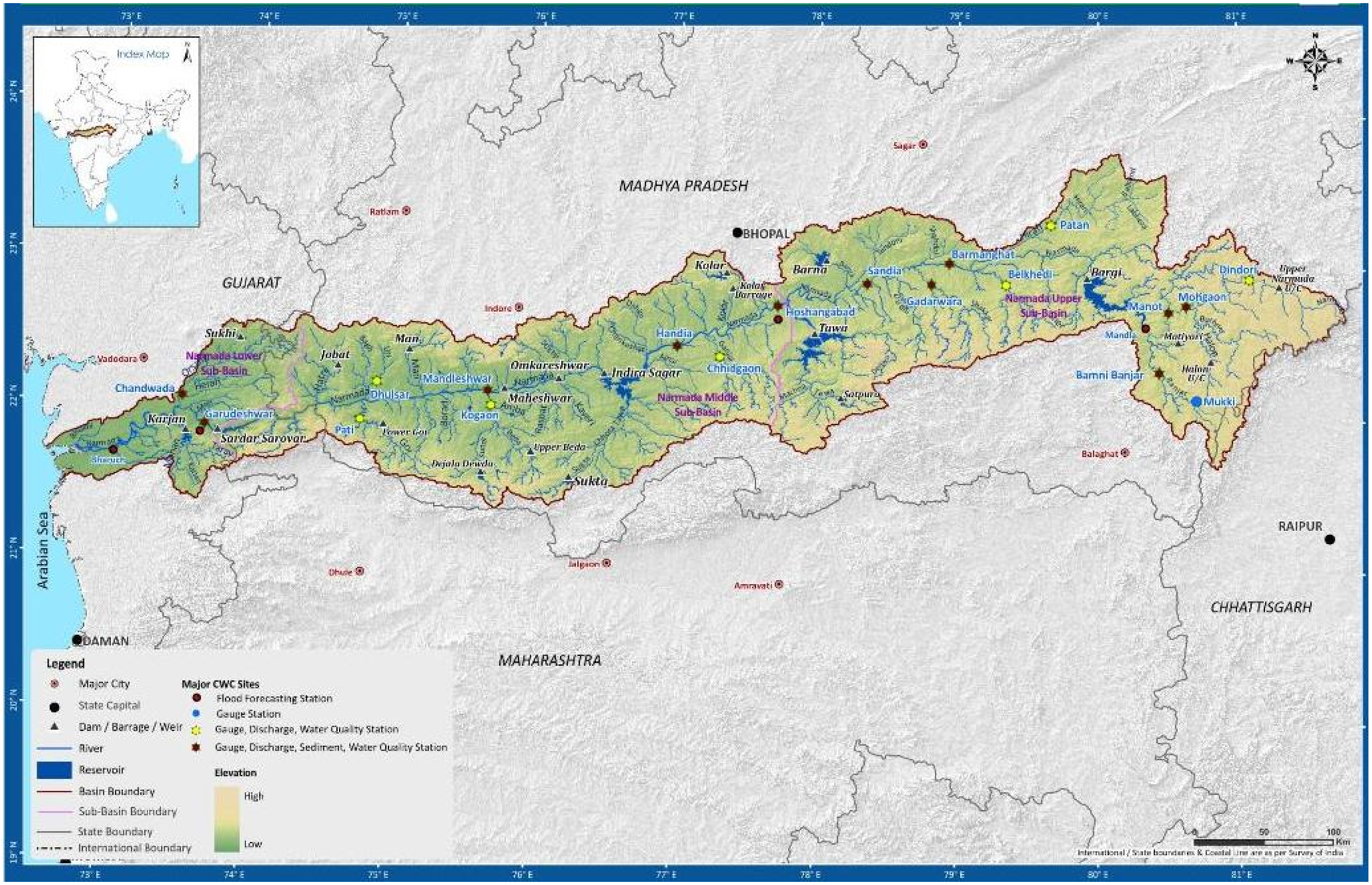

Fig. 3.2: Narmada basin coverage map between States (source: Anonymous 2014)

It is covering an area of 86256 sq. km in the districts of Shahdol, Mandla, Jabalpur, Narsinghpur, Hoshnagabad, Seoni, Chhindwara, Betul, Raisen, Sehore, Dewas, Khandwa, Khargon, Dhar, and Jhabua. Narmada basin is divided into three sub basin namely Lower, Middle and Upper Narmada basin shown in Fig. 3.3. Five revenue districts of upper Narmada basin, namely Dindori, Mandla, Jabalpur, Narsinghpur and Hoshangabad are considered for this study. Location of these districts in Madhya Pradesh is shown in the Table 3.1 through Longitude and Latitudes. Fig. 3.4 shows the district covered by upper Narmada basin.

Table 3.1: Location of districts under study area

S.No.	District Name	Longitude	Latitude
1	Dindori	$80^{o}35'$-$81^{o}58'$E	$22^{o}17'$-$23^{o}20'$N
2	Mandla	$80^{o}18'$-$81^{o}51'$E	$22^{o}12'$-$23^{o}12'$N
3	Jabalpur	$79^{o}21'$-$80^{o}53'$E	$22^{o}49'$-$24^{o}08'$N
4	Narsinghpur	$78^{o}27'$-$79^{o}40'$E	$23^{o}16'$-$24^{o}36'$N
5	Hoshangabad	$77^{o}15'$-$78^{o}42'$E	$22^{o}15'$-$23^{o}60'$N

3.2.1 Topography:

The basin has five well defined physiographic zones. They are (i). The upper hilly areas (ii). The upper plains (iii). The middle plains (iv).The lower hilly areas and (v).The lower plains.

The upper hilly areas and plains come under the Vindhyanchal Baghelkhand region. The region is a hill-valley complex covering Annupur, Shahdol, Dindori, Mandla, Balaghat, Jabalpur, Narsinghapur and Chhindwara districts of Madhya Pradesh falling in Narmada basin.

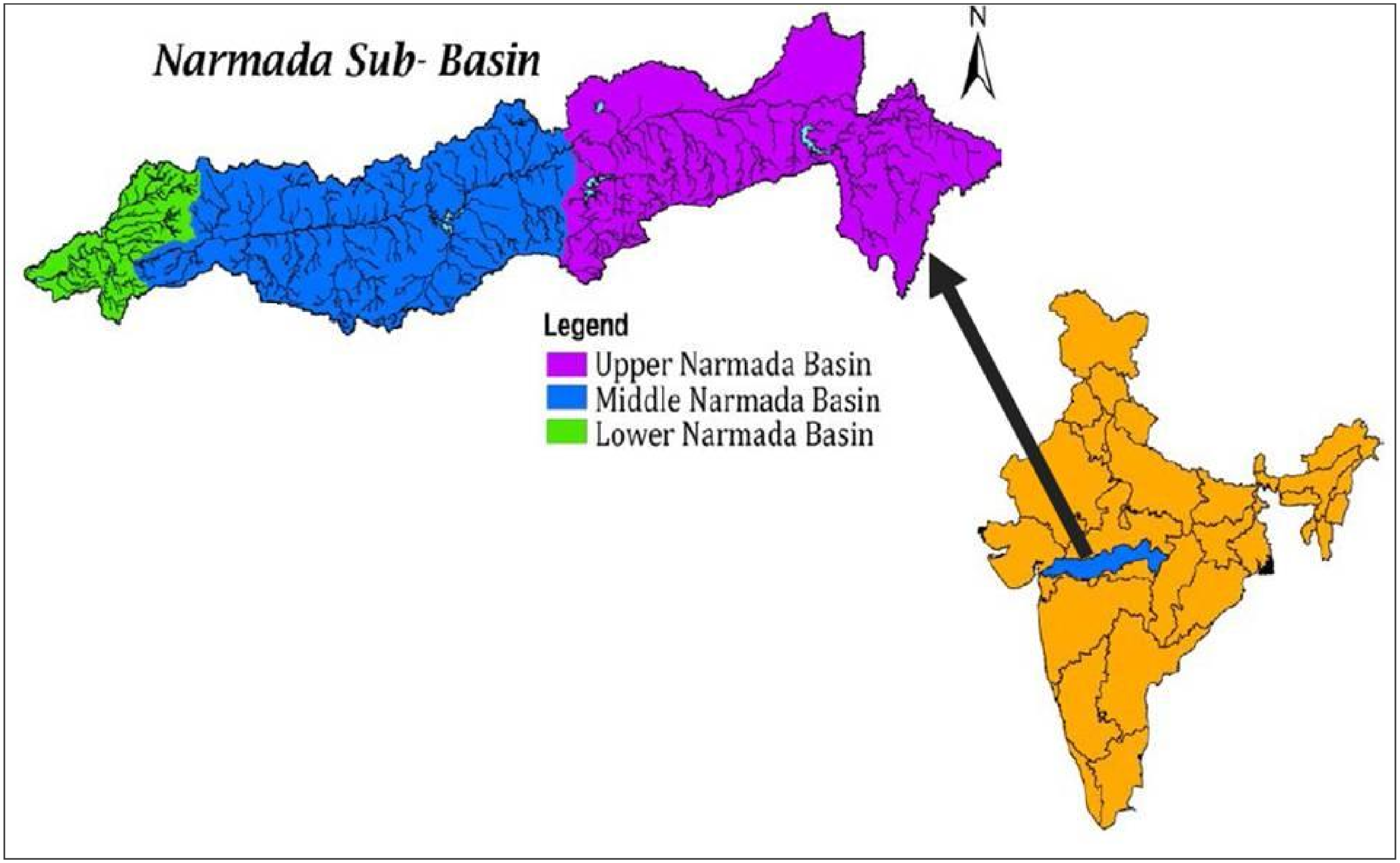

Fig. 3.3: Sub-basin division's distribution in Narmada basin

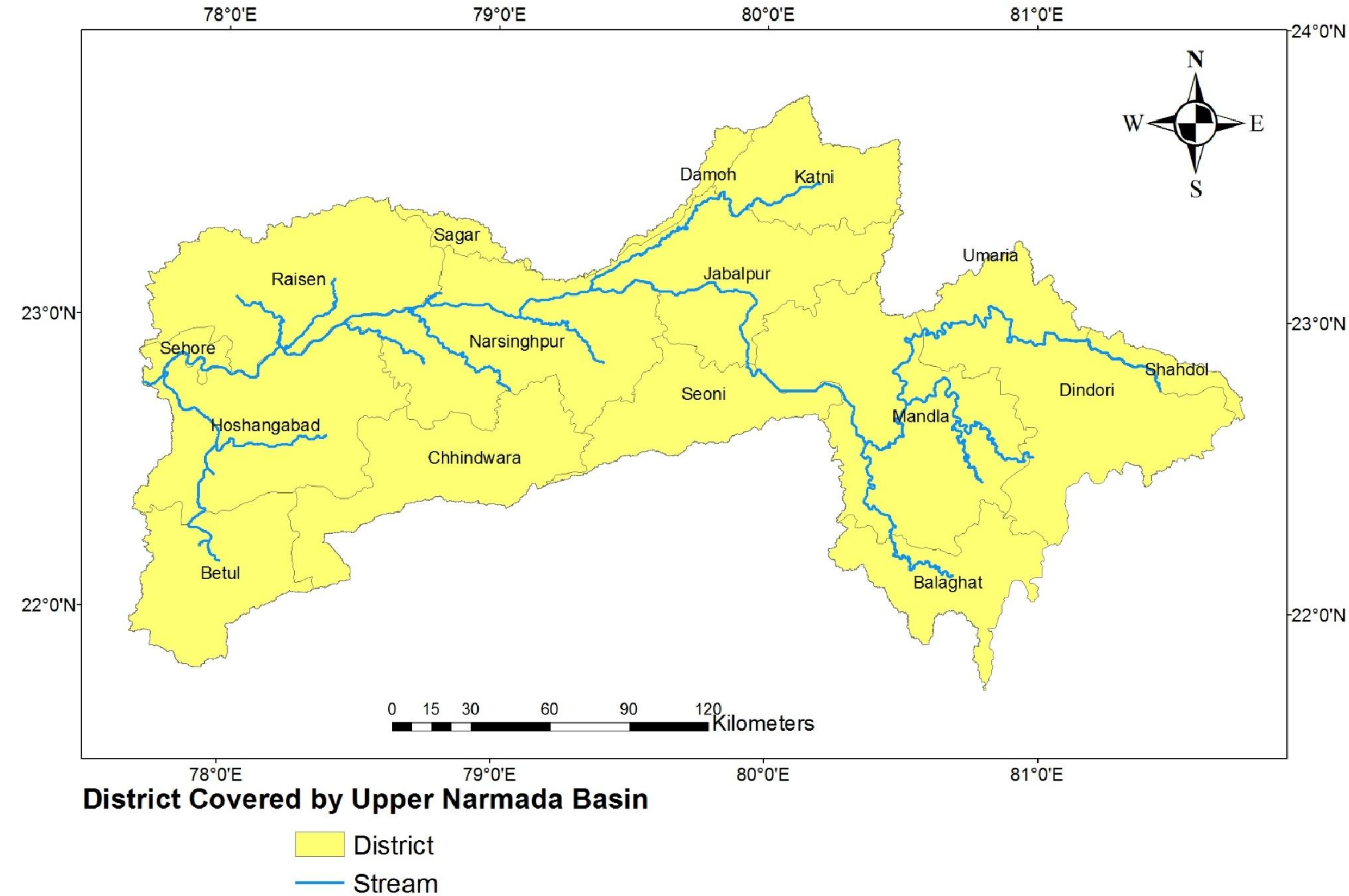

Fig.3.4: Districts covered in upper Narmada basin

The main elements of this region, spreading over Narmada basin are scraps of (i).Vindhyan sandstones and (ii). Narmada-Son Trough on its south. The latter is a structural dislocation along the junction of Archaeans and the Bijawars with the Vindhyans. The Narmada valley has youthful appearance and has falls, rapids and gorges in its course. The Dhuandhar falls (Bheraghat, 15 m) followed by a 3 km long marble gorge is an example in point. South of the trough, lies the geological and physiographic complex (eastern expansion of the Satpura) and here is located country's core of the radial drainage, the Amarkantak (1,087 m) in the Maikala range.The whole surface is an assemblage of flat-topped plateaus (Chhindwara, Seoni, Maikal, Deogarh, etc.) with 600-900 m general elevation. The middle plains and the lower hilly areas come under the Malwa region. The region covers Hoshangabad, Betul, East Nimar, West Nimar, Barwani, Dhar, Dewas, Sehore and Jhabua districts of Madhya Pradesh falling in the basin. Malwa region, in the basin falls into following well-marked physiographic units: (i) West Vindhyas, (ii) West Narmada Trough and (iii) West Satpuras.The Vindhya range runs in a curve for the first 100 km from its western terminus, its convex side facing the Narmada Valley. For the next 160 km, a more open type of country prevails and the basaltic escarpment becomes more prominent near Hoshangabad, the rock type changes, the Vindhya Range comes down very close to the Narmada River and presents a terraced slope built of hard sandstones alternating with shales. Western Narmada Trough is a tract of fertile land. The Narmada valley has a variable longitudinal slope and is broken up into parts separated by hills. Narmada flows through a gorge (the Mandhata gorge) carved out of Vindhyan sandstones. North of Narmada is the Dhar Upland, a hilly and forested area. Nimar upland stretches from east to west in the north of the Satpuras. The Western Satpuras separate the Narmada and the Tapi basins.

3.2.2 Climate

The Tropic of Cancer crosses the Narmada basin in the upper plains area and a major part of the basin lies just below this line. The climate of the basin is humid and tropical, although at places extremes of heat and cold are often encountered.

In the year, four distinct seasons occur in the basin. They are (i) Cold weather, (ii) Hot weather, (iii) South-west monsoon and (iv) Post-monsoon. The cold weather season which commences in November and continues till the end of February, is characterized by bright cloudless days and clean nights and piercing winds. There is slight precipitation in the basin during this season.
The hot weather starts in March and continues up to the middle of June. May is usually the hottest month. This season is generally dry.

The south-west monsoon sets in by the middle of June and withdraws by the first week of October. June to September is the rainiest months. During this season, the weather is somewhat sultry and oppressive, especially in areas adjoining the Narmada River.

In the post-monsoon season, a few thunder-storms occur, especially in October. Thereafter, the weather clears up and dry pleasant weather prevails throughout the valley. (Source: Anonymous, 2014)

3.2.3 Rainfall

Rainfall is heavy in the upper hilly and upper plains areas of the basin. It gradually decreases towards the lower plains and the lower hilly areas and again increases towards the coast and south-western portions of the basin.

In the upper hilly areas, the annual rainfall, in general, is more than 1400 mm but it goes up to 1650 mm in some parts. In the upper plains, near Jabalpur to near Punasa dam site, the annual rainfall decreases from 1400 mm to less than 1000 mm with the high rainfall zone around Pachmarhi where the annual rainfall exceeds 1800 mm. In the lower plains the annual rainfall decreases rapidly from 1000 mm at the eastern and to less than 650 mm around Barwani. This area represents the most arid part of the Narmada Basin. In the lower hill areas, the annual rainfall again increases to a little over 750 mm (Source: *www.nca.gov.in*). A major portion of the precipitation in the basin takes place during the southwest monsoon, and accounts for about 85% to 95% of the total precipitation. The post monsoon accounts for about 9% of the precipitation whereas the winter and the pre-monsoon, together account for about a maximum of 10% of the total precipitation.

The maximum and minimum 24 hours rainfall in upper Narmada basin is 360 mm and 260 mm respectively. Nearly 90% of this rainfall is received during the five monsoon months from June to October and about 60% is received in the two months of July and August (source: Anonymous 2014).

3.2.4 Temperature

Temperature of Narmada Basin is like any other part of Central India. The difference between the maximum and minimum temperature, in any part of the basin, is quite pronounced. The temperature is maximum in the month of May and minimum in the month of January. In general, the upper Narmada Basin records lower temperature as compared to middle basin. In lower section of the basin, the influence of the sea is prominent, and temperature though lower than the middle basin, is higher than the upper reaches of Narmada river.

3.3 Soils

Soil is composed of minerals, mixed with some organic matter, which differ from its parent materials in terms of its texture, structure, consistency, and color, chemical, biological and other characteristics. Information on the soil profile is also required for simulating the hydrological character of the basin.

Soil of the upper basin, is characterized by shallow black soils. These soils are erosional products of trap basalts. The black soils are rich in smeclite clays having a high water holding capacity. These clay lattices expand when they absorb water and thus reduce the water drainage. The organic matter is generally less than 5% in black soils. These soils are often interspersed with red sandy or laterite soils. The profile is generally shallow and mainly covers the hilltops and plateau regions. The red soils are the result of intense chemical leaching of basalts whereby all the minerals in the rock are leached out except the oxides of silica, iron and aluminum. Due to intense leaching, these soils have a reasonably good drainage but lacking in nutrients essential for plant growth.

The soils in the Vindhyan and Satpura plateau region of the middle basin range from shallow black soils to medium black soils. Around Hoshangabad, recent alluviums with varied thickness can be witnessed. This soil is extremely fertile and supports cotton, Jawar and wheat.

3.4 Agro-climatic zones

The Narmada basin is divided into 4 Agro-climatic zones. The Eastern Plateau and Hills Region (6%), Central Plateau and Hills region (51%), Western Plateau and Hills Region (38%) and Gujarat plains and hills region (5%). Agro climatic zone map of Narmada basin are presented in Fig.3.5.

The Eastern Plateau and Hills Region covers parts of Balaghat and Mandla districts of Madhya Pradesh. Major parts of districts of MP covering Narmada basin (Betul, Chhindwara, Harda, Hoshangabad, Jabalpur, Narsimhapur, Raisen and Sehore) falls in Central Plateau and Hills zone.

The Western Plateau and Hills Region covers parts of Barwani, Dhar, East Nimar, Jhabua, West Nimar (MP) and Nandurbur (Maharashtra) districts. The parts of Bharuch, Narmada and Vadodara districts of Gujarat covering Narmada basin falls in Gujarat plains and hills region.

3.5 Agro-ecological zones

Agro-ecological zones of Narmada Basin are shown in the Fig.3.6. On the basis of Agro-ecological zones, the Narmada basin is broadly divided into 2 zones (source: Anonymous 2014). The upper most hot sub-humid eco-region with red and black soils (Agro-Ecoregion 10) zone covers 57.6% of the basin. Parts of Balaghat, Betul, Chhindwara, Harda, Hoshangabad, Narsimhapur, Raisen, Sehore, Mandla, Dewas and Dindori districts (MP) falls under this Zone. The climate of the region is characterised by hot summers and mild winters. Some of the eastern districts (Balaghat, Mandla, Chhindwara, Seoni), however, are relatively more humid and here the Length of Growth Period (LGP) ranges from 180-210 days in a year. The soil continuum comprises largely medium and deep Black soils interspersed in patches of Red soils. The natural vegetation comprises tropical moist deciduous forest. Rice, sorghum, pigeonpea and soybean are common Kharif crops, while gram, wheat and vegetables are common Rabi crops.

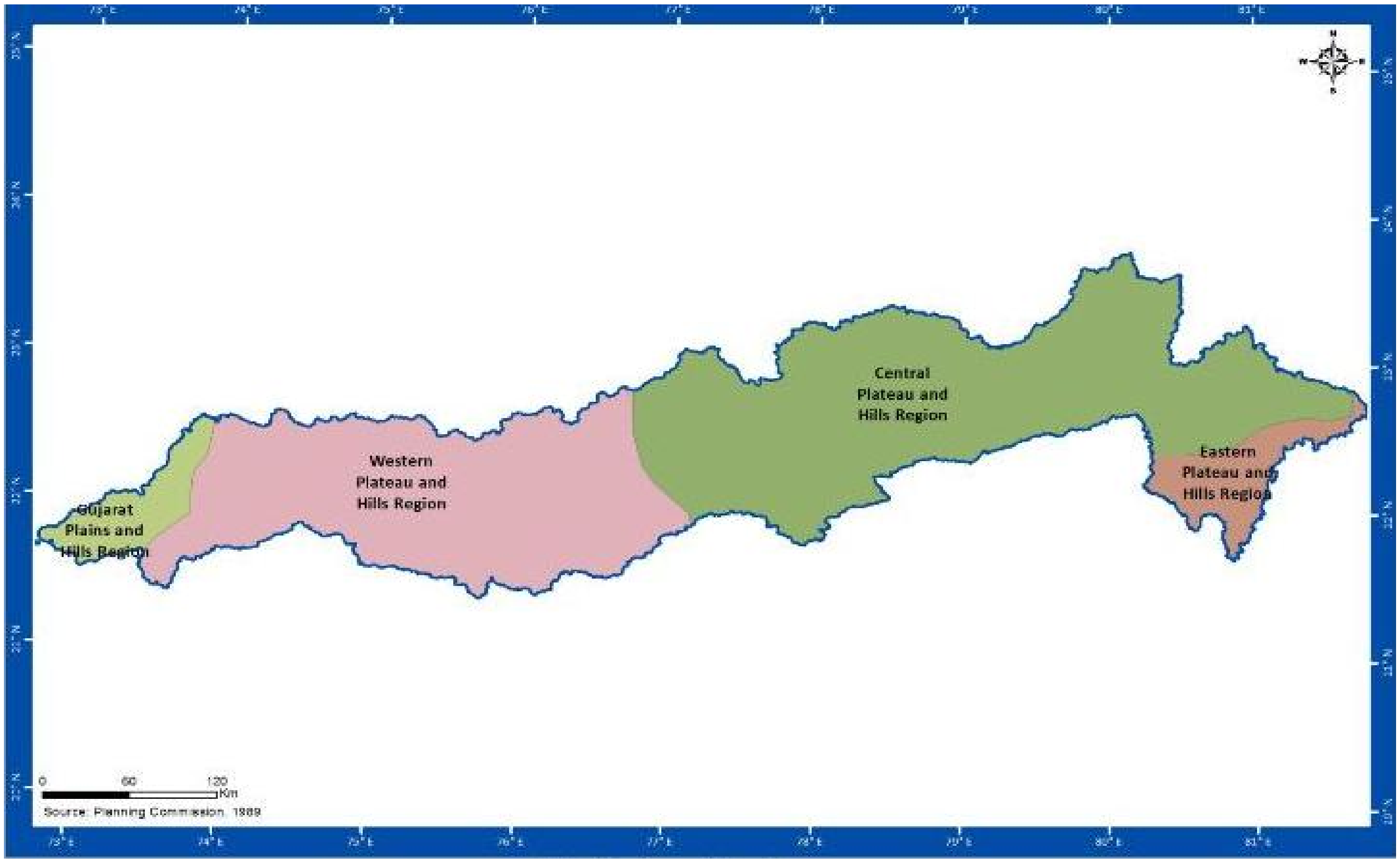

Fig. 3.5: Agro-climatic zone map of Narmada basin

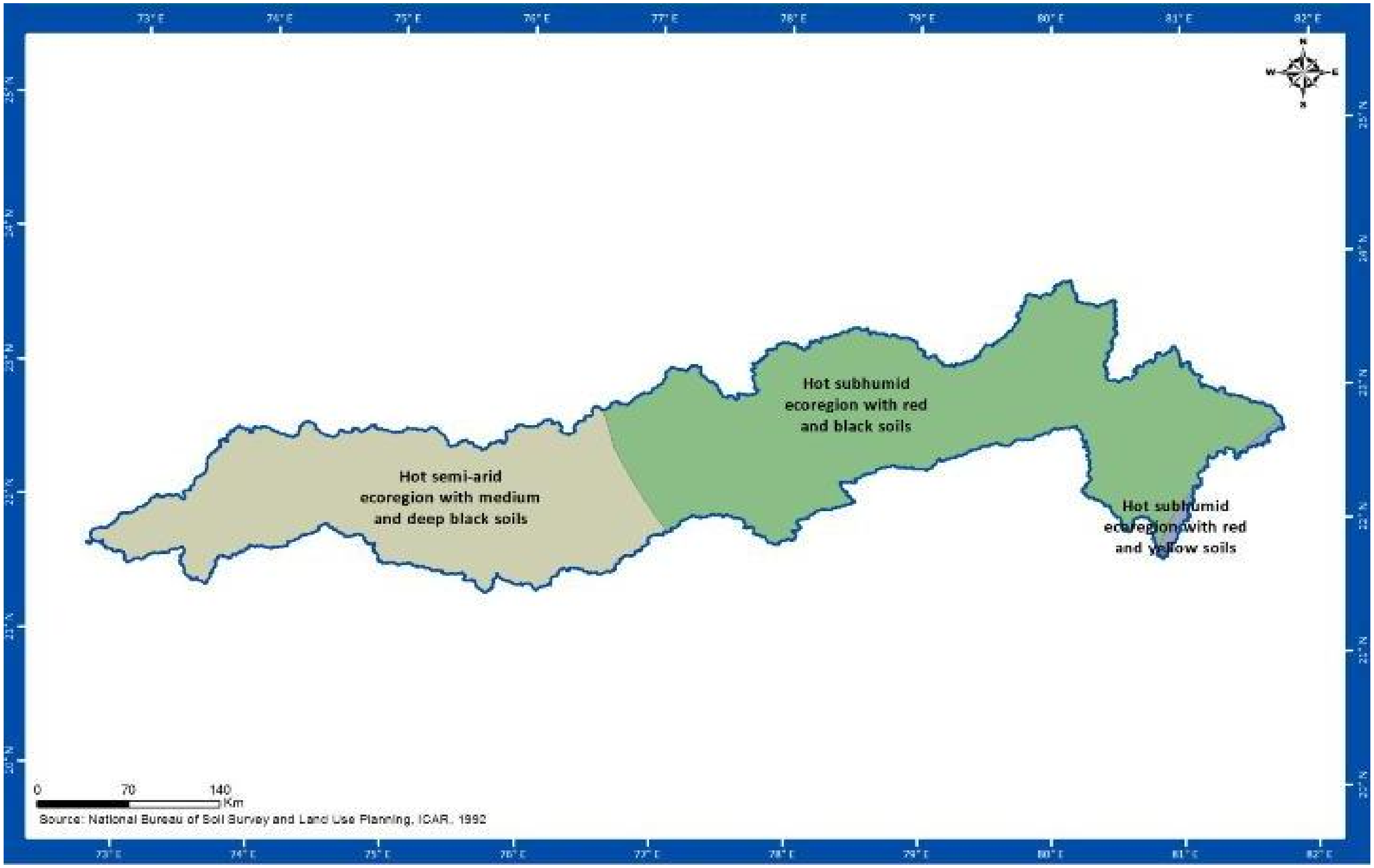

Fig. 3.6: Agro-ecological zones of Narmada basin

3.6 Demography

According to cencuss-11, Jabalpur a district falling in the basin has the highest population (more than 2 lakh), and Hoshangabad, Mandla and Narsimhapur district of M.P. falling in the basin are also the most populous district having population more than one lakh. District wise population and basin coverage is given in Table 3.2. Out of the total population, 50.8% are literates and 49.2 % are illiterates.

Table 3.2: District wise population and area coverage in basin

S.No.	State	District	Population	District Area in Basin (Sq. Km)
1.	Madhya Pradesh	Balaghat	1701698	2210.54
2.	Madhya Pradesh	Betul	1575362	3712.61
3.	Madhya Pradesh	Chhindwara	2090922	3389.22
4.	Madhya Pradesh	Damoh	1264219	417.79
5.	Madhya Pradesh	Dindori	704524	4598.04
6.	Madhya Pradesh	Hoshangabad	1241350	6456.42
7.	Madhya Pradesh	Jabalpur	2463289	4619.32
8.	Madhya Pradesh	Katni	1292042	1093.93
9.	Madhya Pradesh	Mandla	1054905	6371.63
10.	Madhya Pradesh	Narsimhapur	1091854	4818.19
11.	Madhya Pradesh	Raisen	1331597	4494.04
12.	Madhya Pradesh	Sagar	2378458	371.79
13.	Madhya Pradesh	Sehore	1311332	3143.66
14.	Madhya Pradesh	Seoni	1379131	2153.12
15.	Madhya Pradesh	Shahdol	-	1184.90
16.	Madhya Pradesh	Umaria	644758	0.47

(Source: Census-2011)

3.7 Land use and crop

The major land use/ cover classes of Narmada Basin are- Agriculture, Forest, Wasteland, Waterbodies and the Built-up. Detailed information on land use pattern and crop grown has been collected from the Department of Farmers Welfare and Agriculture Development and also district

KVK (Krishi Vigyan Kendra) of concerned district. Forest is the major land cover in Mandla district, whereas cropped area is major land use in other district. District wise major land use of the upper Narmada basin is given in Table 3.3(a). District wise distribution of area under cereal crops, pulses, oilseed and fiber crops is given in Table 3.3 (b), (c), (d) respectively.

Table 3.3(a): Land use pattern in upper Narmada basin

(Area in Thousand ha)

District	Total Geographical Area	Forest	Agriculture	Fallow	Barren
Dindori	358.9	25.3	203.7	65.2	10.9
Mandla	965.6	593.2	214.3	63.6	10.6
Jabalpur	519.8	77.7	273.8	32.3	37.0
Narsinghpur	513.6	136.5	303.7	9.2	1.0
Hoshangabad	668.7	256.1	300.9	14.1	2.5

Table 3.3(b): Area under cereal crops in upper Narmada basin

(Area in Thousand ha)

District	cereals				
	Wheat	Paddy	Nizer	Maize	KodoKutki
Dindori	48.8	79.4	35.9	25.0	43.9
Mandla	29.4	111.5	8.3	18.5	39.7
Jabalpur	88.6	60.2	6.0	5.0	11.5
Narsinghpur	71.5	13.0	-	-	-
Hoshangabad	1.70	16.5	-	9.40	-

Table 3.3(c): Area under Pulses and other crops in upper Narmada basin

(Area in Thousand ha)

District	Pulses					
	Gram	Pea	Lentil	Chickpea	Pigeonpea	Sugarcane
Dindori	5.8	9.1	25.7	7.8	-	5.0
Mandla	-	16.8	14.8	5.8	3.9	2.8
Jabalpur	-	36.4	40.1	66.2	8.1	1.6
Narsinghpur	14.0	12.8	29.6	136.2	27.8	32.4
Hoshangabad	4.6	1.4	1.6	201.0	21.20	3.5

Table3.3 (d): Area under Oilseeds and Fiber crops in upper Narmada basin

(Area in Thousand ha)

District	Oilseeds				Fiber
	Soybean	**Linseed**	**Mustard**	**Sorghum**	**Jute**
Dindori	6.5	9.4	25.9	-	35.0
Mandla	2.6	-	16.2	-	282.0
Jabalpur	5.6	2.5	3.9	4.3	32.0
Narsinghpur	98.5	-	-	2.4	53.0
Hoshangabad	196.6	-	-	-	32.0

3.8 Data collection

3.8.1 Satellite data

Remote sensing data for the study area (Table 3.4) have been obtained for the year of 1989, 2000 and 2011 from three different sources.

Table 3.4: Characteristics of satellite images

S. No.	Year	Satellite	Spatial resolution	Source
1	October-November, 1989	Landsat TM^{+}MSS	28.5 meter	http://www.landcover.org
2	October-November, 2000	Landsat ETM^{+}	28.5 meter	http://www.landsat.org
3	October-November, 2011	Resourcesat LISS III	23.5 meter	http://bhuvan.nrsc.gov.in

3.8.2 Ancillary data

Digital elevation model (DEM)

Digital Elevation Model (DEM) with a spatial resolution of 30 meter was acquired from the URL http://bhuvan.nrsc.gov.in and presented in Fig. 3.7.

Soil map

Soil map of Madhya Pradesh were obtained at 1:2, 50,000 scale from NBSSLUP (National Bureau of Soil Survey and Land Use Planning), Nagpur. Then map was scanned, georeferenced and digitized for preparation of vector soil map for the study (Fig. 3.8).

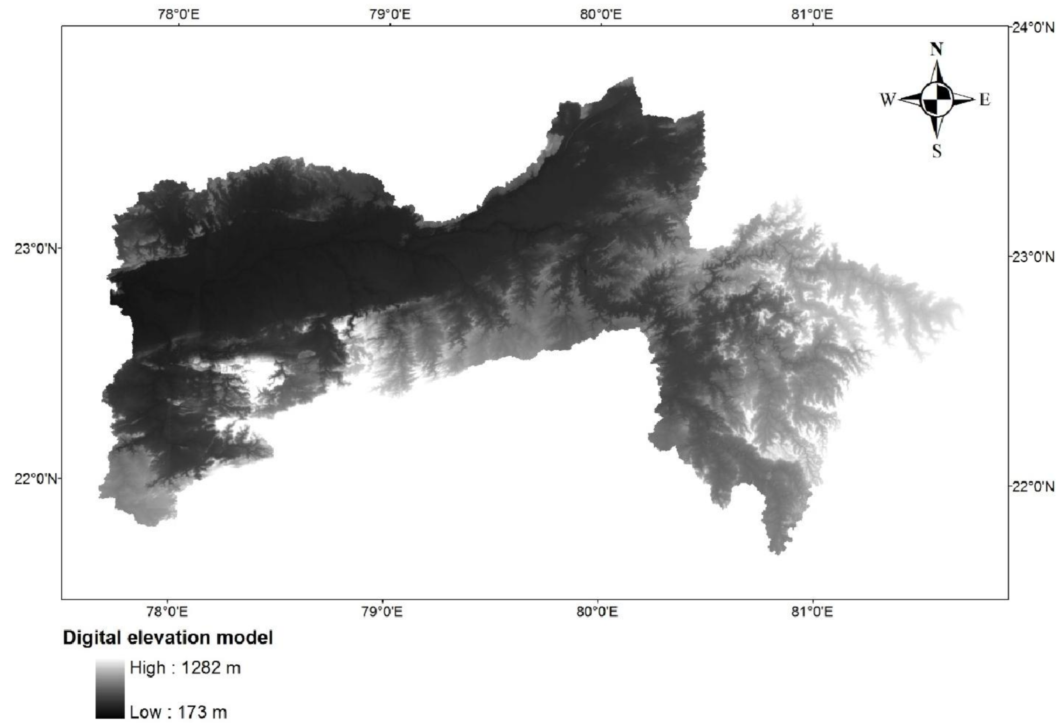

Fig.3.7: Digital elevation model at 30 meter resolution

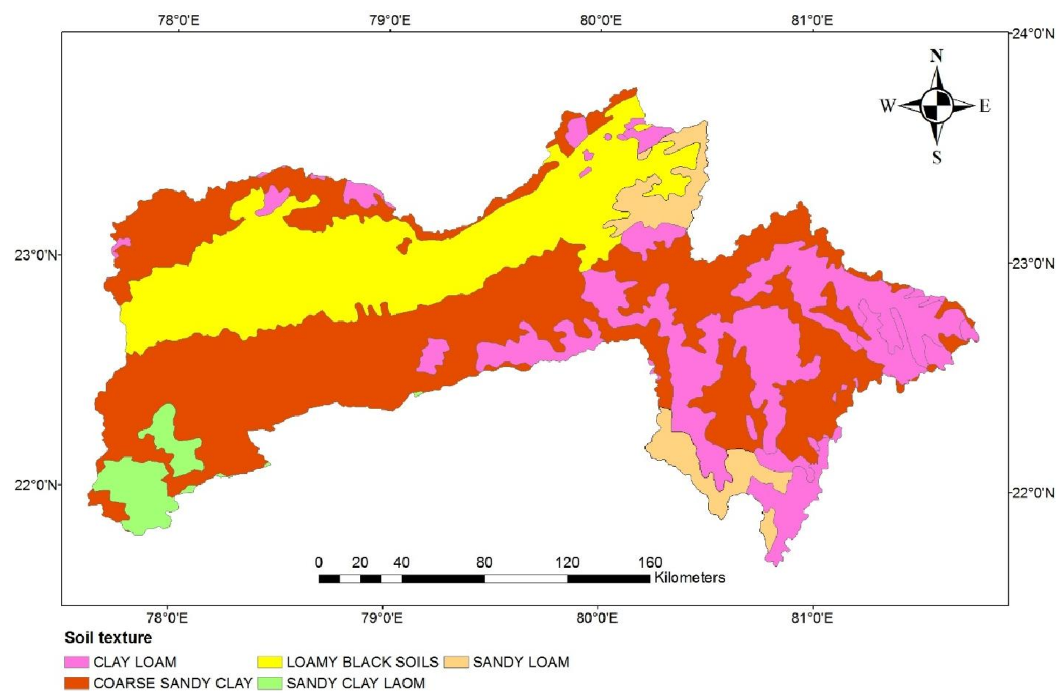

Fig.3.8: Soil map of upper Narmada basin

3.8.3 Meteorological Data

Meteorological data have been collected from India Meteorological Department (IMD) Pune and Global weather data center. Meteorological data (for the period 1979-2013) used for the study are categorized into maximum and minimum temperature, wind speed, sunshine hour, relative humidity and rainfall. The details of 12 meteorological stations for which data have been collected is shown in Table 3.5. location of these stations in the study area is depicted in Fig. 3.9. See Appendix-A for Selected station data.

Table 3.5: Location of meteorological stations

S.No.	Station ID	Station Name	Latitude	Longitude
1	233800	Patan	23°16'49.767"N	79°59'23.608"E
2	229809	Dindori	22°56'42.728"N	80°56'24.716"E
3	229800	Jabalpur	22°56'31.446"N	80°0'3.311"E
4	223806	Bmahni Banjar	22°18'25.134"N	80°35'52.008"E
5	229781	Sandia	22°57'1.592"N	78°6'51.946"E
6	233788	Silwani	23°15'34.885"N	78°44'47.061"E
7	226778	Hoshangabad	22°38'2.39"N	77°48'42.544"E
8	223781	Tawa	22°19'43.93"N	78°6'22.517"E
9	226791	Gadarwara	22°38'46.234"N	79°3'57.625"E
10	226806	Manot	22°38'58.371"N	80°37'50.588"E
11	229794	Barmanghat	22°56'12.707"N	79°22'19.401"E
12	223809	Mawai	22°18'55.235"N	80°56'25.694"E

3.8.4 Hydrologic data

Daily series of discharge data (period 1989 -2011) of the upper Narmada basin were collected from Central Water Commission, Bhopal Upper Narmada office Jabalpur. Hydrologic data for various gauging stations are presented in Appendix-B.

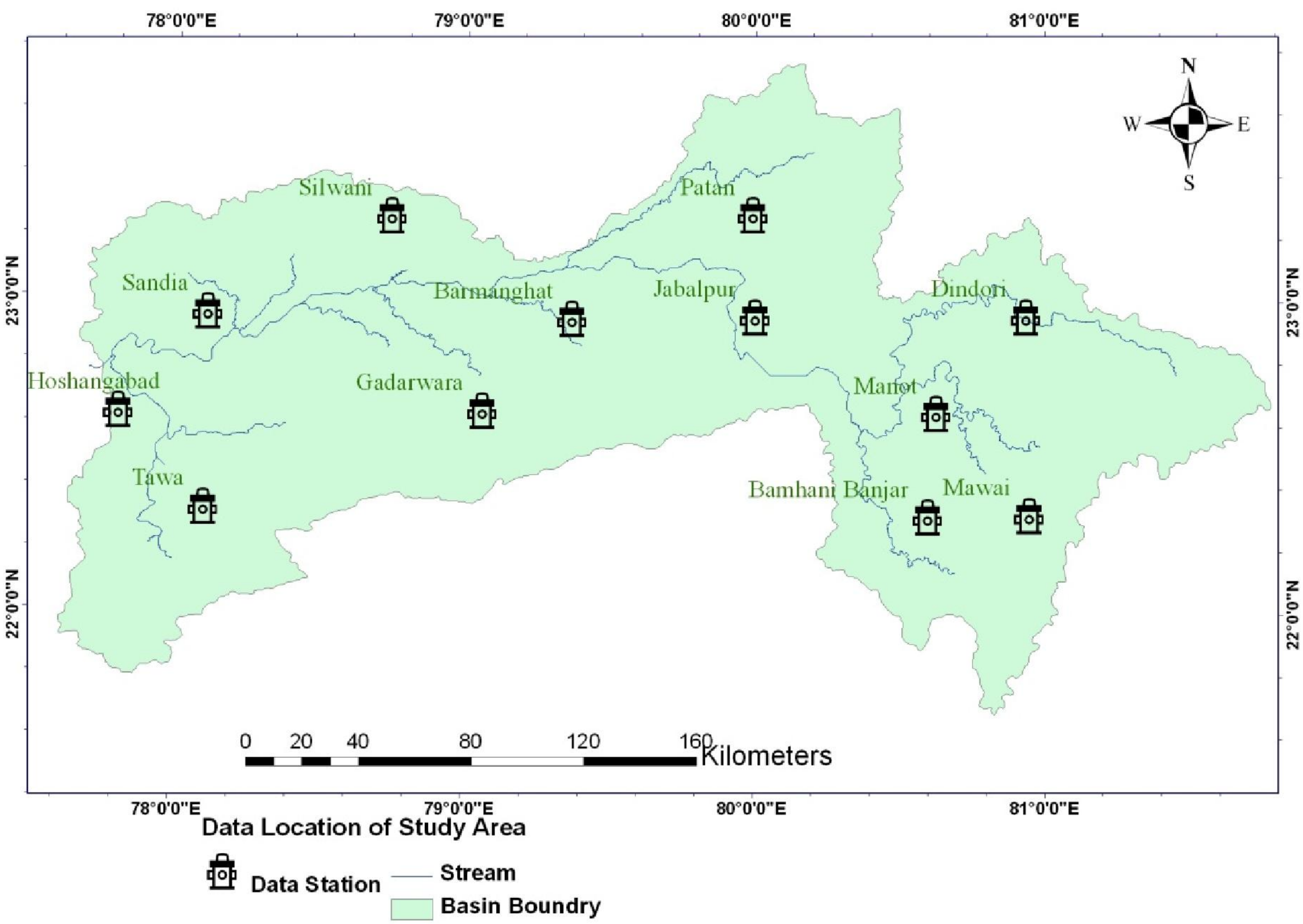

Fig. 3.9: Meteorological and hydrological data station of upper Narmada basin

3.9 Methodology

Fig. 3.10 presents a flow chart of the process and methodology adopted in this study.

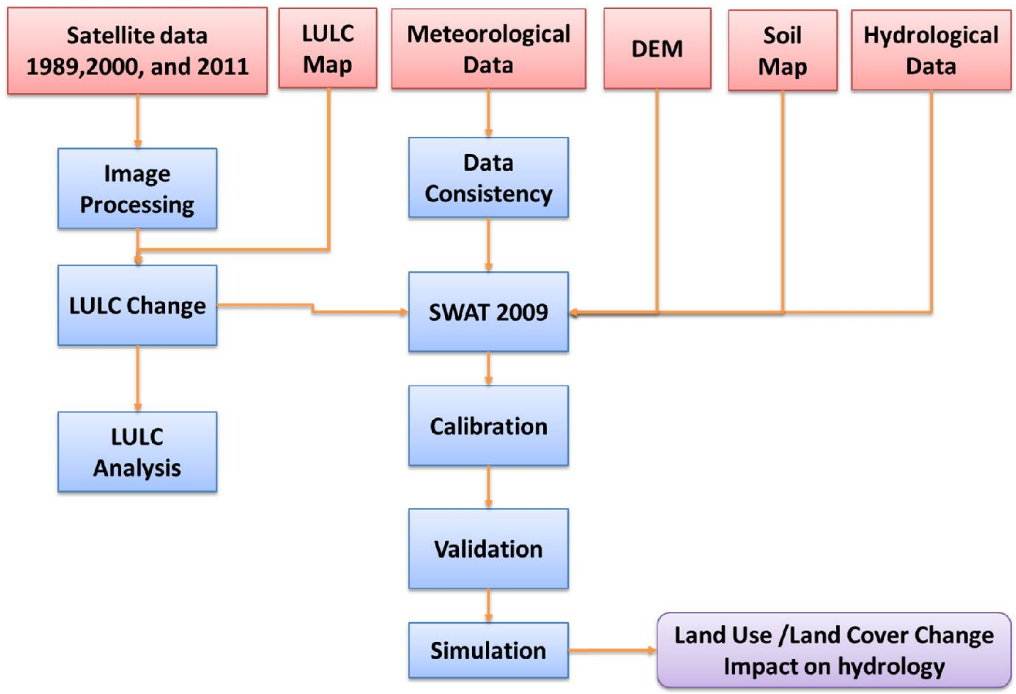

Fig. 3.10: Flow chart of the process and methodology adopted

3.9.1 Data analysis

Data collected were first pre-processed before any quantitative and qualitative analysis. A quality control helped checking their accurateness, reliability and relevance to the study. Quantitative data analysis in this study essentially involved with descriptive statistics, time series analysis, non-parametric tests and change detection analysis. To analyze remotely sensed images, the different images representing different bands were stacked. This allowed for different combinations of Red, Green and Blue band (RGB) to be shown in the view. This process was done using ERDAS imagine 10 software.

3.9.2 Image preparation

Consistency in the image handling requires a thorough pre-processing of satellite data for inter and intra image alignments in terms of geometry and radiometry. Image covering the study areas, as available in specific scene-id is to be identified. In general it is intended to keep the image data in GeoTiff format and it need be it may be imported using suitable format converters .While changing the raster image format care should be taken to maintain the geo referencing and an informal check on projection parameters may be done after the conversion. It is suggested that interpretation may be initiated on the appropriate data, which facilitates to delineate maximum possible land LULC classes. Before starting up the interpretation it is advised to thoroughly examine the temporal data sets for the variability in signature of a particular Class type. In general, first eliminate the areas where there is no scope for a particular type of land class to occur. For example good vegetal cover / good canal irrigation supporting more than two crops, etc. The vector interpreted using a particular season data can be overlaid on to other two data sets in the order of clarity in signature. The temporal data will be useful in assessing the severity of the problem.

3.9.3 Image enhancements

To improve the quality of an image for easy recognition of various earth features, the enhancement techniques namely, contrast enhancement and histogram equalization were used. The image enhancement were applied separately to each band of multispectral images to expand the narrow range of brightness values typically present in an input images. It increased the visual contrast between two areas of different uniform densities, which helps to interpret and discriminate easily between areas initially having a small difference density. In the present study, histogram equalization was applied in this technique; histogram of original image is redistributed to produce a uniform population density. This is obtained by grouping certain adjacent gray values. Thus the number of levels in the enhanced image is less than the number of gray levels in the original images. The redistribution of the histogram results in the greatest contrast being applied to the most populated range of brightness values in the original image. In this process the light and the dark tails of the original histogram are compressed, thereby resulting in some loss of detail in those region. This method gives large improvement in image quality when the histogram is highly peaked.

3.9.4 Band combinations

Color composites of different bands can yield varied levels of information due to diverse reflectance pattern in bands. Different combinations need to be considered for separability of LULC class types.

3.10 Image interpretation

Image interpretation is defined as the ‘the art of examining images for the purpose of identifying objects or surface features and judging their significance. Interpreter studies the remotely sensed data and attempts through logical processes in detecting and identifying, classifying, measuring and evaluating the significance of physical and cultural significance of spatial relationship.

3.11 Classification of land use / land cover

The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or "themes”.

This categorized data is used to produce thematic maps of the land cover present in an image. Normally, multispectral data are used to perform the classification and, indeed, the spectral pattern present within the data for each pixel is used as the numerical basis for categorization (Lillesand and Kiefer, 1994). The objective of image classification is to identify and portray, as a unique gray level (or color), the features occurring in an image in terms of the object or type of land cover these features actually represent on the ground. Two main classification methods are used Supervised Classification and Unsupervised Classification.

3.11.1 Unsupervised classification

In this type of classification, the computer produces spectral classes based on the digital numbers (DN) without any direction from the user. It gives initial information on the potential spectral clusters to be assigned to thematic classes. Therefore, subsets of the satellite data were first classified using unsupervised classification. This classification has been used as a guide in the selection of training sites for input into the supervised classification.

Unsupervised classification is used to cluster pixels in a data set into classes based on statistics only. These classes are spectral classes and their identity is not initially known, until they are compared with some reference data. This method calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculate means and reclassifies pixels with respect to the new means. All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified. If some pixels do not meet the selected criteria, they will be unclassified. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached. The final clusters are used to classify the image with classifiers such as the minimum distance or maximum likelihood.

The output however requires post classification operations to make the results more meaningful. The output of this method is used in the process of supervised classification. In this study, total outputs of major six land use /land cover class's map of the Upper Narmada basin. Land use/ land cover classification was derived from LISS-III and Landsat satellite images of three different years 1989, 2000 and 2011.

ERDAS Imagine software is use for unsupervised classification in which six LULC classes namely Forest, Agriculture/Other vegetation, Waterbodies, Built-up land, Fallow/Barren and Wasteland are classified. The procedure used for the classification of the satellite images are shown in Fig. 3.11. These images were verified by using the existing Google Earth and field ground truth.

Finally three LULC maps were generated for three years, 1989, 2000 and 2011. The changes in the land use land cover through the time were also determined. Graphs have been generated to indicate the variability of the land use /land cover in different years and to view the statistics result of each land use /land cover change.

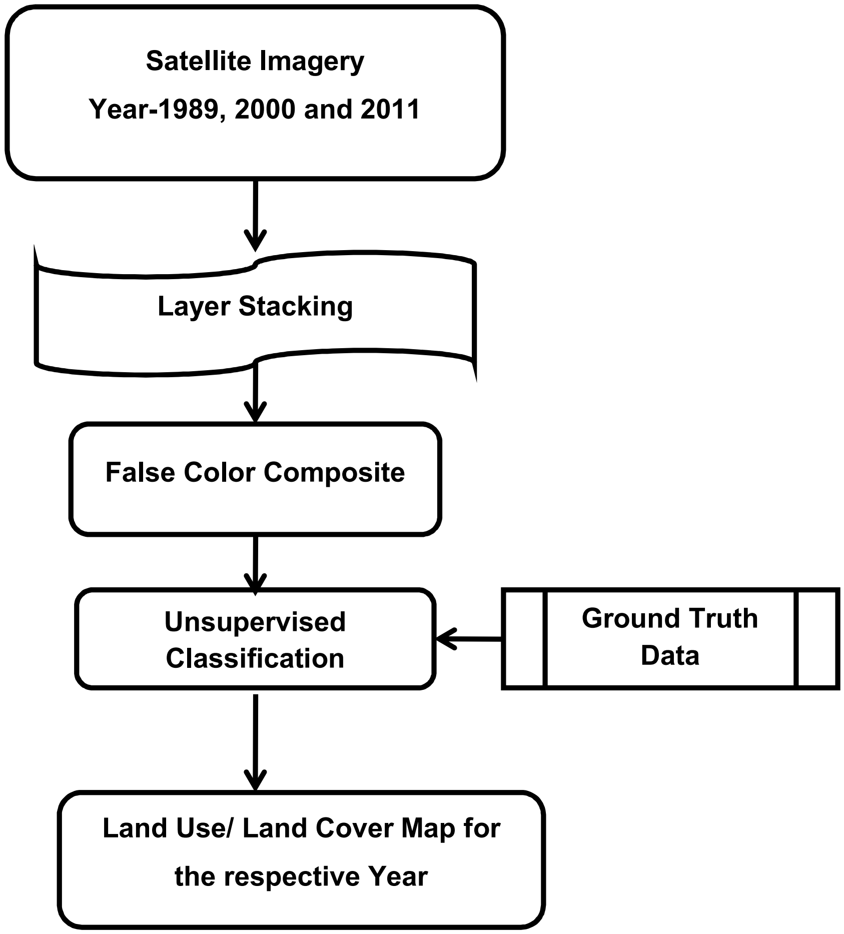

Fig. 3.11: Flowchart of land use /land cover classification

3.11.2 Training data sets acquisition and signature editing

After sub-setting the image the training data sets were created from the satellite image with the help of ground truth data. The photographic interpretation information was used as a guide for defining the feature classes in the satellite images. The classes identified in this way were agricultural land, wasteland, water body, and forest, fallow and built up land. These classes were sampled from the satellite image by using the region grows in ERDAS Imagine. The region grow method simply allows drawing a polygon that defines the location of the pixels which represent the particular spectral class. Once the base training sets were established, each training set was stored in signature editor and assigned the color desired for the particular feature class. The training data sets were used to generate class signatures and classify the rest of the image into meaningful information classes.

3.11.3 Site reconnaissance and ground truth verification

A preliminary reconnaissance was conducted in Upper Narmada Basin. The existing situation of the sub-basin and the general idea of the physical characteristics of the area were captured. Visual observations through Global Positioning System (GPS) were made along selected routes for the identification of LULC types. However, fieldwork was conducted for ground truth verification of mapped features. Special attention was paid to hotspots so as to document factors driving such changes. The GPS used in this study was Garmin Map 60 with accuracy of four meters. This was used to collect coordinates to verify the accuracy of the classified satellite images.

Ground truth or field survey is done in order to observe and collect information about the actual condition on the ground at a test site and determine the relationship between remotely sensed data and the object to be observed. It is recommended to have a ground truth at the same time of data acquisition, or at least within the time that the environmental condition does not change.

Classification accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true to determine the accuracy of the classification process. Usually, the assumed true data are derived from ground truth. It is usually not practical to ground truth or otherwise test every pixel of a classified image. Therefore, a set of reference pixels is usually used. Reference pixels are points on the classified image for which actual data are (will be) known. The reference pixels are randomly selected. (Congalton, 1991)

3.12 Accuracy of classification

The accuracy assessment of an image classification was done by creating the classification error matrix. In this confusion matrix, classification results were compared to ground truth data and Google earth obtained during fieldwork. This was done by selecting the menu item classifier>accuracy assessment, then importing the ground coordinates of the ground truth samples from an Excel file which was already saved in text format . According to Coppin and Bauer (1996), whatever the algorithm used, the spectral image classification always results in accuracies which range between 50% and 75%, depending on the number of available image registrations, the quality of the ground truth and the number of considered change classes.

3.12.1 Kappa coefficient

Cohen's kappa coefficient is a statistical measure of inter-rater agreement or inter-annotator agreement for qualitative (categorical) items. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification (Coppin and Bauer, 1996). Kappa was computed as follows:

$$KHAT = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}{N^2 - \sum_{i=1}^{r}\left(x_{i+} \times x_{+i}\right)}$$

Where,

r = number of rows in the error matrix

Xii = number of observations in row I and column I (I The diagonal element)

Xi+ = marginal totals of row

X+i= marginal totals of column

N = Total number of observations

KHAT = Kappa Coefficient

3.13 Change detection analysis

The land-use /land cover change detection was done by involving the images of (1989 between 2000), (2000 between 2011) and (1989 between 2011) time using confusion matrix. This is due to the fact that the matrix operation from the GIS analysis allows two thematic images or vector files of different years to be compared. By comparing two classified sets of data, the matrix operation was able to show all the changes from one class to another. Data analysis was used to analyze objectives one and three for the period of 1989, 2000 and 2011.

For interpretation of images and change detection, a post classification comparison method of change detection was also applied. The cross operation process of mapping LULC change over time began with mapping the present 2011 satellite imagery, then looking back in time to map the past 1989 imagery. Post-classification is among the most widely applied techniques for change detection purpose (Lunetta and Elvidge, 1999; Chen, 2000; Singh, 1989; Coppin and Bauer, 1996; Pettit et al, 2001). The analysis of land-use change maps involved technical procedures of integration using the ERDAS Imagine and ArcGIS software technique. The detection of the changes provided an understanding of human interference on the sub-catchment over years and its possible influence on the water flow in the river systems. The LULC change in percentage was then calculated as (Lambin, 2001):

$$\text{Percentage change} = \frac{\text{Observed Change}}{\text{Sum of Area}} \text{ X } 100$$

3.14 Hydrological Modeling

The simulation of the hydrology of a watershed is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapo-transpiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_O + \sum_{i=1}^{t} R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}$$

In which

SW_t is the final soil water content (mm),

SW_o is the initial soil water content on day i (mm),

t is the time (days),

R_{day} is the amount of precipitation on day i (mm),

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

E_a is the amount of evapotranspiration on day i (mm),

W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm),

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

3.14.1 Surface runoff generation

Surface runoff or overland flow is a flow that occurs along a sloping surface and it occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. It is the major component of the hydrologic cycle.

SWAT2009 provides two surface runoff computation methods; a modification of the Soil Conservation Service (SCS) Curve Number (CN) method (USDA, Soil Conservation Service, 1972) or the Green and Ampt infiltration method (Green and Ampt, 1911). The CN method was initially developed for small agricultural watersheds and the CN varies non-linearly with the moisture content of the soil. It drops to zero as the soil approaches the wilting point and increases to near 100 as the soil approaches saturation, with higher CNs associated with higher runoff potential watershed.

In this study, the SCS curve number method was used to estimate surface runoff because of the unavailability of sub daily data for Green and Ampt method. The method is an empirical model, which is based on the following equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

Where:

Q_{surf} is accumulated runoff or rainfall excess (mm water),

R_{day} is rainfall depth for the day (mm water),

I_a is an initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm water),

S is a holding parameter (mm water).

The holding parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. It is mathematically expressed as:

$$S = 25.4(\frac{100}{CN} - 10)$$

Where:

CN is the curve number for the day.

CN=f (land use, practice, soil permeability, soil hydrologic group) For the definition of the soil hydrologic groups(See Appendix-D), the model uses the U.S. Natural Resource Conservation Service (NRCS) classification, which classifies soils into four hydrologic groups (A, B, C, and D) based on infiltration characteristics of the soils. Group A, B, C and D soils have high, moderate, slow, and very low infiltration rates with low, moderate, high, and very high runoff potential, respectively. The initial abstraction, Ia, is commonly approximated as 0.2S and the equation becomes

$$Q_{surf} = \frac{(R_{day} - 0.2s)^2}{(R_{day} + 0.8S)^2}$$

Runoff will only occur when $R_{day}>I_a$Curve number is based on the soils and land uses in the watershed.

3.14.2 Arc SWAT Model

In conjunction with the SWAT model, Arc SWAT was used to preprocess GIS data. Arc SWAT is an extension to the SWAT model that runs within ArcGIS. It provides a graphical user interface that allows for GIS data to be easily formatted for use in SWAT model simulations. Arc SWAT breaks preprocessing into four main steps: Watershed Delineation, Hydrologic Response Unit (HRU) Analysis, Weather Data Definition and SWAT simulation including sensitivity analysis and calibration Fig. 3.12 Shows the Component and Input /Output data of SWAT model. In order to understand how each section works within the modeling process, it is important to understand the conceptual framework of each step, as well as what data are used and how they are integrated into Arc SWAT.

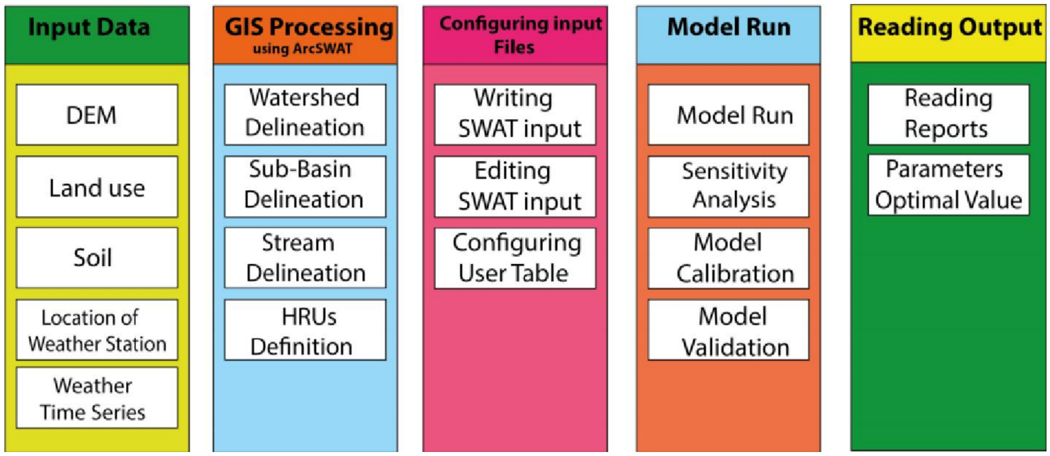

Fig. 3.12: Component and Input /output data of SWAT model.

3.14.3 SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be linked to SWAT. This is demonstrated by the program links GLUE, Parasol, SUFI2, and MCMC procedures to SWAT. In this particular study it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to observed data) are extracted from the model output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model.

3.15 Model set-up

3.15.1 Watershed delineation

As mentioned before, the analysis for the Upper Narmada Basin was performed using ArcSWAT2009. An imported a 30 m x 30 m resolution DEM (Fig.3.7) to Arc SWAT workspace was used to delineate the watershed of the study area. The stream network and the sub-basin outlets were defined. Catchment, the gauge station inside the basin, was manually added and defined as an outlet. The basin was delineated into sub basins (Fig.3.13). Fig.3.14 present the drainage network of the study area.

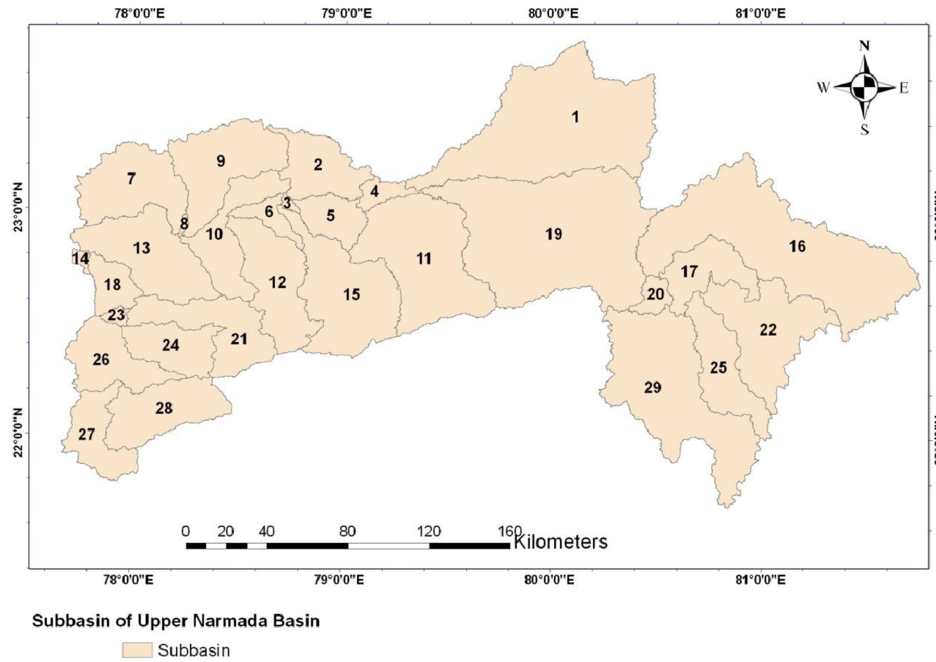

Fig.3.13: Delineated Sub-basins of upper Narmada basin

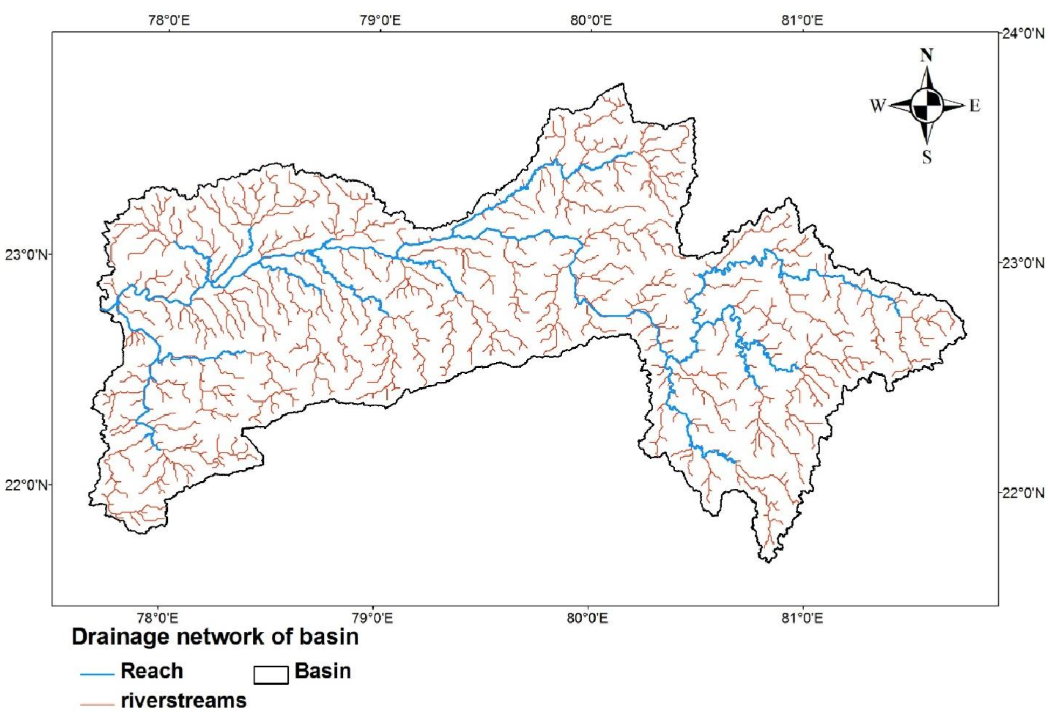

Fig.3.14: Drainage network of upper Narmada basin

SWAT model require LULC and soil data in order to determine the area and the hydrologic parameters of each land use and soil category simulated in each sub watershed. The land use/cover, slop and soil map were imported into the interface and reclassified (Fig.3.15, 3.16 and 3.17).Classes which belonged to the same category and had close hydrological properties were combined into six land use/cover major classes presented in Table 3.6.The very small classes which are far less than 5% percent of the total area were ignored. This was done using Arc Map interface. Land use, slop and soil were reclassified again in Arc SWAT interface.

Current SWAT database has only values of hydrological property parameters of the most common type of LULC classes. Some of the land use/cover classes and their parametric values did not exist in SWAT default data base. It was necessary to replace these classes with land use/cover classes of the SWAT database which have similar hydrological properties.

Therefore, during reclassification, land use/cover classes which were not exist in SWAT database substituted by classes which exist in SWAT data base and have similar hydrological properties.

Table 3.6: Land use/ land cover in the study and corresponding SWAT land use class.

S.No	**LULC**	**SWAT LULC**
1	Agriculture/Other Vegetation	AGRL
2	Built-up land	URBN
3	Forest land	FRST
4	Fallow land	PAST
5	Wasteland	RNGB
6	Water body	WATR

The soil map of the study area was reclassified according to Arc SWAT requirements. It was reclassified into the most representative classes of the study area (Fig. 3.16). National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) soil classification system which was supported by other additional method was used to determine soil types and properties of each soil class. The soil map has five soil type classes was generated.

Slope classification was carried out based on the height range of the DEM used during watershed delineation. The slope values were reclassified in percent. It was reclassified into four classes (Fig.3.17).

In the next step, all the reclassified three maps were overlaid. This procedure helped to determine land use/cover /soil /slope class combination and distribution for the delineated watersheds and each respective sub-watershed. Then, the sub basins were divided into Hydrologic Response Units (HRUs) by assigning the threshold values of land use/cover and soil percentage. While assigning multiple HRUs to each sub basin the thresh hold level should be defined in which the user can specify sensitivities for land use/cover, soil and slope data that will be used to determine the number and kind of HRUs in each watershed. In general the thresh hold level used to eliminate minor land use/covers in sub basin, minor soil with in a land use/cover area and minor slope classes with in a soil on specific land use/cover area.

Following minor land use/cover, soil areas and minor slope classes elimination, the area of remaining land use/ land covers, soils and slope classes are reapportioned so that 100% of their respective areas are modeled (SWAT2009) threshold value was chosen for soil and land use/ land cover for defining the number of HRUs sub value was chosen for soil and land use/cover for defining the number of HRUs in each sub basin.

3.15.2 Hydrologic response unit definition

SWAT a watershed is subdivided into sub basins based on the number of tributaries. The sizes of watersheds and number sub basins in the watershed vary from place to place. The sizes of sub-basins also vary based on the nature of the topographic and the stream network system of an area. The sub basins of the watershed are divided into multiple Hydrologic Response Units (HRUs).

The HRUs represent areas with homogeneous land use/cover, management, and soil characteristics. However, they have no separate spatial representation in SWAT simulation. The HRU in SWAT are spatially implicit, their exact position on the surface cannot be identified, and the same HRU may cover different locations in a sub basin (Neitsch et al., 2005) and (Di Luzio et al., 2005). The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2 meters), shallow aquifer (typically 2-20 meters), and deep aquifer (more than 20 meters) (David et al., 2007). Each HRU in a sub watershed is liable for flow sediment, nutrient, and pesticide loadings that are routed through channels, ponds, and/or reservoirs to the watershed outlet. Detailed descriptions of the model and model components can be found in (Arnold et al., 1998) and (Neitsch et al., 2000).

The main part of SWAT analysis can be performed in ArcSWAT2009 interface. Geographical Information System (GIS) is used as an auxiliary and a preprocessor to the SWAT modeling process. Arc Map interface of ArcGIS 9.3 can be used for managing and processing spatial data which were used as SWAT input data in a project.

Spatial data including digital elevation model (DEM), thematic map layers of land use/cover and soil data are necessary data to perform hydrological water balance analysis of a basin in SWAT. The DEM is used to gain the topographical characteristics of an area which are required by SWAT modeling and has direct impact on hydrological cycle. The land use/cover map is used to categorize vegetation type's that have impact on the hydrological process of the area. The soil map is used to identify physical and chemical characteristics of various soils that have major role in the hydrological process of an area. Whereas weather data can be entered in SWAT interface following the reclassification of land use/cover and soil data. It is important for calculating the water balance components in each HRU in the watershed. Further details can be found in the upcoming subsections.

The SWAT model requires the creation of Hydrologic Response Units (HRUs), which are the unique combinations of land use, soil and slope type within each sub-basin. The land use, soil and slop classifications for the model are slightly different than those used in many readily available datasets and therefore, the land use, soil and slope data were reclassified into SWAT land use, Slope and soil classes (Fig. 3.15, 3.16 and 3.17). Model divided the basin in to 29 sub–basin and 277 HRU determined by unique inter section of the LULC, slope and soil within the basin.

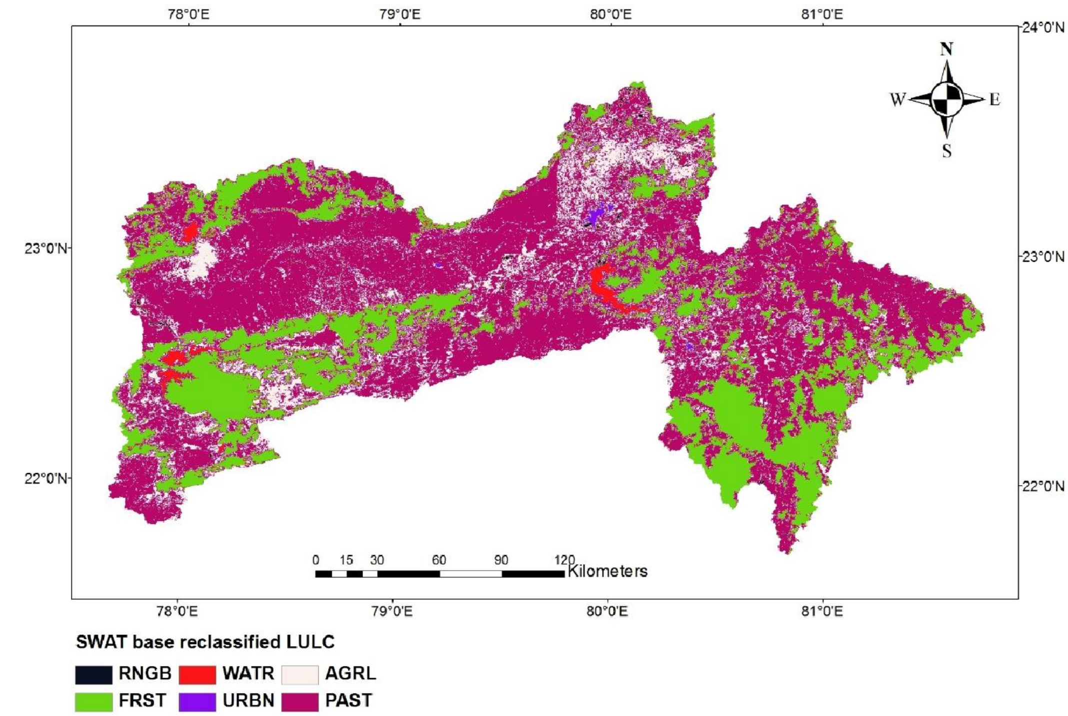

Fig.3.15: Reclassified land use /land cover map of upper Narmada basin

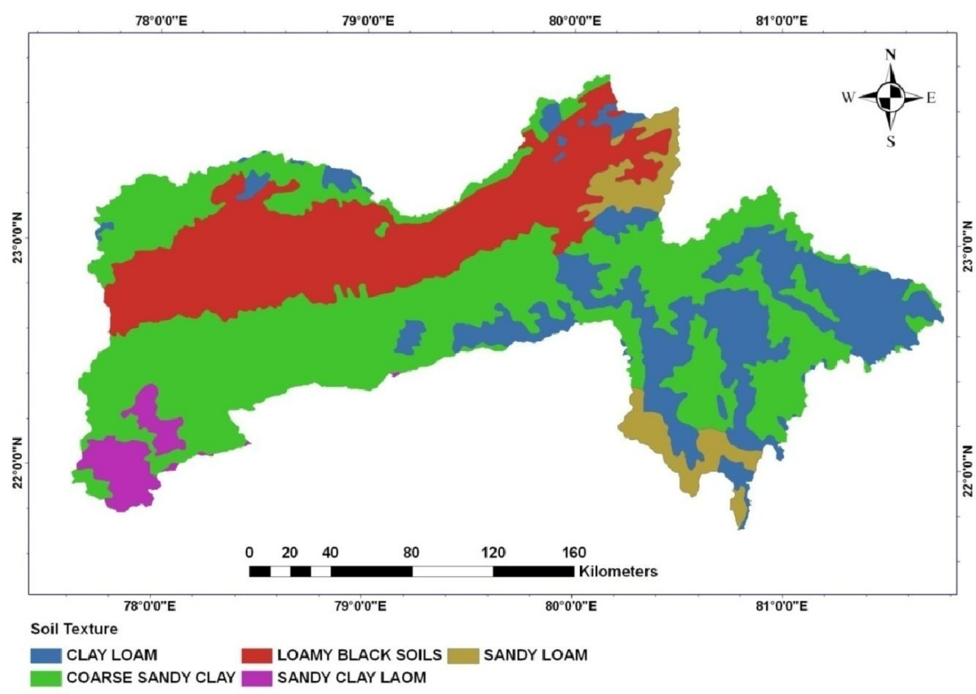

Fig. 3.16: Reclassified soil map of upper Narmada basin

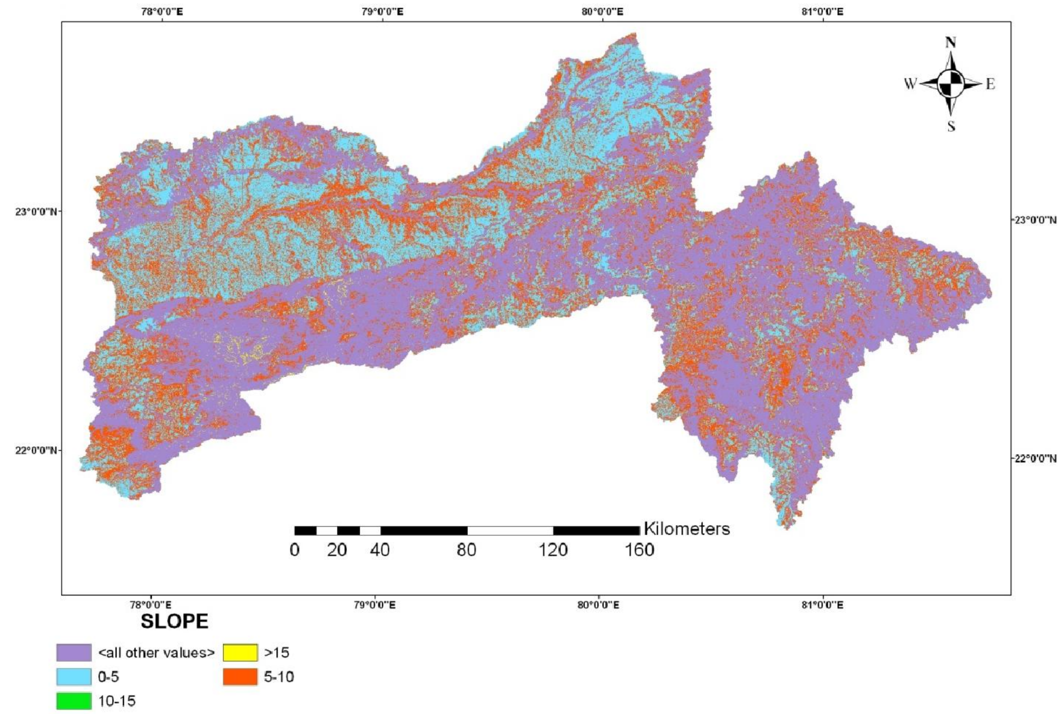

Fig.3.17: Reclassified slope classes of upper Narmada basin

3.15.3 Entering weather data

Daily time-series of weather data, which includes precipitation and maximum and minimum air temperature data, is required for the SWAT modeling. The data stations which were used in the study are called Barmanghat, Dindori, Gadarwara, Hoshangabad, Manot, Patan and Sandia (Fig.3.9). The periods of the measured weather data, which was obtained from Indian Meteorological Department (IMD), Pune and Global weather data for SWAT, was differ from station to station. From January1st1989 to December 31th 2011 period was used for SWAT simulation. To deal with the weather data, it should be stored in a specific tabular and supportive file format of Arc SWAT.

The SWAT Model contains weather generator model called WXGEN (Shapley and Williams, 1990). It is used in SWAT model to generate climatic data or to fill missing data using monthly statistics which is calculated from existing daily data. From the values of weather generator parameters, the weather generator first separately generates precipitation for the day. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated. Lastly, the wind speed is generated independently.

To generate the data, weather parameters were developed by using the Microsoft Excell, Statistical parameter calculator (*pcpSTAT*.exe) and dew point temperature calculator (DEW02), which were downloaded from the SWAT website. The programme *pcpSTAT*.exe calculate monthly daily average and standard deviation as well as probability of wet and dry days, skew coefficient, and average number of precipitation days in the month by reading of the daily values of the variables from the stations. See Appendix-C for Weather Generator parameters (WGEN) used by the SWAT model.

Average Daily Dew Point Temperature was calculated using the Dew point calculator (Dew02) from daily maximum temperature, daily minimum temperature and average relative humidity. Moreover, daily solar radiation was calculated from the daily available sunshine hour's data.

In this case they were stored in DBF and TXT format which is read by Arc SWAT interface. The geographical coordinate's names of the weather stations of the study area were introduced into Arc SWAT database.

3.15.4 SWAT simulation

In the next task, the database files containing the information needed to generate default input for SWAT model were built. In SWAT, once the default input database files are built, the necessary parameters values can later be entered and edited manually. The HRU distribution was also modified whenever it was needed. The soil parameters values of each type of soil were entered.

The land use/cover parameters were edited where it was necessary. Since the Penman-Monteith equation requires detailed climatological data which are not easily available especially in developing nations (Khoob, 2007), the Hargreaves (Hargreaves et al, 2003) method was chosen to calculate evapotranspiration (ETo). Hargreaves equation can be used in the lack of sufficient or reliable data to solve the Penman Monteith equation (Allen1998). The equation can estimate the ETo using only daily mean, maximum and minimum air temperature, usually available at most weather stations worldwide and extraterrestrial radiation (Droogers and Allen, 2002.).

The curve number for runoff and the variable storage for channel routing were chosen. Percolation component was modeled with a layered storage routing technique combined with a crack flow model. A skewed normal distribution was assumed for rainfall distribution. SWAT simulation run was carried out on the 1989-2011 climate data. Two year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. The run output data imported to database and the simulation results were saved in different files of SWAT output. The file named basins.rch contains stream-flow and water quality parameters in streams and rivers. It is used for SWAT model calibration since most of the observations of the watershed's behavior are obtained by measuring these parameters. The basins.subs file stores yearly outputs from HRU's.

3.15.5 Sensitivity analysis

There are several parameters which affect a complex hydrological modeling. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in description of both the elements and processes present in the system are some of the reasons (Holvoet et al., 2004). Therefore, optimizing internal parameters of a model is an important task in order to achieve a well representative hydrological model. This kind of task is called model calibration which is usually supported by sensitivity analysis parameters.

Sensitivity analysis helps to determine the sensitivity of parameters by comparing the output variance due to input variability. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability.

Therefore, the number parameters that can be involved for calibration will be less in number and influential. It also evaluates the model capacity and helps to understand the behavior of the system being modeled. Sensitivity analysis was performed to determine the influence a set of parameters had on predicting total flow. The analysis was carried out to identify the SWAT's hydrologic sensitive parameters by comparing their relative sensitiveness. It was performed on ten different SWAT parameters. Then the model parameters used in the sensitivity analysis of streamflow were selected and the method algorithm for analysis was defined.

In the study the Latin Hypercube One factor at a Time (LHOAT) sensitivity analysis method was used. It is a combination of the One-factor-At-a-Time (OAT) design for simulation and Latin Hypercube (LH) sampling. It basically has the same concept as that of Monte Carlo simulation except the sampling method which is used by LH-OAT is stratified sampling rather than random sampling. By applying default lower and upper boundary parameter values, the parameters were tested for sensitivity analysis for the simulation of the stream flow. 'Average criteria' options have been selected for 'sensitivity analysis output'. Finally the sensitivity analyses were run for the selected gage stations.

In the analysis, parameters, which resulted from the analysis, were ranked according to the magnitudes of response variable sensitivity to each of the model parameters, which divide high and low sensitivities (Table 3.7), which were chosen for calibration processes.

The method used to determine the dominant hydrological parameters and to reduce the number of model parameters which will be used in calibration.

However, parameters that had been not evaluated during sensitivity analysis have to be modified during calibration so that the simulated flow model parameters fit that of the observed stream flow parameters. Modifying parameters other than those identified during sensitivity analysis was carried out with investigating the type of error which occurs in simulated variables.

The sensitivity analysis were carried out for a period of 5 years, which included both the calibration period from January 1st, 1991 to December 31st, 1995 and the warm up period from January 1st, 1989 to December 31st, 1990. Therefore sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (Lenhart et al, 2002).

About 50 iterations were done for the SWAT sensitivity analysis at the outlet of the watershed. It was shown that 10 parameters seven of these mainly affect the surface runoff (CN2, SURLAG, ESCO, SURLAG, EPCO, CANMAX and SOL_AWC), the remaining three affect base flow generation (GW_REVAP, GWQMN and ALPHA_BF).

3.15.6 Model verification

Model verification is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation period stream flows confirm that the model performs satisfactorily. In the validation process, data for a period of three years was used to evaluate the model accuracy. The statistical criteria used during the calibration procedures were also checked here to make sure that the simulated volume is still within the accuracy limits.

Table 3.7: List of sensitive flow parameters

S. No	Sensitive Parameters	Parameters Code	Min Max Relative sensitivity
1	Surface runoff lag time	SURLAG	0.05-24
2	Soil evaporation compensation factor	ESCO	0-1
3	Plant uptake compensation factor	EPCO	0-1
4	Groundwater delay	GW_DELAY	30-450
5	Groundwater "revap" coefficient	GW_REVAP	0.02-0.20
6	Base flow alpha factor	ALPHA_BF	0-1
7	Maximum canopy storage	CANMX	0-100
8	Manning's "n" value for the main channel	GWQMN	0-2
9	Available water capacity of the soil layer	SOL_AWC	0-1
10	SCS runoff curve number for moisture condition II	CN2	25-98

3.16 Model calibration and validation

3.16.1 Model calibration

The time series of discharge at the outlet of the basin was used as data for calibration and validation for SWAT model, the model was calibrated using the measured stream flow data from 1991 to 1995 with worm up period and first the sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity. The parameters were optimized first using the SWAT-CUP calibration tool, then calibration was done by adjusting parameters until the simulated and observed value showed good agreement. In this process, model parameters varied until recorded flow patterns are accurately simulated. Model calibration of SWAT-CUP run can be divided in to several steps. (Refsgaard, 1996) distinguished three types of calibration methods:

A: The manual trial-and-error method,

B: Automatic or numerical parameter optimization method; and

C: A combination of both the above methods

For this research work the observed stream flow data of upper Narmada basin were manually calibrated from a period of 5 years, which included both the automatic calibration period (from January 1st,1991 to December 31st, 1995) and the warm up period (from January 1st, 1989 to December31st, 1990).

3.16.2 Model validation

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation.

As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenario. For this research work the observed stream flow data of Upper Narmada Basin from 1stJanuary1989 to 31st December, 2011 were used.

3.16.3 Model performance evaluation

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (E_{NS}) were the goodness of fit measures used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between measured and predicted values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash, Sutcliffe, 1970). The RSR, PBIAS, E_{NS} and R^2 values are explained in equations below.

(1) RSR, which calculates the ratio of the standardized root mean square error to the observed standard deviation, defined as.

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}[O_i - S_i]^2}}{\sqrt{\sum_{i=1}^{n}[O_i - \bar{O}]^2}}$$

(2) Percent of bias, PBIAS, defined as

$$PBIAS(\%) = \frac{\sum_{i=1}^{n}(O_i - S_i) * 100}{\sum_{i=1}^{n}(O_i)}$$

(3) Nash-Sutcliffe model efficiency coefficient, NSE, defined as

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}[O_i - S_i]^2}{\sum_{i=1}^{n}[O_i - \bar{O}]^2}\right] = 1 - (RSR)^2$$

(4) Square of Pearson's correlation coefficient R^2 between observed and simulated values, also called the coefficient of determination, defined as

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(O_i - S_i)(S_i - \bar{S})}{\left[\sum_{i=1}^{n}(O_i - \bar{O})^2\right]^{0.5}\left[\sum_{i=1}^{n}(S_i - \bar{S})^2\right]^{0.5}} \right\}^2$$

One of the limitations of the use of R^2 is that it only evaluates a linear relationship between observed and simulated predict and (stream flow), hence it is insensitive to additives and proportional differences between the model output and observations.

Based on the values of the performance parameters above, the performance of the watershed simulation model as per guideline given in Table 3.8 (Moriasi et al., 2007).

Table 3.8: Model performance ratings based on the range of values for RSE, NSE and PBIAS.

Performance rating	**RSR**	**NSE**	**PBIAS (%)**
Very good	0.00≤RSR≤0.50	0.75≤NSE≤1.00	PBIAS≤±1.00
Good	0.50<RSR≤0.60	0.65<NSE≤0.75	±10≤PBIAS≤±15
Satisfactory	0.60<RSR≤0.70	0.50≤NSE≤6.5	±15≤PBIAS≤±25
Unsatisfactory	RSR>0.70	NSE<0.50	PBIAS≥±25

3.17 Hydrologic response characteristic

To compare the hydrologic response to land use/ Land cover (LULC) change in upper Narmada basin, SWAT model was employed. In this, approach hydrological modeling was done to evaluate the Surface runoff (SQ), Aquifer recharge, Water yield and Evapotranspiration for the study period.

The trend analysis was performed using nonparametric Mann-Kendall test (Kendall and Gibbons, 1981; Smakhtin et al, 1995). Trend analysis was done on observed data (i.e. rainfall, temperature and stream flow) for respective stations to detect positive or negative trends during the period of 1979 to 2013.

3.17.1 Trend detection analysis

Temperature and precipitation has the maximum influence on the water resources. Trend analysis is used to detect trends in the time series of temperature and precipitation. Different types of trends on each variable interpret different implications on water resources. For instance, increasing trend in temperature will enhance the evaporation, decreasing trend in precipitation will result in drought. There are many parametric and non-parametric tests to detect the trend in a time series on each climatic variable. In the present study, Mann Kendall Test and Sen's slope estimator has been used. Non-parametric Mann Kendall test is used to find out the presence of a monotonic increasing or decreasing trend and the slope of the linear trend is estimated with the nonparametric Sen's method (Sen,1968). Missing values are allowed and the data need not confirm to any particular distribution. MAKESENS excel template has been used to estimate the Mann Kendall Test and Sen's slope estimator for estimating the magnitude of the trend.

3.17.1.1 Mann-Kendall test

The computational procedure for the Mann Kendall test considers the time series of n data points. Mann-Kendall test had been formulated by Mann (1945) as non-parametric test for trend detection and the test statistic distribution had been given by Kendall (1975) for testing nonlinear trend and turning point. In the computation of this statistical test MAKESENS developed both statistics, one is the S statistics given in Gilbert (1987) and the normal approximation (Z statistics). If the time series has less than 10 data points the S test is used, and if the time series has 10 or more data points the normal approximation (Z statistics) is used.

Let x1, x2, x3, ………. xn, represents n data points and i and j be two sub-sets of data ,then the Mann-Kendall test statistic S is given by following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i)$$

Where,

Xi=

1,2,3,4 ……..….n-1

Xj= i+1, 2,……..n

Xi and xj are the sequential data values, n is the length of the data set. Each of the data point xiis taken as a reference point which is compared with the rest of the data point's xj, equation as:

$$sign(x_j - x_i) \begin{matrix} = 1 if x_j - x_i > 0 \\ = 0 if x_j - x_i = 0 \\ = -1 if x_j - x_i < 0 \end{matrix} \Bigg\}$$

The variance of S is computed by the equation (4.3) which takes into account that ties may be present:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m}(t_i)(i)(i-1)(2i+5)}{18}.$$

Where ti is consider as the no. of ties up to sample i.

As the no. of data points are more than 10, therefore normal approximation is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10. The presence of a statistically significant trend is evaluated using the Z value given in equation:

$$\left.\begin{matrix} Z = \dfrac{S-1}{\{VAR(S)\}^{\frac{1}{2}}} If S > 0 \\ z = 0 If S = 0 \\ Z = \dfrac{S+1}{\{VAR(S)\}^{\frac{1}{2}}} If S < 0 \end{matrix}\right\}$$

A positive and negative value of Z indicates an upward and downward trend. The statistic Z has a normal distribution. To test for either an upward or downward monotone trend at α level of significance, H0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where$Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In MAKESENS the tested significance levels α are 0.001, 0.01, 0.05 and 0.1. Trends at significance below the 90% confidence level were not considered.

3.17.1.2 Sen's slope estimator

The Sen's nonparametric method is used to estimate the true slope of an existing trend. In equation, the slope N of all data pairs is computed as (Sen, 1968):

$$N = \frac{x_j - x_i}{j - i}.$$

Where xj and xi are considered as data values at time j and i (j>i) correspondingly.

The median of these n values of Q is represented as Sen's estimator of slope which is given in equation as:

$$Q = T_{\frac{n+1}{2}} If N is odd$$

$$Q = \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+1}{2}}\right) If N is even$$

Sen's estimator is computed as

Q=T (N+1)/2

if N appears odd, and

it is considered as

Q= [TN/2+T(N+2)/2]/2 if N appears even.

At the end, Q is computed by a two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Q indicates an upward or increasing trend and a negative value of Q gives a downward or decreasing trend in the time series.

3.18 Land use /land cover change scenarios development

Land use/ Land cover changes are driven by global change processes, especially by markets and political reforms and constrained by the given natural characteristics and socio-economic conditions of a region. This complexity gives rise to a wide range of approaches that range from extreme land-use changes such as total deforestation of a watershed, to the development of models that consider regional socioeconomic aspects.

Scenarios of changes in land use/land cover, in particular, are very critical to understand the complex behaviors of hydrological cycle. The study will give an insight how future change may affect society and how the processes connect to regional and local conditions.

For the current study, the scenarios of LULC change are derived from past research studies, the results will help to assess the future vulnerability of a hydrological system. The results will also support future National Assessments for the sustainability to suffice the increasing demand of food, feed, fiber and fresh water.

Although the models might not be able to accurately predict future events they may be used to simulate different land use scenarios (Hessel et al, 2003; Jetten et al, 1999).

Therefore, in this study used LULC for 2011 as baseline condition for evaluate the effects of the different land use scenarios, four LULC scenarios were developed with five level of each scenario and simple hypothetical scenarios were set considering the current LULC trend of the study area as tabulated in Table 3.9.

Table 3.9: The predictive LULC scenarios used in the study

Scenario	**Scenario Level**	**Land use/ land cover type**	**Condition**
First	I-5 I-10 I-15 I-20 I-25	Increase in Built-up area	Converting Agriculture/Other Vegetation + fallow / Barren to Built-up area
Second	II-5 II-10 II-15 II-20 II-25	Increase in Forest area	Converting wasteland +such area occupied by agriculture and fallow land

Third	III-5 III-10 III-15 III-20 III-25	Increase in Agriculture area	Converting fallow / Barren land to Agriculture
Fourth	IV-5 IV-10 IV-15 IV-20 IV-25	Increase in Combine area of Built-up and Agriculture/Other Vegetation area	Converting fallow /Barren to Agriculture/other Vegetation and Built-up area

Where

In First Scenario

I-5 = Increase Built-up area by 5 % and reduced 5% of Agriculture /other vegetation with Fallow/Barren land.

I-10 = Increase Built-up area by 10 % and reduced 10% of Agriculture /other vegetation with Fallow/Barren land.

1-15 = Increase Built-up area by 15% and reduced 15% of Agriculture /other vegetation with Fallow/Barren land.

1-20 = Increase Built-up area by 20 % and reduced 20% of Agriculture /other vegetation with Fallow/Barren land.

I-25 = Increase Built-up area by 25 % and reduced 25% of Agriculture /other vegetation with Fallow/Barren land.

In Second Scenario

II-5 = Increase Forest area by 5 % and reduced 5 % of wasteland with reducing such area of forest occupied by agriculture and fallow land.

II-10 = Increase Forest area by 10 % and reduced 10 % of wasteland with reducing such area of forest occupied by agriculture and fallow land.

II-15 = Increase Forest area by 15 % and reduced 15 % of wasteland with reducing such area of forest occupied by agriculture and fallow land.

II-20 = Increase Forest area by 20 % and reduced 20 % of wasteland with reducing such area of forest occupied by agriculture and fallow land.

II-25 = Increase Forest area by 25 % and reduced 25 % of wasteland with reducing such area of forest occupied by agriculture and fallow land.

In Third Scenario

III-5 = Increase Agriculture/Other Vegetation by 5 % and reduced 5% of fallow/Barren land.

III-10 = Increase Agriculture/Other Vegetation by 10 % and reduced 10 % of fallow/Barren land.

III-15 = Increase Agriculture/Other Vegetation by 15 % and reduced 15 % of fallow/Barren land.

III-20 = Increase Agriculture/Other Vegetation by 20 % and reduced 20 % fallow/Barren land.

III-25 = Increase Agriculture/Other Vegetation by 25 % and reduced 25% of fallow/Barren land.

In Forth Scenario

IV-5 = Increase combination of Built-up and Agriculture/Other Vegetation by 5 % and reduced 5 % of fallow /Barren land.

IV-10 = Increase combination of Built-up and Agriculture/Other Vegetation by 10 % and reduced 10 % of fallow / Barren land.

IV-15 = Increase combination of Built-up and Agriculture/Other Vegetation by 15 % and reduced 15 % of fallow /Barren land.

IV-20 = Increase combination of Built-up and Agriculture/Other Vegetation by 20 % and reduced 20 % of fallow / Barren land.

IV-25 = Increase combination of Built-up and Agriculture/Other Vegetation by 25 % and reduced 25 % of fallow / Barren land.

4. RESULTS AND DISCUSSION

4.1 General

This chapter presents the results obtained adopting methods as described in the chapter III, and a brief discussion on results.

4.2 Base maps

Boundary was delineated using georeferenced scanned map. Fig. 4.1 presents the basin boundary of the study area i.e. upper Narmada basin.

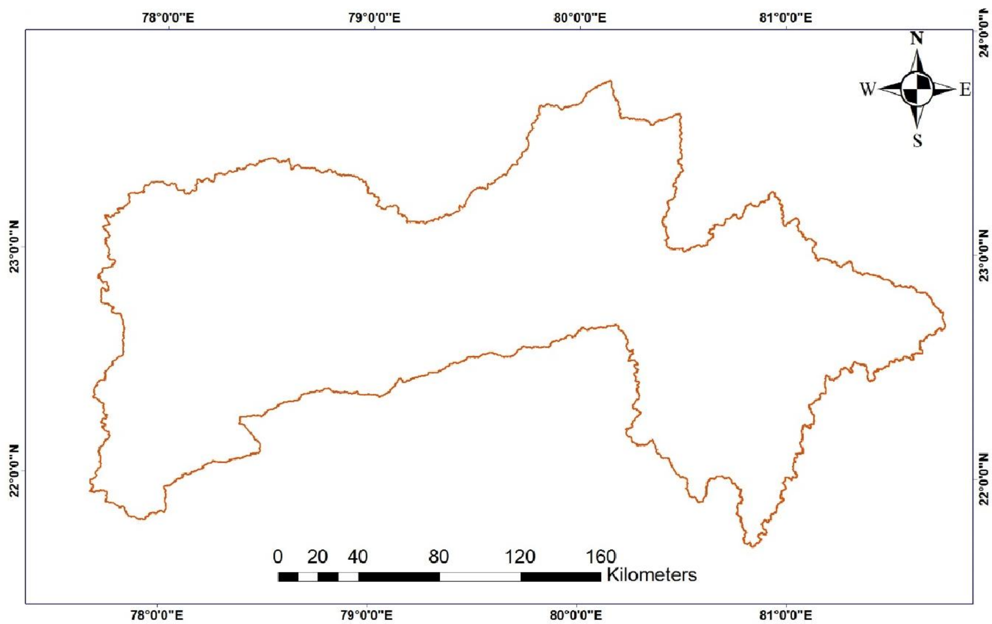

Fig. 4.1: Boundary map of the upper Narmada basin

4.3 Land use /land cover dynamics of upper Narmada basin

Ground features area identified on the basis of reflectance recorded by the sensor and converted into digital values which are classified by unsupervised classification of satellite image. For satellite image classification False Color Composite (FCC) of study area was prepared. Mosaic (FCC) was subset for the upper Narmada basin Fig. 4.2, Fig. 4.3 and Fig. 4.4 depicts the FCC of the study area for 1989, 2000 and 2011 respectively. In upper Narmada basin 6 LULC classes were identified i.e. Wasteland, Waterbody, Built-up area, Agriculture/Other vegetation, Fallow/Barren land and Forest area.

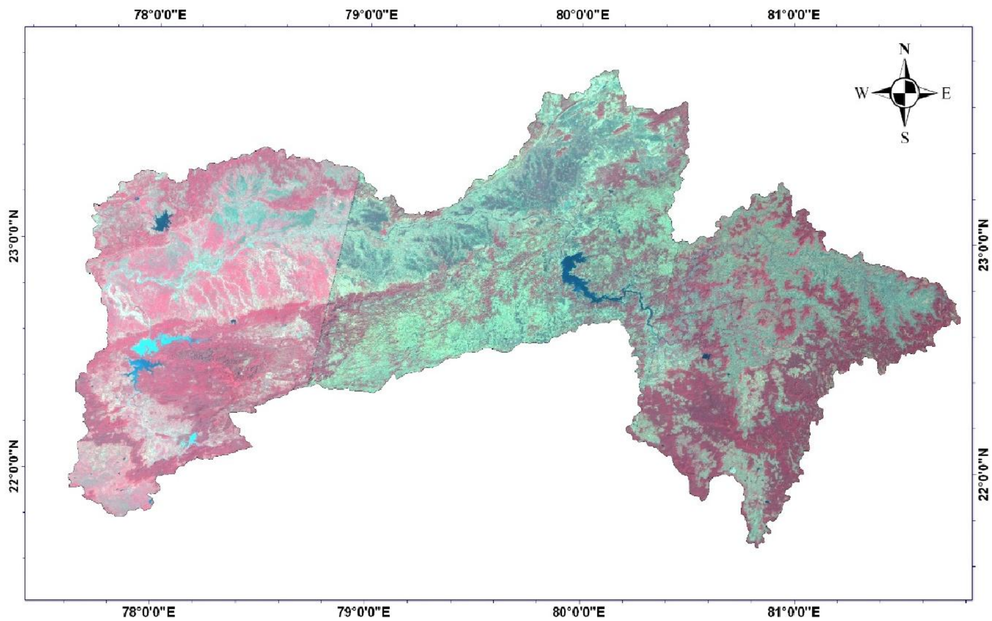

Fig. 4.2: Satellite Image of upper Narmada basin for the year-1989

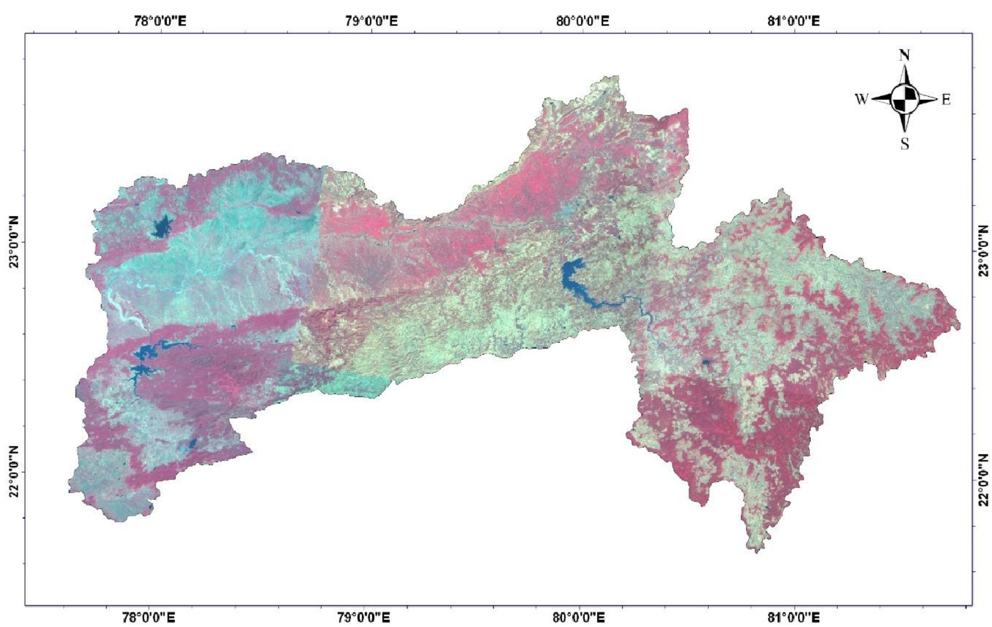

Fig.4.3: Satellite Image of upper Narmada basin for the year-2000

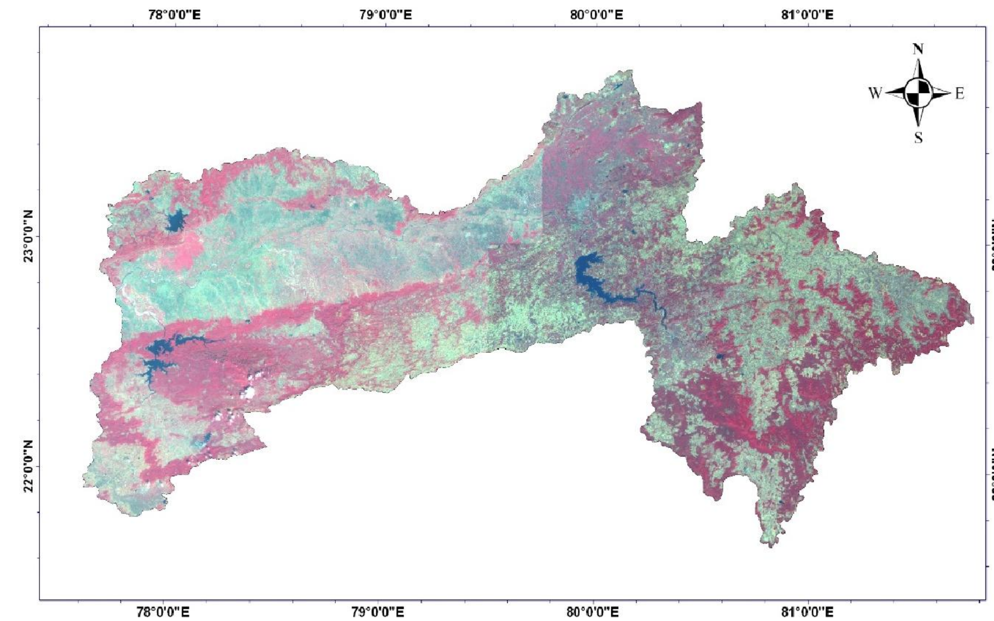

Fig.4.4: Satellite Image of upper Narmada basin for the year-2011

In order to assess the accuracy of the classification randomly selected 256 points have been verified by ground truth based on the class obtained by ground truthing and google earth and the class obtained by unsupervised classification for reference points error matrix have been prepared and presented in Table 4.1 for the year 1989.It can be seen that pixel classified for each training site are wasteland-10,forest-63, waterbody-14,built-up-12, agriculture/other vegetation-62 and fallow/barren land-48. The matrix error shows that there is 63 cell which should be calssified as forest but classified as Agriculture/ other Vegitation and Fallow/ Barren.There are 12 cell which should be classified as builtup land but classified as wasteland. There are 62 cell were which should be Agriculture/ other Vegitation but classified in forest,waterbody built-up and fallow/barren. There are 48 cell which should classified in fallow/barren but calssified in forest and waterbody. A comparasion of producers and Users is accuracy presented in Table 4.2 for the year 1989. The producer accuracy for wasteland were-100%, forest-82.89%, waterbody-100%, built-up-92.31%, Agriculture/ other Vegitation-76.54% and fallow/barren land-77.42% and for users accuracy wasteland-71.43%, forest-96.92%, waterbody-

87.50%, built-up land-92.31%, Agriculture/ other Vegitation-72.09% and fallow/barren land-77.42% were calculated.The total accuracy in this calssification accuracy is 81.64%.This means training sites selected are 81.64% spectral separable, and the training areas were classified very well. The overall kappa statistics was 0.75 presented in Table 4.3.

For the year 2000, it can be seen that the error matrix Table 4.4 shows that the pixel classified for each training site were wasteland-5, forest-60, waterbody-15, built-up-10 agriculture/other Vegetation-45, and fallow/barren-65.

A comparasion of producers and Users is accuracy presented in Table 4.5 for the year 2000.The producer accuracy for wasteland-100%, forest-84.51%, waterbody-93.75%, built-up-100%, Agriculture/ other Vegitation-65.22% and fallow/barren land-77.38% and users accuracy for wasteland-35.71%, forest-96.77%, waterbody-93.75%, built-upland-76.92%, Agriculture/ other Vegitation-67.16% and fallow/barren land-77.38% were calculated. The overall calssification accuracy was 78.13%.The overall kappa statistics was 0.70 shown in Table 4.6.Similarly for the year 2011, it can be seen that in error matrix Table 4.7 shows that the pixel classified for each training site were wasteland-1, forest-73, waterbody-4, built-up-1, agriculture/other Vegetation-51 and fallow/barren-83. And comparasion of producers and Users is accuracy presented in Table 4.8 for the year 2011.The producer accuracy for wasteland -14.29%, forest-86.90%, waterbody-50%, built-up-10%, Agriculture/ oth. Vegitation-85% and fallow/barren land-95.40% were found and users accuracy for wasteland-100%, forest-96.05%, waterbody-100%, built-up land-100%, Agriculture/other vegitation-70.83% and fallow/barren land-81.37% were calculated. The overall calssification accuracy was 83.20%. and the overall kappa statistics was 0.76 shown in Table 4.9.

Hence, Landis and Koch (1977) stated that the chance of agreement is poor when Kappa (K) <0.40, good when $0.4<K<0.7$ and excellent when $K>0.75$.

Alternatively Monserud (1990) suggested the use of subjective Kappa value as remarked $< 40\%$ as poor, 40-55% fair, 55-70% good, 70-85% very good and $>85\%$ as excellent. Thus, according to their classification scales the classification for this study area is acceptable i.e. very good.

Table 4.1: Error matrix for 1989

Classified Data	Reference Data						
	Wasteland	Forest	Water body	Built-up	Agriculture / oth. Veg.	Fallow/ Barren	**Row Total**
Wasteland	10	0	0	1	3	0	14
Forest	0	63	0	0	1	1	65
Water body	0	0	14	0	1	1	16
Built-up	0	0	0	12	1	0	13
Agriculture/Other Vegetation	0	12	0	0	62	12	86
Fallow/Barren	0	1	0	0	13	48	62
Total	**10**	**76**	**14**	**13**	**81**	**62**	**256**

Table 4.2: Producer and User accuracy

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy**	**User Accuracy**
Wasteland	10	14	10	100.00%	71.43%
Forest	76	65	63	82.89%	96.92%
Water body	14	16	14	100.00%	87.50%
Built-up	13	13	12	92.31%	92.31%
Agriculture/Other Vegetation	81	86	62	76.54%	72.09%
Fallow/Barren	62	62	48	77.42%	77.42%
Totals	**256**	**256**	**209**		
Overall Classification Accuracy = 81.64%					

Table 4.3: KAPPA (K^) STATISTICS

Class Name	Wasteland	Forest	Water body	Built-up	Agriculture/Oth Veg.	Fallow/Barren
Kappa	0.7027	0.9562	0.8678	0.919	0.5918	0.702
						Overall Kappa Statistics = 0.7557

Table 4.4: Error matrix for 2000

Classified Data	Reference Data						
	Wasteland	Forest	Water body	Built-up	Agriculture/oth. Veg.	Fallow/ Barren	**Row Total**
Wasteland	5	0	0	0	4	4	13
Forest	0	60	0	0	1	1	62
Water body	0	0	15	0	0	1	16
Built-up	0	0	0	10	2	1	13
Agriculture/ Other Vegetation	0	10	0	0	45	12	67
Fallow/Barren	0	2	1	0	17	65	85
Total	**5**	**72**	**16**	**10**	**69**	**84**	**256**

Table 4.5: Producer and User Accuracy

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Wasteland	5	14	5	100.00%	35.71%
Forest	72	62	60	84.51%	96.77%
Water body	16	16	15	93.75%	93.75%
Built-up	10	13	10	100.00%	76.92%
Agriculture/Other Vegetation	69	67	45	65.22%	67.16%
Fallow/Barren	85	84	65	77.38%	77.38%
Totals	**256**	**256**	**200**		
Overall Classification Accuracy = 78.13%					

Table 4.6: KAPPA (K^) STATISTICS

Class Name	Wasteland	Forest	Water body	Built-up	Agriculture/oth. Veg.	Fallow/Barren
Kappa	0.3443	0.9554	0.9333	0.7598	0.5505	0.6633
						Overall Kappa Statistics = 0.7074

Table 4.7: Error matrix for 2011

Classified Data	Reference Data						
	Wasteland	Forest	Waterbody	Built-up	Agriculture/oth. Veg	Fallow/ Barren	**Row Total**
Wasteland	1	0	0	0	0	0	1
Forest	0	73	0	0	3	0	76
Water body	0	0	4	0	0	0	4
Built-up	0	0	0	1	0	0	1
Agriculture/ Other Vegetation	1	11	3	2	51	4	72
Fallow/Barren	5	0	1	7	6	83	102
Total	**7**	**84**	**8**	**10**	**60**	**87**	**256**

Table 4.8: Producer and User Accuracy

Class Name	**Reference Totals**	**Classified Totals**	**Number Correct**	**Producers Accuracy**	**Users Accuracy**
Wasteland	7	1	1	14.29%	100.00%
Forest	84	76	73	86.90%	96.05%
Water body	8	4	4	50.00%	100.00%
Built-up	10	1	1	10.00%	100.00%
Agriculture/Other Vegetation	60	72	51	85.00%	70.83%
Fallow/Barren	87	102	83	95.40%	81.37%
Totals	**256**	**256**	**213**		
Overall Classification Accuracy = 83.20%					

Table 4.9: KAPPA (K^) STATISTICS

Class Name	Wasteland	Forest	Water body	Built-up	Agriculture/Oth. Veg.	Fallow/Barren
Kappa	1	0.9412	1	1	0.619	0.7178
						Overall Kappa Statistics = 0.7602

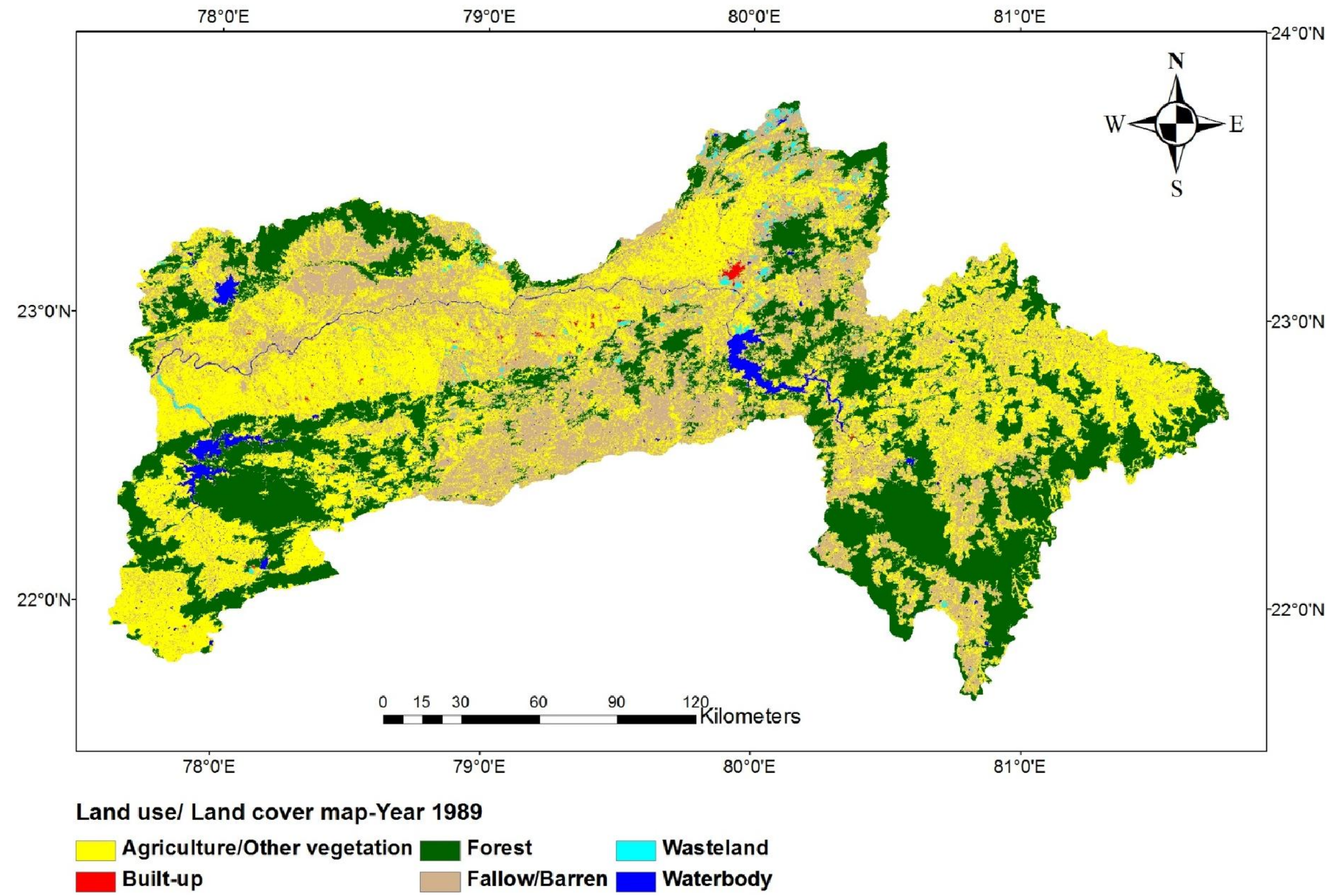

Fig.4.5: Land use /land cover map of upper Narmada basin –year 1989

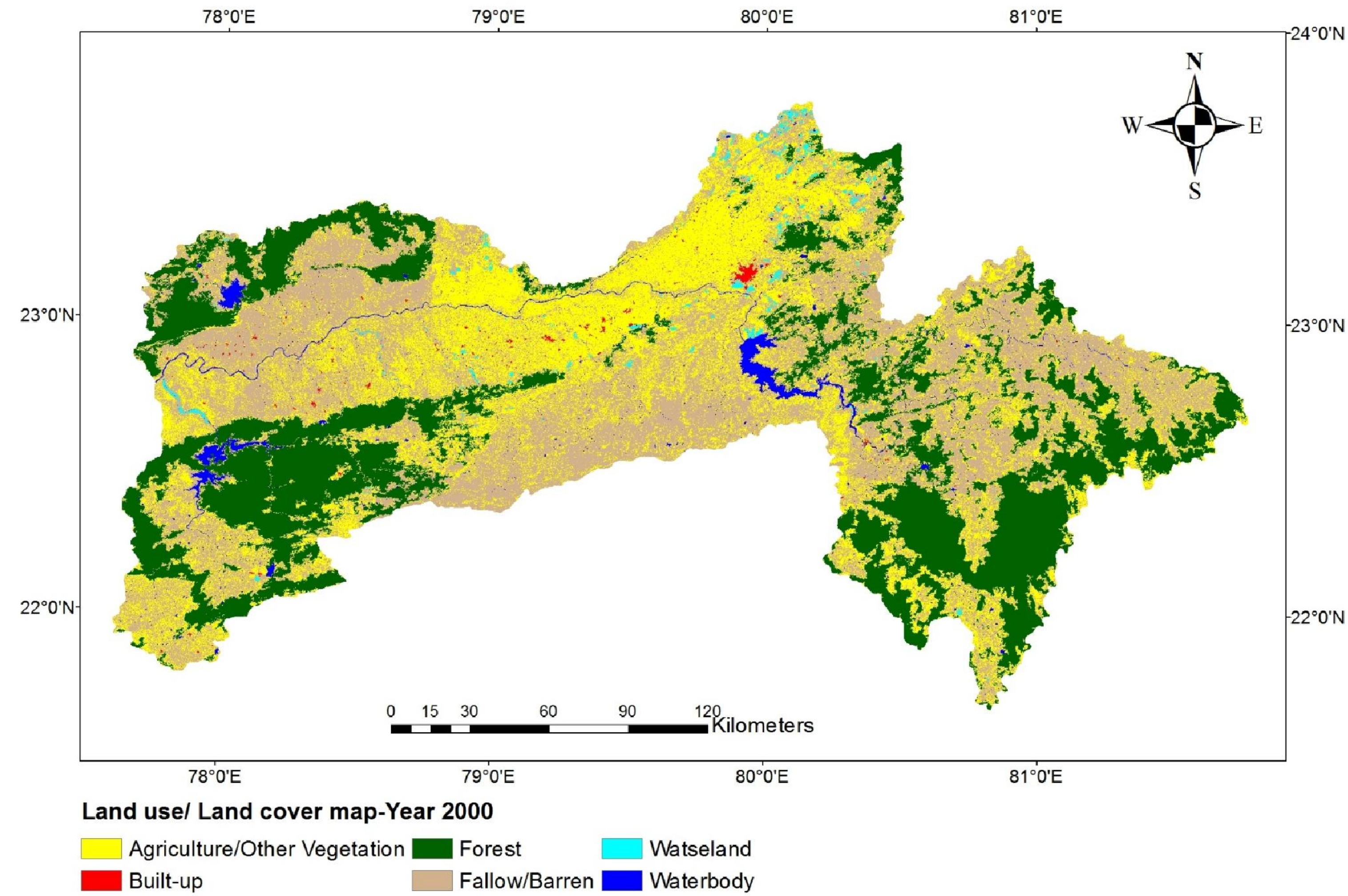

Fig. 4.6: Land use/ land cover map of upper Narmada basin –year 2000

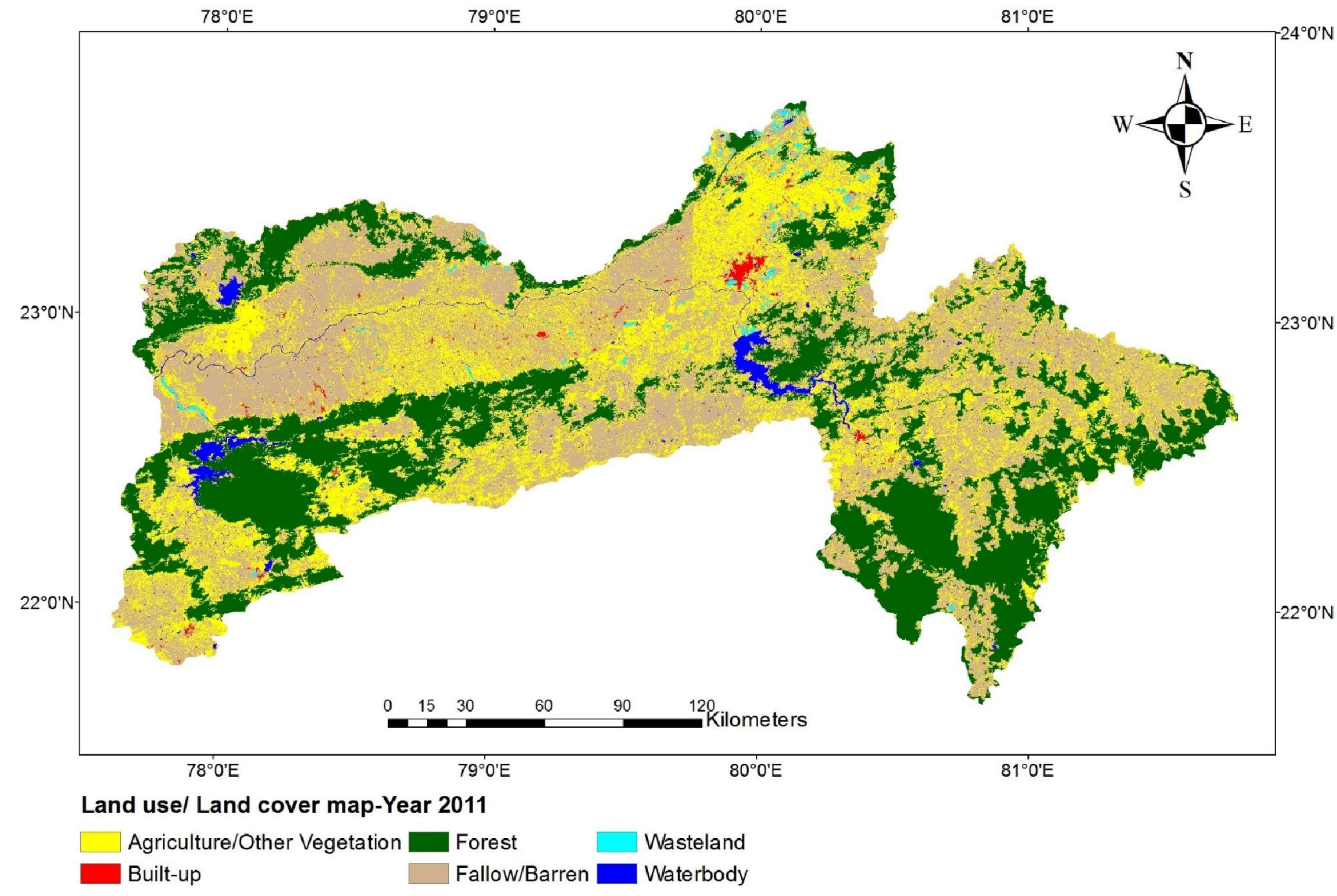

Fig. 4.7: Land use/ land cover map of upper Narmada basin –year 2011

4.3.1 Land use /land cover map

Land use/ land cover (LULC) map of the study area is presented in Fig. 4.5, 4.6 and 4.7 for the year 1989, 2000 and 2011 respectively. The The distribution of LULC of the study area is presented in Fig. 4.8 presents the histogram of LULC 1989, it can be seen that about 40.68 percent of the upper Narmada basin was covered by Agriculture / other vegetation, 27.43 percent by fallow/barren, 29 percent by Forest land, 1.86 percent by water body, and very little about 1 percent by wasteland.

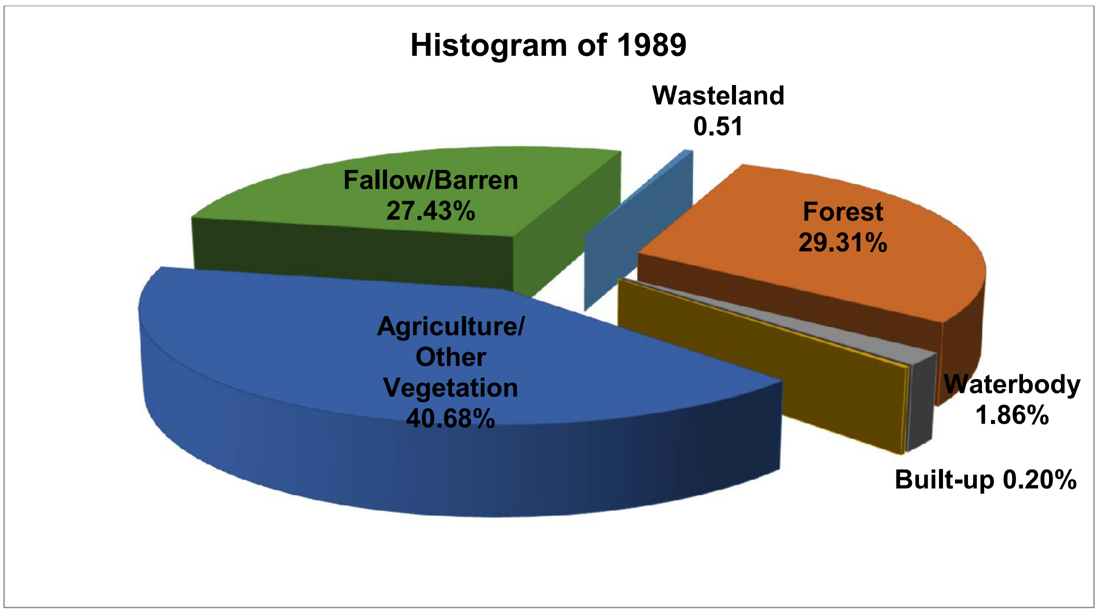

Fig. 4.8: Percentage of land use / land cover types for 1989

The LULC for the year of 2000 histogram Fig. 4.9 shows that the basin was covered by 27 percent forest, 39.81 percent Agriculture and other vegetation, 30.23 percent fallow/open land, 0.3 percent built-up land,1 percent wasteland and 2 percent waterbody.

And also for the year 2011 the LULC distribution are shown in Fig. 4.10. Histogram indicates that forest 30 percent, agriculture/ other vegetation 34.87

percent, fallow/open land 32.92 percent, maximum whereas built-up land, wasteland was found 0.5 percent and waterbody covered 2 percent.

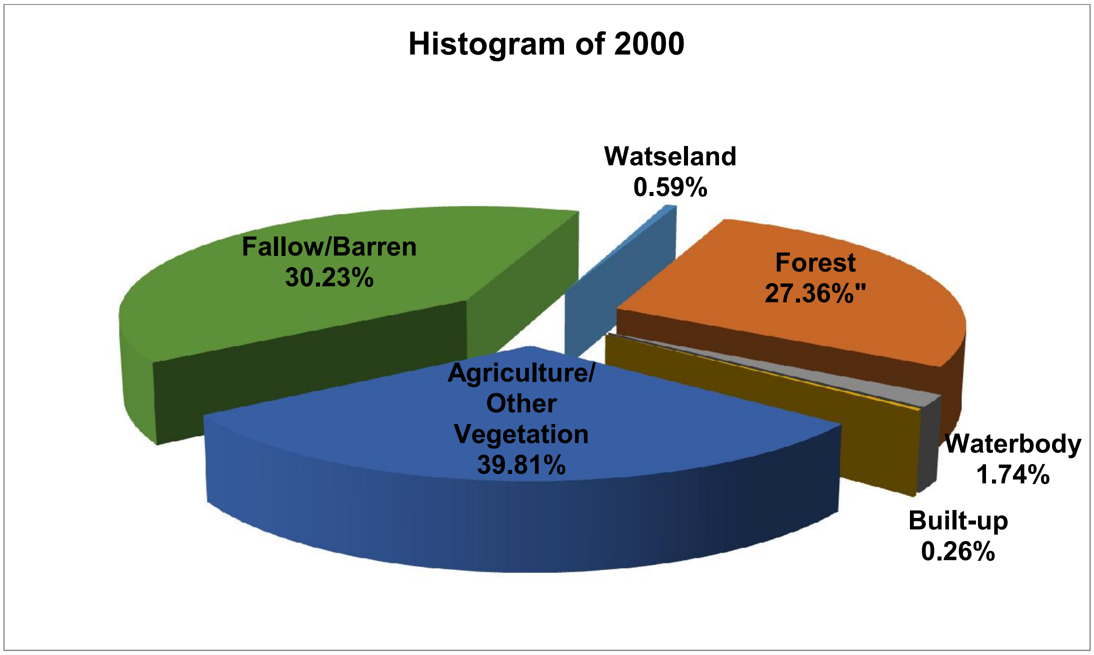

Fig. 4.9: Percentage of Land use / land cover types for 2000

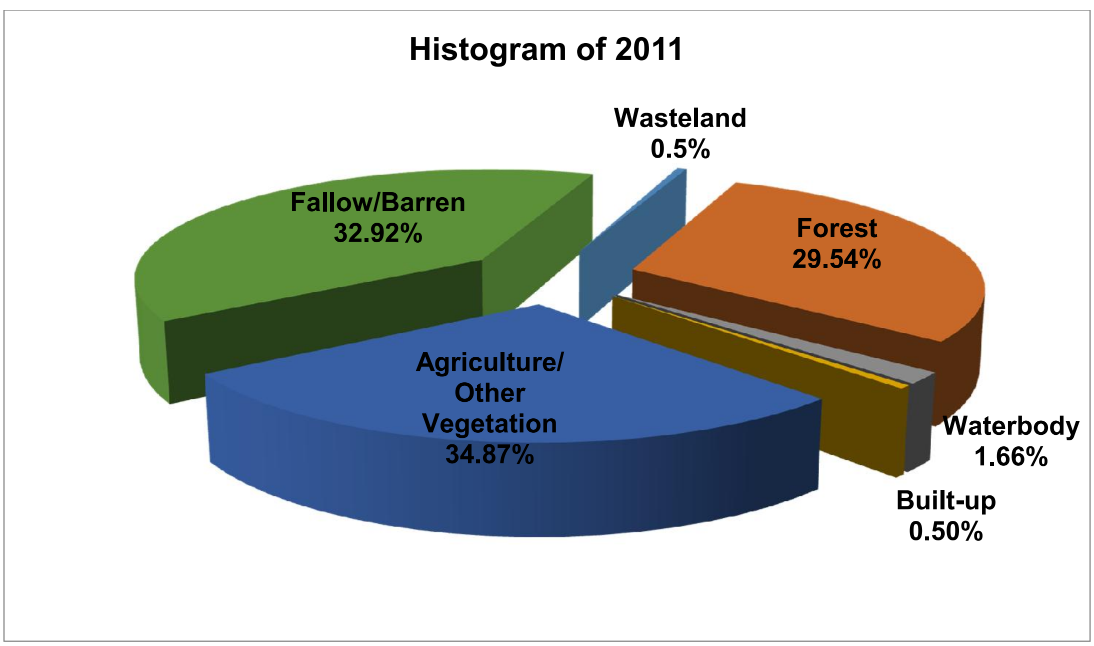

Fig.4.10: Percentage of land use / land cover types for 2011

4.4 Land use / land cover change detection analysis

The Upper Narmada basin has undergone various land use and land cover changes. The results from Table 4.10 and 4.11 indicated that there has been a significant LULC change in the basin from 1989 and 2011.

The area under different classes during the year 1989, 2000 and 2011 is presented in Table 4.10, which presents the classes distribution in square kilometer in Upper Narmada basin during the study area. From the Table 4.10 it can be observed that from period 1989 to 2000 Agriculture/Other vegetation area declined by 2.14 percent while it declined by 12.40 percent during 2000 to 2011.

And built-up area is increased by 27.68 percent to 88.73 percent during year 1989-2000, 2000-2011 period respectively. This could be attributed to the increase of population that has increased demand for shelters in the basin and also changing environment. Farmers in this area commonly cleared forests and sub-divided plots to create houses and small farms.

While in waterbody area decreasing rate from 6.14 percent to 4.64 percent during 1989 to 2000 and 2000 to 2011 study period. While in Forest, area is declined during 1989 to 2000 period at 6.64 percent but after 2000 or during 2000 to 2011 it is increased by 7.95 percent

Table 4.10: Land use / Land cover distribution of Upper Narmada basin during study period.

LULC CLASS	Year		
	1989	**2000**	**2011**
	Area	**Area**	**Area**
Wasteland	231.81	267.41	229.03
Forest	13273.70	12392.43	13377.82
Water body	841.25	789.57	752.96
Built-up	93.40	119.26	225.08
Agriculture/Other Vegetation	18422.21	18028.27	15792.10
Fallow/Barren	12424.12	13689.54	14909.55
Total	**45286.50**	**45286.50**	**45286.50**

However, it can be seen that from Table 4.10 Fallow/Barren land is increased by 10.18 percent during 1989-2000 and at the rate of 8.91 percent increased during 2000-2011.

The distribution as percentage of the total geographical area in the Upper Narmada basin during the period 1989 to 2011 is presented in Table 4.11, where class percentage is calculated from total to individual class and also presents the percentage change in in the area under various classes w.r.t. to the year 1989.

Table 4.11: Percentage Land use/ Land cover change of Upper Narmada basin

LULC CLASS	Year			% change *w.r.t* 1989	
	1989	2000	2011		
	%	%	%	2000	2011
Wasteland	0.51	0.59	0.50	+15.68	-0.02
Forest	29.31	27.36	29.54	-6.65	+0.78
Water body	1.86	1.74	1.66	-6.45	-10.75
Built-up	0.21	0.26	0.50	+23.80	+138.1
Agriculture/Other Vegetation	40.68	39.81	34.87	-2.14	-12.41
Fallow/Barren	27.43	30.23	32.92	+10.20	+20.01
Total	**100.00**	**100.00**	**100.00**		

There has been a significant land use/cover change in the basin where the agricultural land covered 40.68 % in 1989, decreased to 39.81 % in 2000 and decreased to 34.87 % in 2011. This could be attributed to the increase in population that has increased the demand for agricultural and Built-up land in the sub-basin.

The area occupied by built up land increased from 0.21% in 1989, 0.26% in 2000 to 0.50% in 2011. There is also a decrease in forest land from 29.31% in 1989 to 27.36% in 2000 but increase in 29.54% in 2011.

However, the area covered by water body was 1.86 % in 1989 and showed a slight decrease of 1.74 % in 2000 to 1.66 % in 2011. According to 1989, 2000 and 2011 LULC upstream which is uplands tended to be more forested, has undergone more agricultural activities, and has medium development (Fig. 4.5, 4.6 and 4.7).

Conversely, downstream which is a lowland region had more built up area in 2011 compared to the upland plots. The lowland area contained more cleared land indicative of agricultural and sub-urban activity. However, the increasing number of farms upstream and built up area in 2011decreased Agriculture/other Vegetation land in the basin.

Finally from Table 4.11 revealed that from 1989 to 2000 built-up area increase by 23.80 percent while in overall view it was by 138.1 percent from 1989 to 2011. The distribution of Waterbody shows decline by -6.45 (between1989-2000) to -10.75 (between period 2000-2011) and agriculture /other vegetation also decline by -2.41 percent (between1989-2000) to 12.41 percent (between 2000 - 2011) during the period, it may cause of pressure of population which increase the built-up area.

However, fallow/barren land shows rise by 10.20 to 8.91 percent from the period 1989-2000 and 2000-2011. It is mainly because of reduction of water bodies due to uneven rainfall and increasing population pressure. Forest cover increase by 0.78 percent from 1989 to 2011, the increase is attributed to conversion of wasteland plantation.

The extract figures are reported change detection matrix Table 4.12(a), 4.12(b) and 4.12(c) also known as confusion matrix shows that transition of LULC class during the period. In that, the values on the diagonal are the areas that had not changed during the 23 years. However it was observed that built-up area dominant the land use of agriculture/ other vegetation and fallow /barren.

To evaluate the result of LULC change confusion matrix, has been derived between 1989-2000, 2000-2011 and 1989 -2011. The matrix read from left to right for time one and up to down for time two.

For instance Table 4.12(a) shows that change in LULC categories from 1989 to 2000. The area statistics obtain for the forest cover are different than those found in the literature. However, this difference in figures can be due to difference in scale of interpretation and the image resolutions. It can be seen that forest area (13273.21 Km^2) has been occupied by wasteland, Waterbody and Fallow/ Barren area i.e. 307.09 km^2. However, the study also marks the decreasing forest cover which is also reported in the Forest survey of India (FSI) reports (anonymous 1999).While in Agriculture/Other Vegetation (18422.21 km^2) declined up to 18028.27 km^2, which is occupied the area 1090.85 km^2 by fallow/Barren, Wasteland and Built-up area.

Also increase the area of Fallow/ Barren i.e. from 12424.12 to 13689.54 km^2 where it is added with wasteland, forest and Waterbody and Built-up area i.e. 1973.57Km^2 during 1989 to 2000 period.

Between 2000-2011 and 2011-2012 in Table 4.12(a) and 4.12(b) can be revealed that forest area is increased which might be the afforestation over these lands is important reason behind this change as mentioned in FSI reports.

Overall 1989-2011 built-up area was inclined up to +138.1 percent and decrease the area of Agriculture/ other Vegetation -14.28 percent and increase Fallow/Barren land +20.01 percent i.e 14909.98 km^2. However, which demarcated the clear relation to the increasing population reported over the census 2011.

Table 4.12(a): Change detection matrix for the period 1989 to 2000 (All Values in Square Km.**)**

1989 → / 2000 ↓	Wasteland	Forest	Water body	Built-up	Agriculture/ Other Veg.	Fallow/ Barren	Total
Wasteland	226.33	0.30	0.60	0.21	3.99	0.37	**231.81**
Forest	2.90	10309.66	11.07	0.12	1001.82	1947.64	**13273.21**
Water body	0.59	12.56	718.04	0.06	84.68	25.32	**841.25**
Built-up	0.00	0.00	0.10	92.70	0.36	0.24	**93.40**
Agriculture/Other Vegetation	4.43	1775.68	38.26	10.95	8218.59	8374.38	**18422.21**
Fallow/Barren	33.16	294.23	21.49	15.22	8718.82	3341.59	**12424.12**
Total	**267.41**	**12392.43**	**789.57**	**119.26**	**18028.27**	**13689.54**	**45286.5**

Table 4.12(b): Change detection matrix for the period 2000 to 2011 (All Values in Square Km.**)**

2011 ↓ / 2000 →	Wasteland	Forest	Water body	Built-up	Agriculture/ Other Veg.	Fallow/ Barren	Total
Wasteland	220.57	6.33	0.38	4.56	14.32	21.25	**267.41**
Forest	0.61	10372.47	9.07	1.36	1546.26	462.65	**12392.43**
Water body	0.64	12.37	665.38	0.65	25.48	85.05	**789.57**
Built-up	0.20	0.00	0.01	67.52	21.93	29.60	**119.26**
Agriculture/Other Vegetation	4.81	1036.31	63.60	95.93	8042.74	8784.87	**18028.27**
Fallow/Barren	2.19	1950.33	14.52	55.06	6141.37	5526.06	**13689.54**
Total	**229.03**	**13377.82**	**752.96**	**225.08**	**15792.10**	**14909.54**	**45286.5**

Table 4.12(c): Change detection matrix for the period 1989 to 2011(All Values in Square Km.)

1989 → / 2011 ↓	Wasteland	Forest	Water body	Built-up	Agriculture/ Other Veg.	Fallow/ Barren	Total
Wasteland	202.40	4.85	0.17	3.91	9.20	11.29	**231.81**
Forest	2.85	10571.18	9.46	2.04	1969.98	718.19	**13273.70**
Water body	0.36	14.45	726.51	0.52	24.57	74.84	**841.25**
Built-up	0.11	0.00	0.00	53.71	16.98	22.60	**93.40**
Agriculture/Other Vegetation	3.19	2165.93	11.14	73.56	9128.70	7039.77	**18422.21**
Fallow/Barren	20.13	621.41	5.69	91.34	4642.67	7043.28	**12424.12**
Total	**229.03**	**13377.82**	**752.96**	**225.08**	**15792.10**	**14909.54**	**45286.5**

4.5 Hydrologic modeling to land use / land cover change

4.5.1 Model Calibration and validation

The SWAT2009 model outputs depend on many input parameters related to the soil, land use, management, weather etc. Therefore, modeling LULC response with SWAT2009 necessitates evaluation of the sensitivity of flow output to the selected parameters. The sensitivities to the model performance give insight in parameter identifiability using the available information daily streamflow data. In this research, a LHOAT sensitivity analysis, which is incorporated in SWAT2009, is used to perform sensitivity analysis. The analysis was carried out based on the objective function of the Sum of the squares of the residuals (SSQ) for all the 10 models parameters. After set-up the SWAT2009 model and incorporating all the input parameters simulations were carried out.

4.5.2 Calibration analysis

After the sensitive parameters identification calibration followed by verification were executed for the significant parameters. The calibration of the model was executed to evaluate the performance of the model simulation using SWAT-CUPSUFI2 calibration tools for basin**.**

Since calibration gives a better result on fitting the parameters of simulated and observed flow, it was utilized following to the calibration. Initially it was carried out using the most sensitive parameters and the best parameters values which were resulted from sensitivity analysis and calibration. Among the ten parameters which resulted from sensitivity analysis method SCN curve number (CN).

Threshold Surface runoff lag time (SURLAG), Soil Evaporation Compensation Factor (ESCO), Plant uptake compensation factor(EPCO), Threshold Groundwater delay (GW_DELAY), Groundwater re-evaporation coefficient (GW_REVAP), Available water capacity of the soil layer (SOL_AWC), Base-flow alpha factor (Alpha_Bf), Manning’s “n” and Maximum canopy index (Canmax) were found the most influential parameters (Presented in Table 3.7).

Table 4.13: Calibrated values of model sensitivity parameters

Parameter	Rank	Input value	Fitted value
Surface runoff lag time.	5	15.30	20.14
Soil evaporation compensation factor.	4	1	0.5
Plant uptake compensation factor.	7	1	0.5
Groundwater delay.	9	135.00	178.57
Groundwater "revap" coefficient.	10	0.137	0.0751
Base flow alpha factor.	1	0.550	0.163
Maximum canopy storage.	3	50.001	44.91
Manning's "n" value for the main channel	6	1.70	2.72
Available water capacity of the soil layer	8	0.214	0.241
SCS runoff curve number for moisture condition II	2	78.54	69.92

Most models are provided with default values of the parameters. However, in this case initial values of the model parameters were defined. The minimum and maximum acceptable values were provided based on the information of related pervious works SWAT CUP manual and literatures. The calibrating was made by varying the values of the sensitive parameters within their permissible values. It was carried out repeatedly by changing one of the more sensitive parameters in the model and then observing the corresponding changes in the simulated flow. While performing the process, the model's input parameters were attuned, by means of the effective parameters which were selected and ranked in the sensitivity analysis process (presented in Table 4.14).

After the calibration result the model was run and the simulated flow was compared with the observed flow. Below shows the hydrographs of the observed and simulated flows from 01 January, 1991 to 31 December 1995. The calibration period has shown a good agreement between monthly observed and simulated flows (Table 4.14 and Fig. 4.11 (a, b, c, d, e, f, and g)). The scatters plot of the values of the measured and the simulated monthly stream flows data has also shown a fair linear correlation between the two data sets. The trend and the magnitude of the two data set values are shown in (Fig. 4.12 (a, b, c, d, e, f, and g).

Table 4.14: Model performance evaluation parameters value at calibration

ID	Station	R^2	N_{SE}	P_{Bias}	RSR
229800	Patan	0.92	0.73	+18.6	0.52
229794	Barmanghat	0.86	0.72	-13.2	0.53
229781	Sandia	0.77	0.82	+12.5	0.46
226791	Gadarwara	0.75	0.69	-19.1	0.57
229809	Dindori	0.66	0.68	+18.2	0.56
226778	Hoshangabad	0.72	0.70	+8.9	0.55
226806	Manot	0.84	0.69	-16.9	0.59

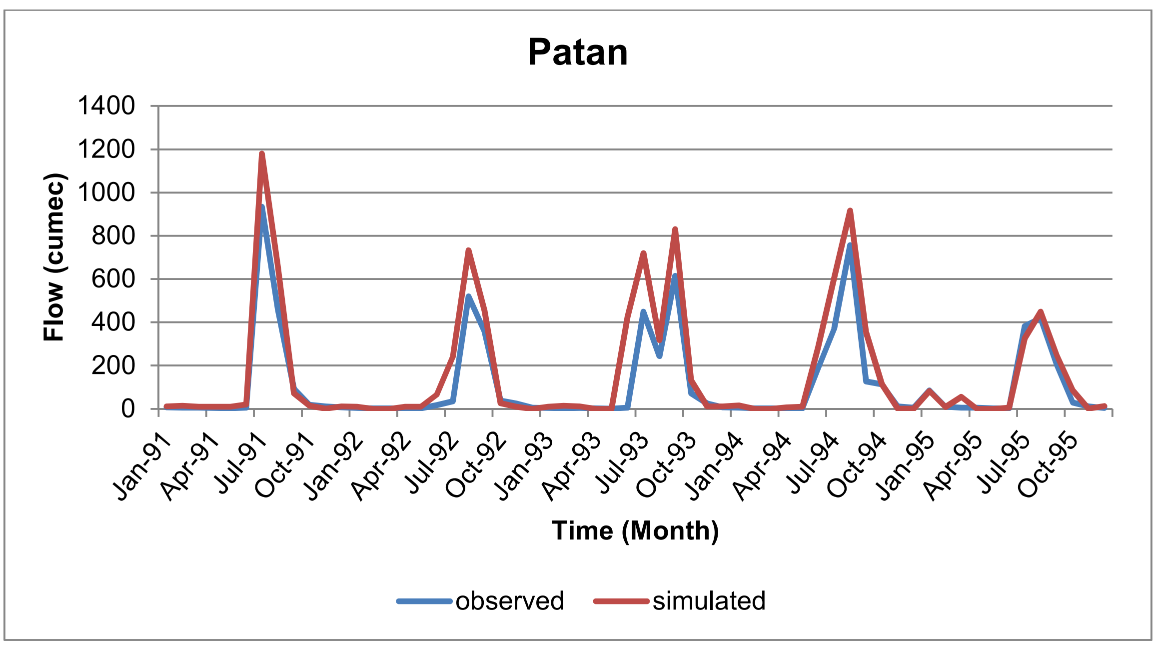

Fig. 4.11 (a): Observed and simulated discharge for period 1991-1995 during calibration

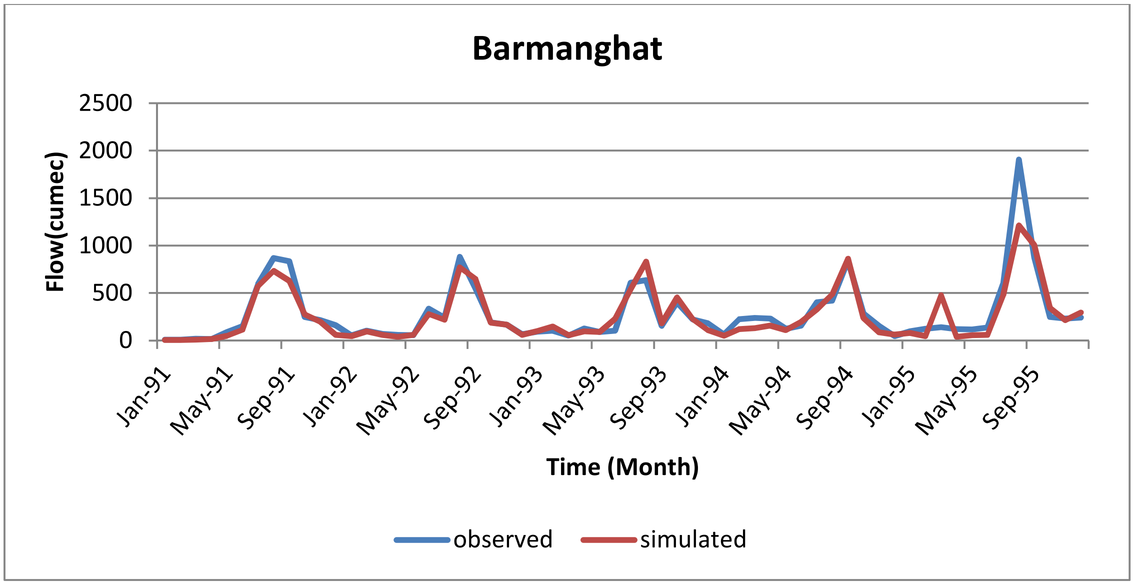

Fig. 4.11 (b): Observed and simulated discharge for period 1991-1995 during calibration

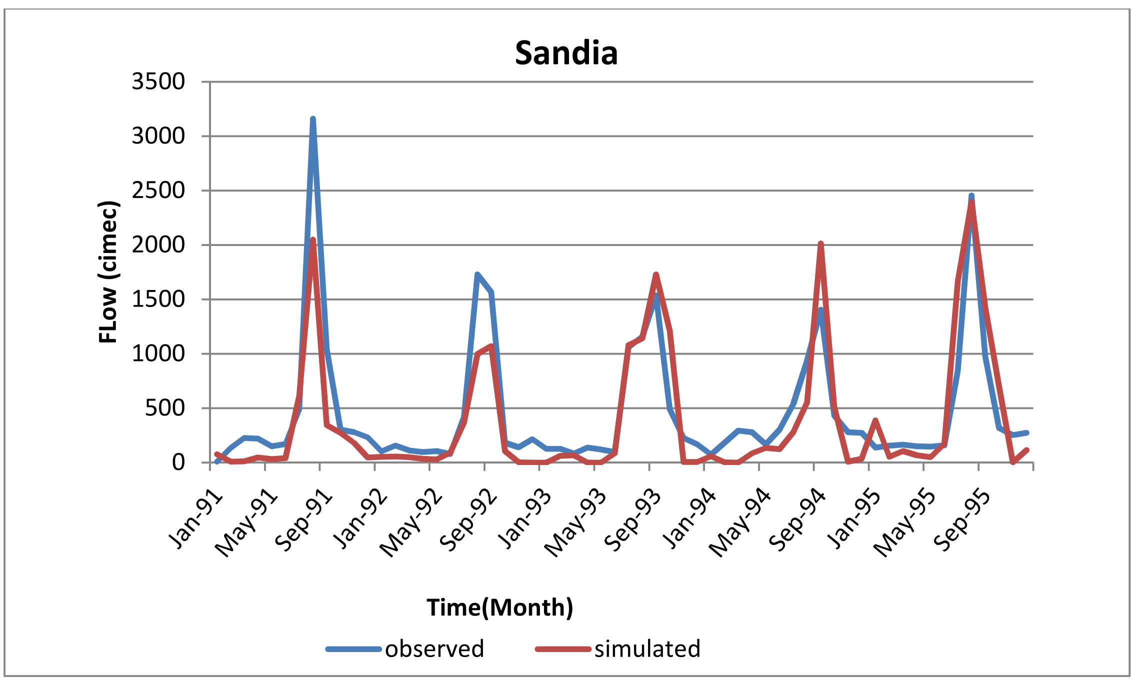

Fig. 4.11(c): Observed and simulated discharge for period 1991-1995 during calibration

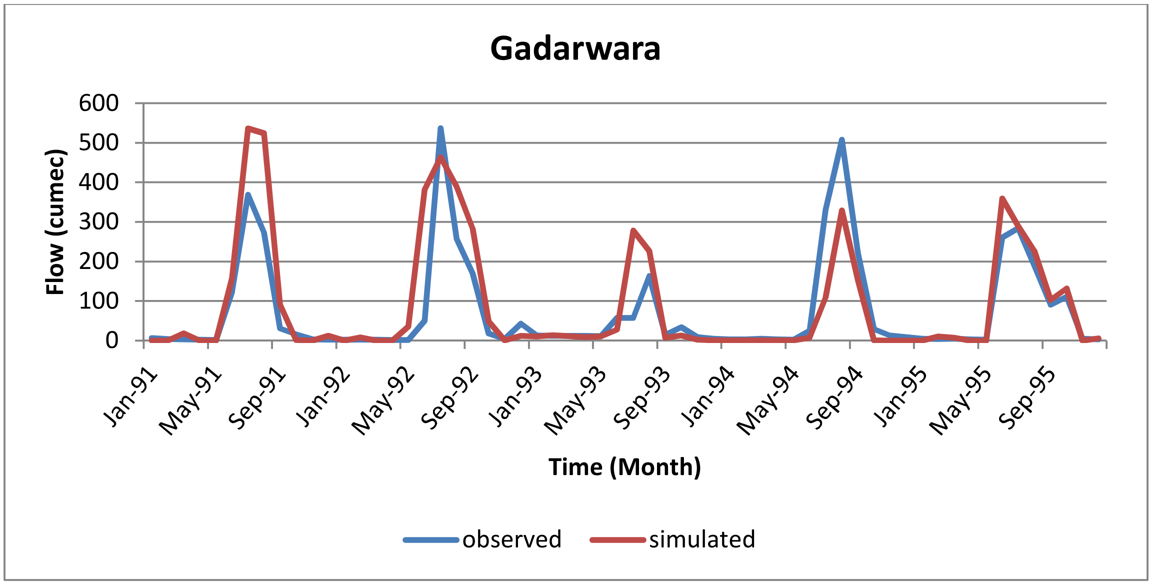

Fig. 4.11 (d): Observed and simulated discharge for period 1991-1995 during calibration

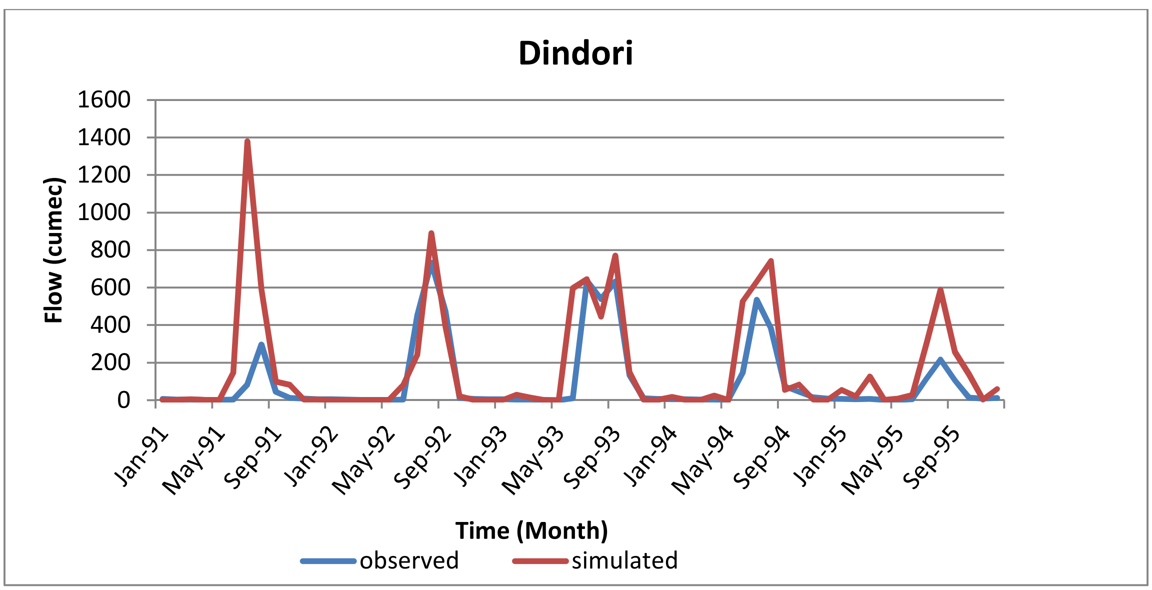

Fig. 11 (e): Observed and simulated discharge for period 1991-1995 during calibration

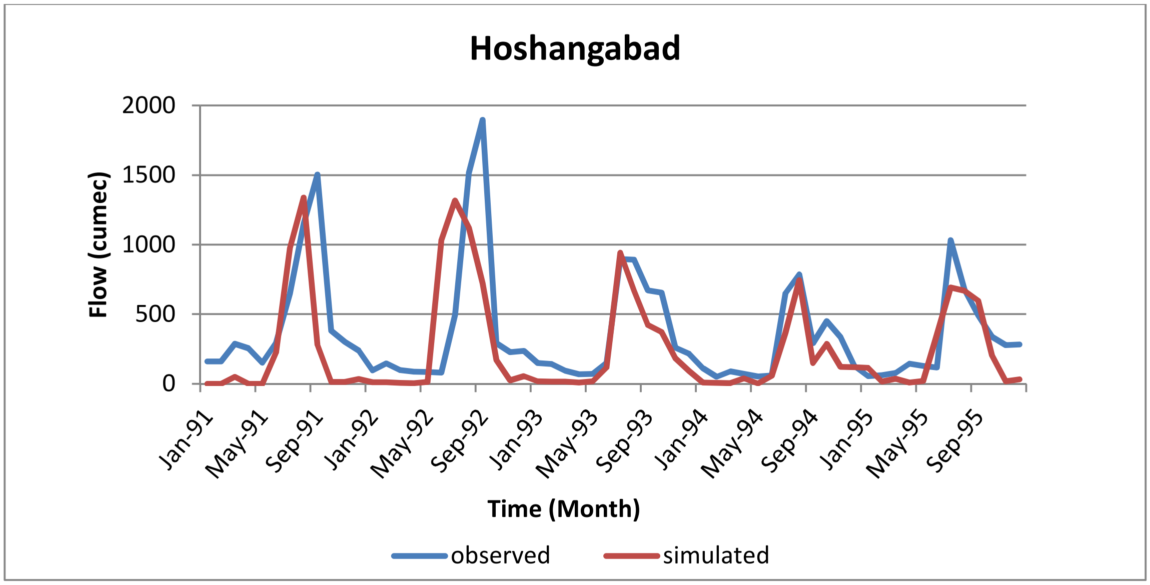

Fig. 4.11 (f): Observed and simulated discharge for period 1991-1995 during calibration

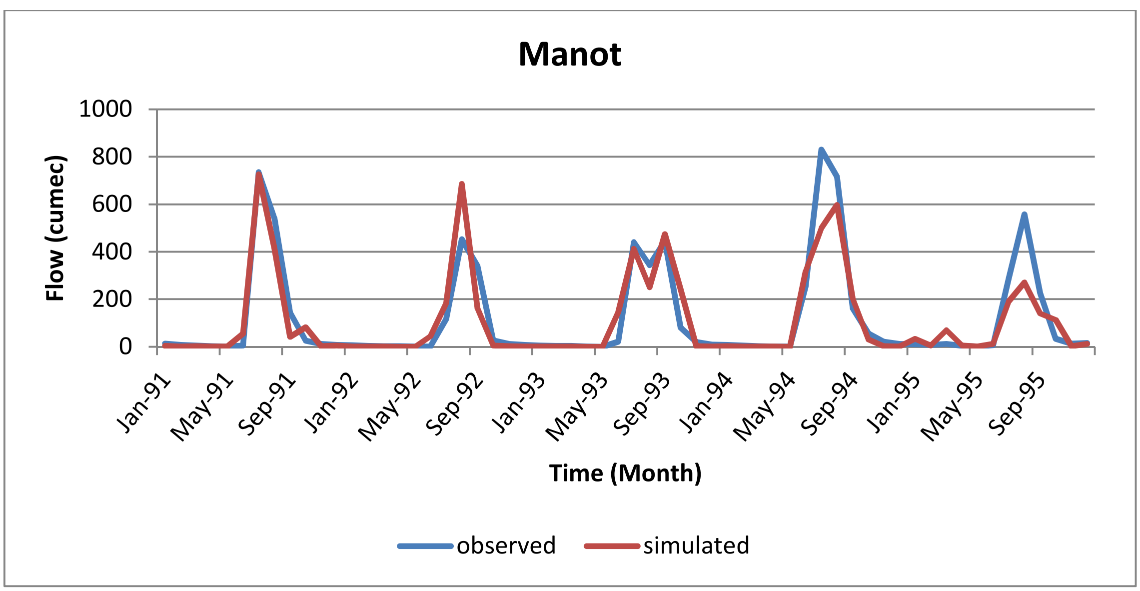

Fig. 4.11 (g): Observed and simulated discharge for period 1991-1995 during calibration

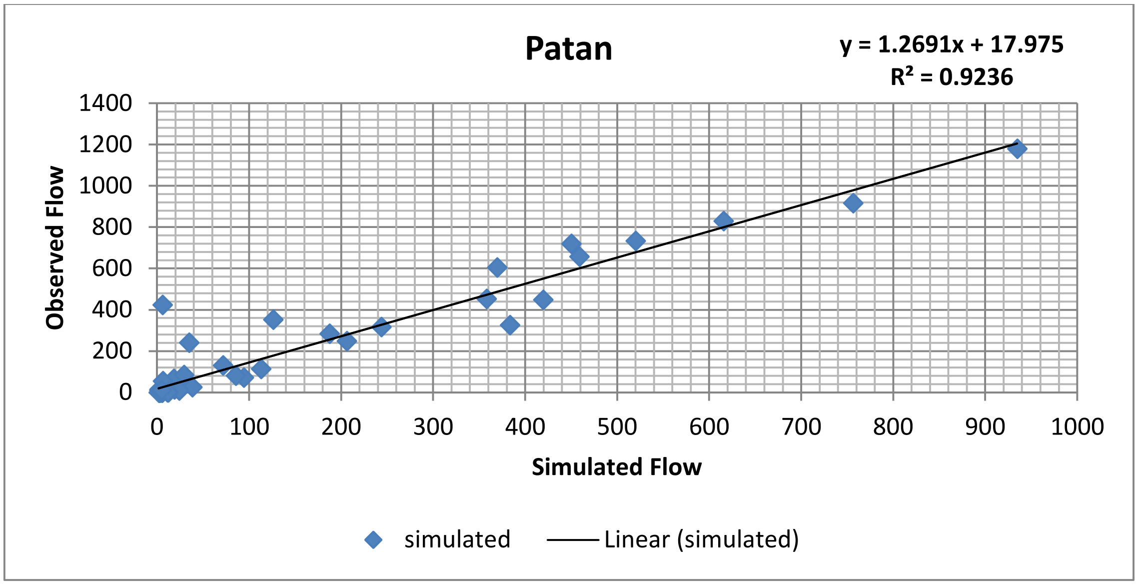

Fig. 4.12 (a): Scatter plot of simulated and observed flow for the calibration

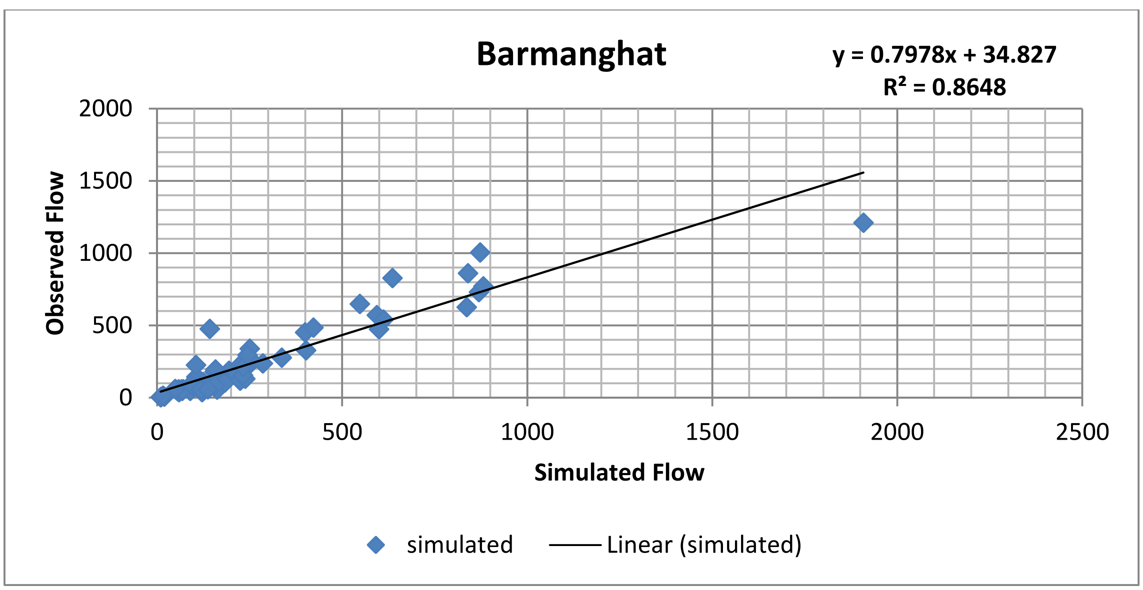

Fig. 4.12(b): Scatter plot of simulated and observed flow for the calibration

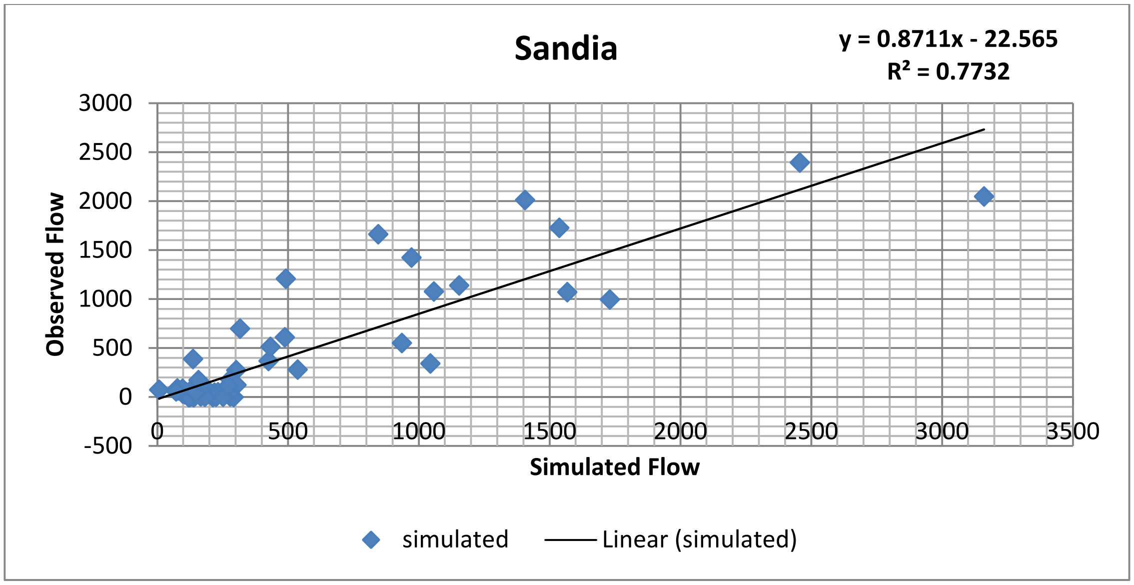

Fig. 4.12(c): Scatter plot of simulated and observed flow for the calibration

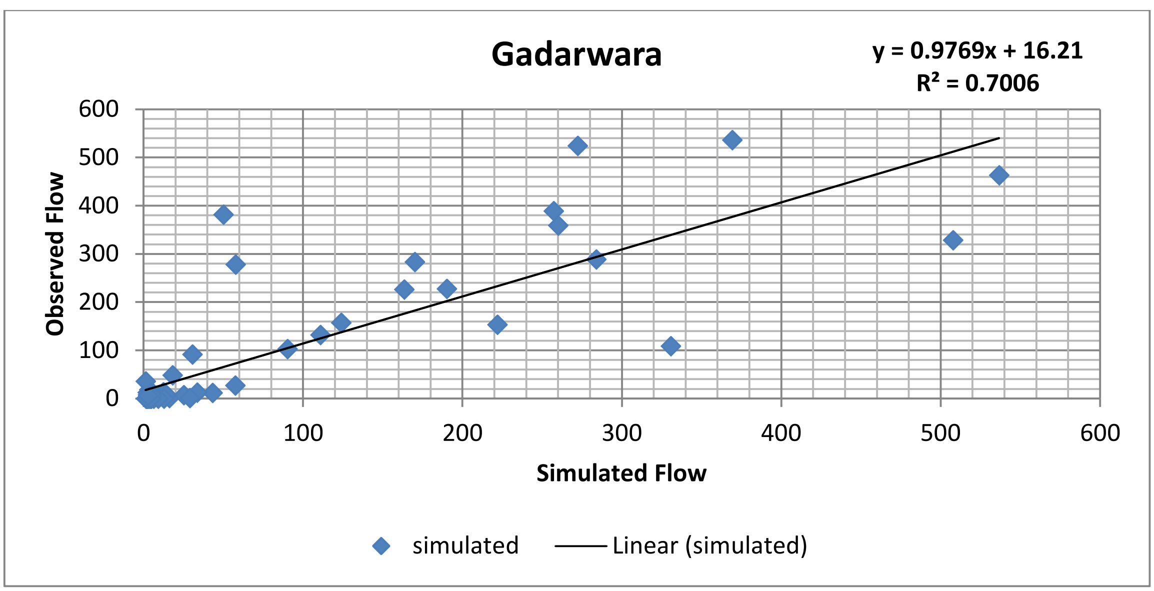

Fig. 4.12 (d): Scatter plot of simulated and observed flow for the calibration

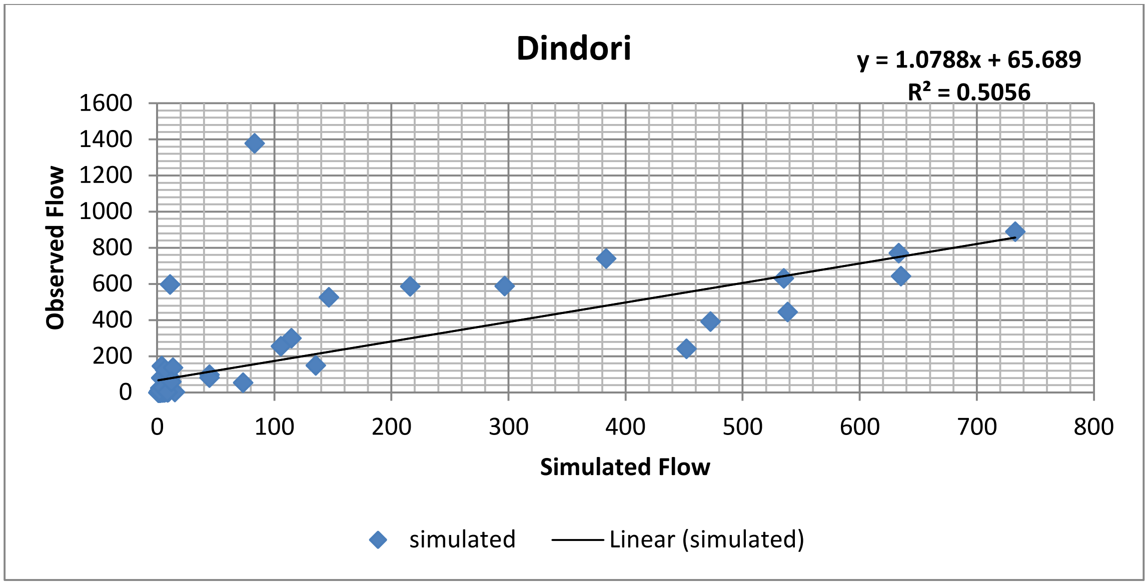

Fig. 4.12 (e): Scatter plot of simulated and observed flow for the calibration

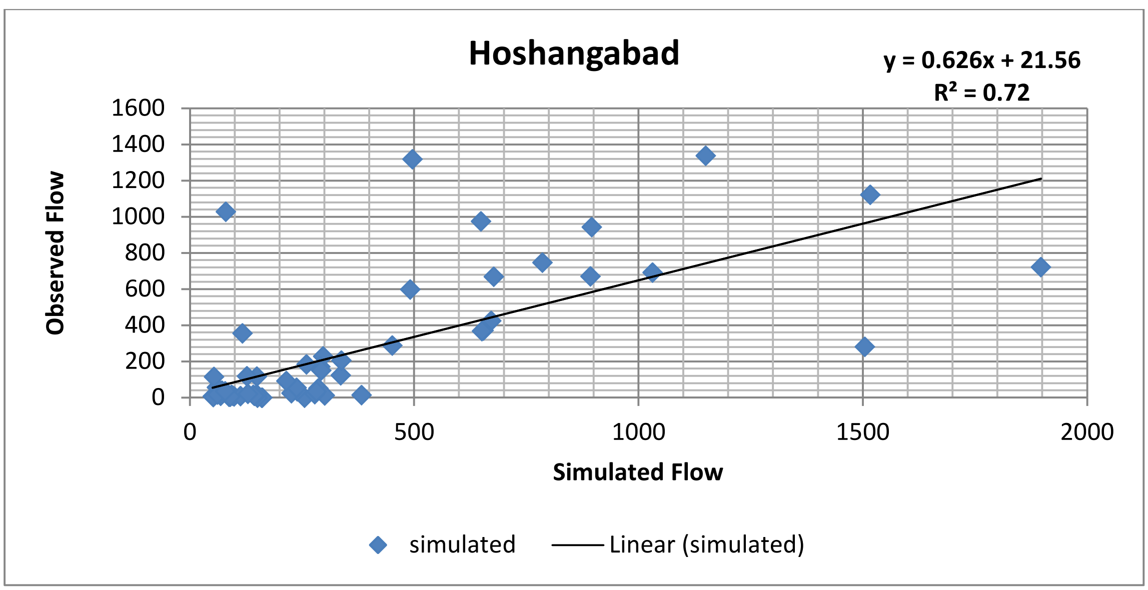

Fig. 4.12 (f): Scatter plot of simulated and observed flow for the calibration

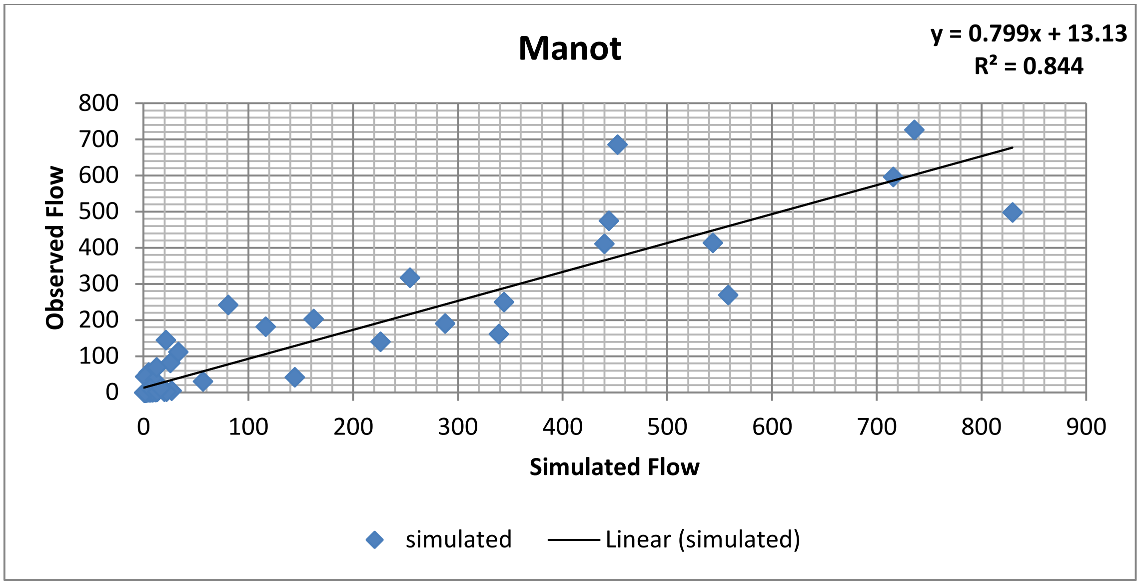

Fig. 4.12 (g): Scatter plot of simulated and observed flow for the calibration

4.5.3 Validation analysis

Validation process using an independent set of observed data is necessary to comprehend the degree of the certainty of the model prediction. Model performance in calibration and validation periods may not be similar. Recent studies revealed that there are a number of difficulties of climate model validation. That is because of the complexity of the nature of climate and time dependent uncertainties of modeling dataset. Another reason is the hydrologic condition in the calibration period may not be the same as the hydrologic condition during the validation period (Beven, 2001).

The arithmetic ensemble mean and Bayesian Model Averaging (BMA) methods can be used to account and asses such calibration and validation models differences. To assess the performance the methods estimate values of the difference in properties in calibrated and validated models. In a good performance, the estimated values must match with the expected coverage percentage.

The validation was carried out using the calibrated parameters. For model validation the observed stream flow data of Upper Narmada basin from 01 January 1996 to 31 December 2000 were used. In the validation process, the model was run with input parameters set during the calibration process without any change.

The validation period has also shown a good agreement between monthly observed and simulated flows Fig. 4.13 (a, b, c, d, e, f, and g). The validation analysis result presented in the Table 4.15.

Table 4.15: Model performance evaluation parameters values at validation

ID	**Station**	**R^2**	**N_{SE}**	**P_{Bias}**	**RSR**
229800	Patan	0.79	0.79	-6.9	0.46
229794	Barmanghat	0.77	0.68	22.2	0.49
229781	Sandia	0.91	0.72	23.0	0.53
226791	Gadarwara	0.71	0.63	-15.6	0.52
229809	Dindori	0.77	0.62	18.2	0.62
226778	Hoshangabad	0.86	0.78	17.8	0.55
226806	Manot	0.88	0.70	-14.9	0.59

In general, the model performance assessment indicated a good correlation and agreement between the monthly observed and simulated flows. The scatters plot of the values of the observed and the simulated monthly stream flows data has also shown a fair linear correlation between the two datasets. The trend and the magnitude of the two data set values are shown in Fig. 4.14 (a, b, c, d, e, f, and g).

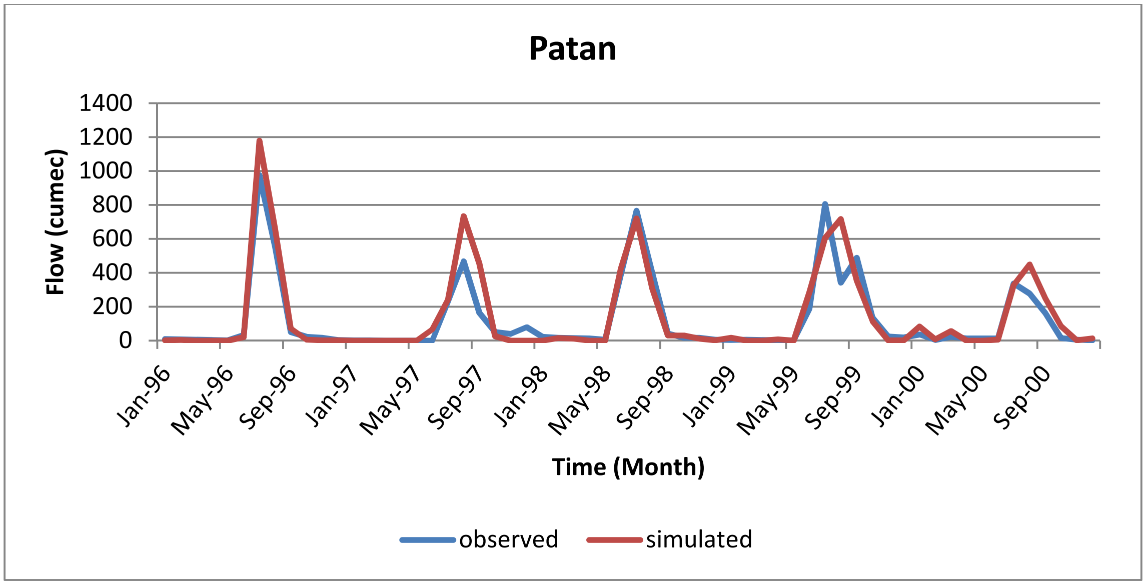

Fig. 4.13 (a): Observed and simulated discharge for period 1996-2000 during validation

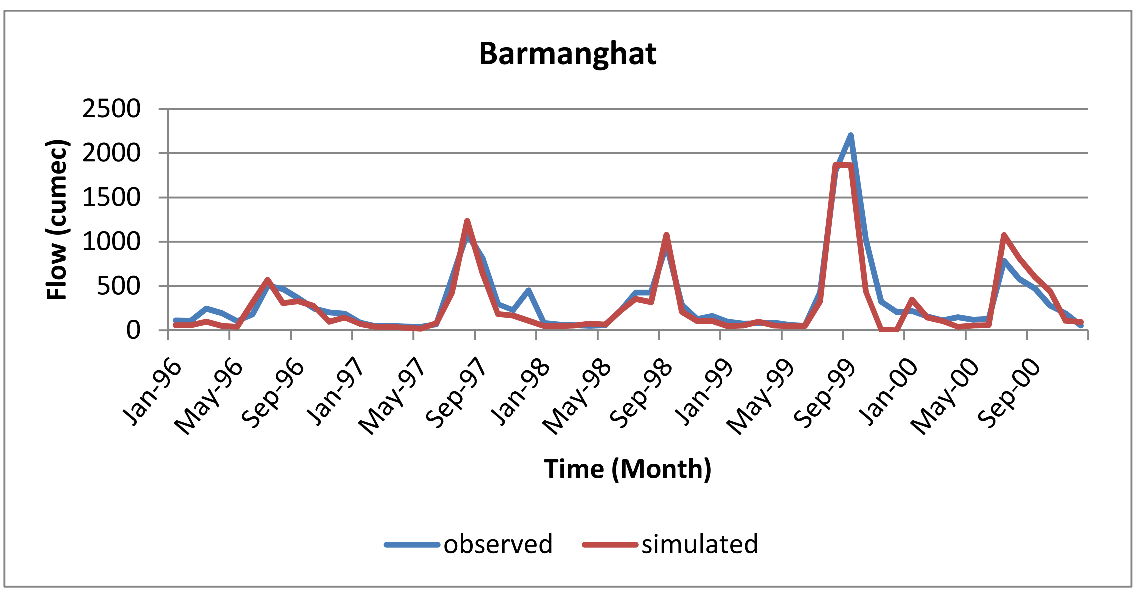

Fig. 4.13 (b): Observed and simulated discharge for period 1996-2000 during validation

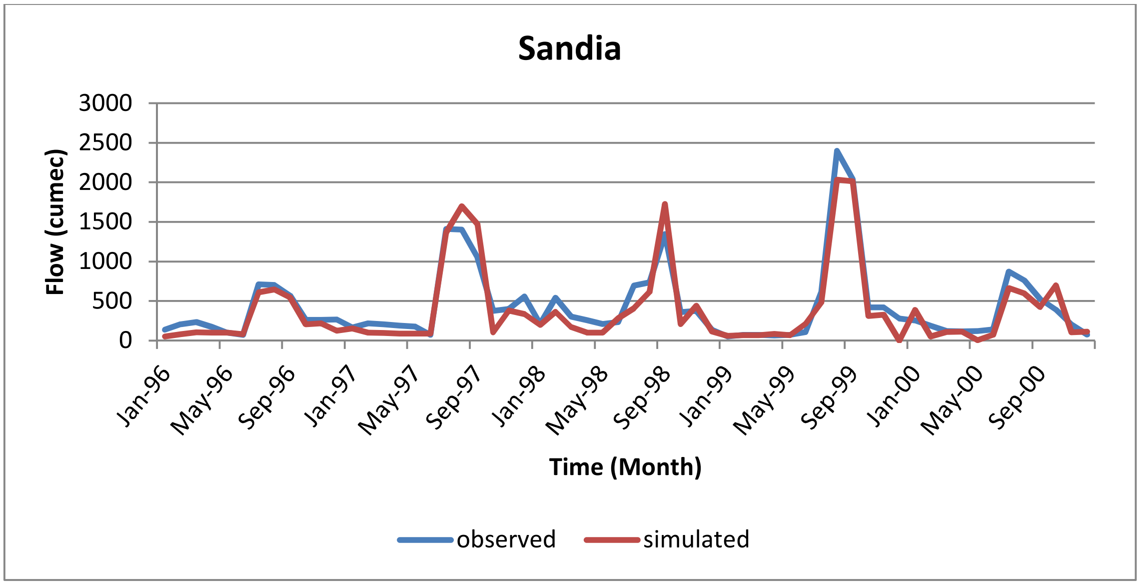

Fig. 4.13(c): Observed and simulated discharge for period 1996-2000 during validation

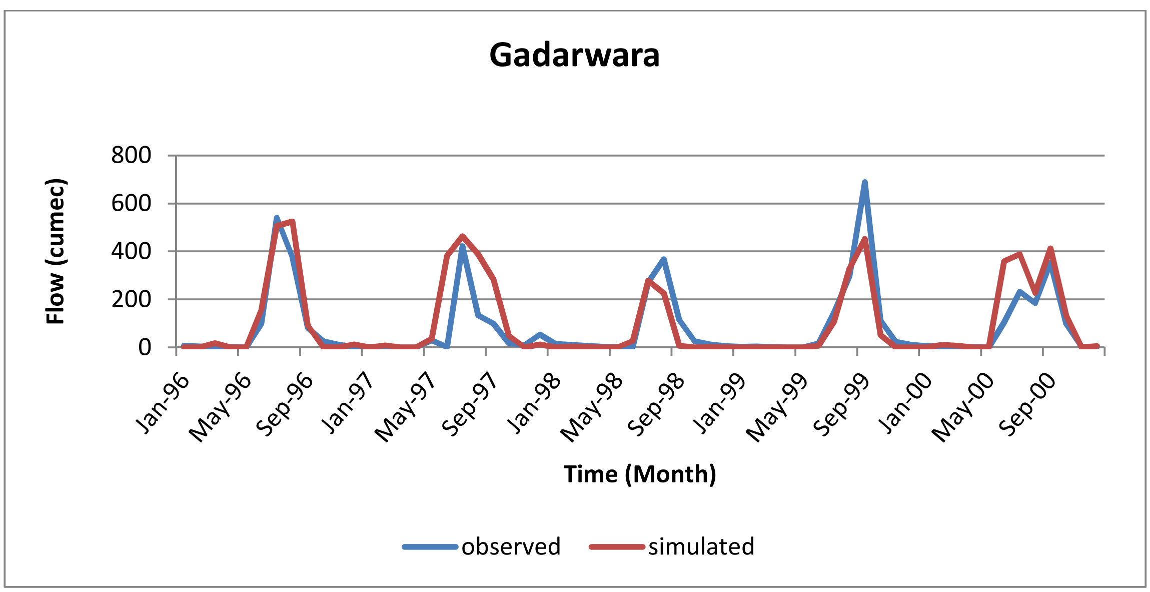

Fig. 4.13 (d): Observed and simulated discharge for period 1996-2000 during validation

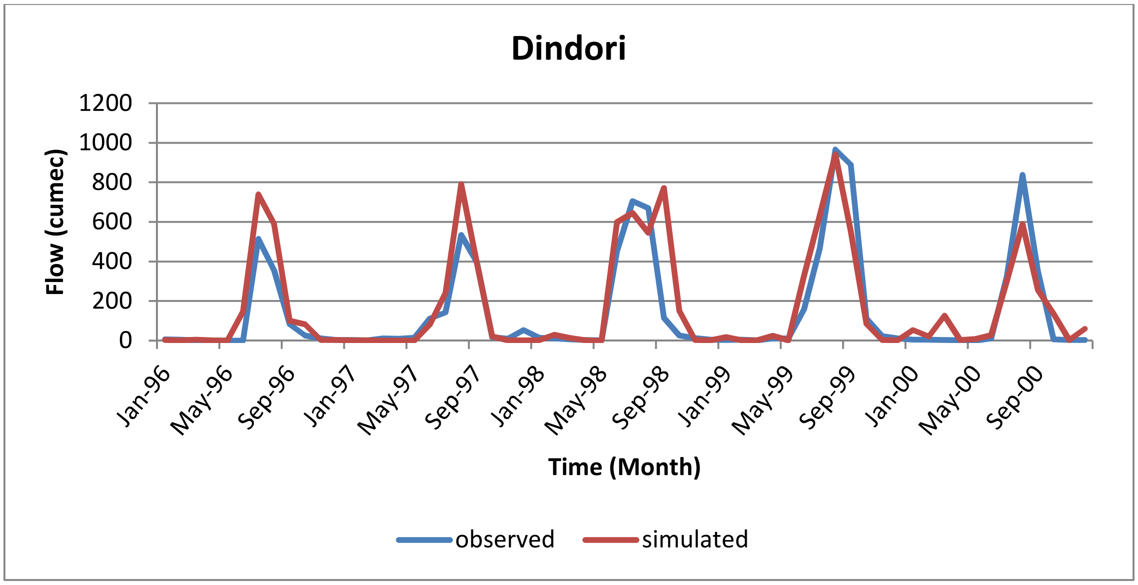

Fig. 4.13 (e): Observed and simulated discharge for period 1996-2000 during validation

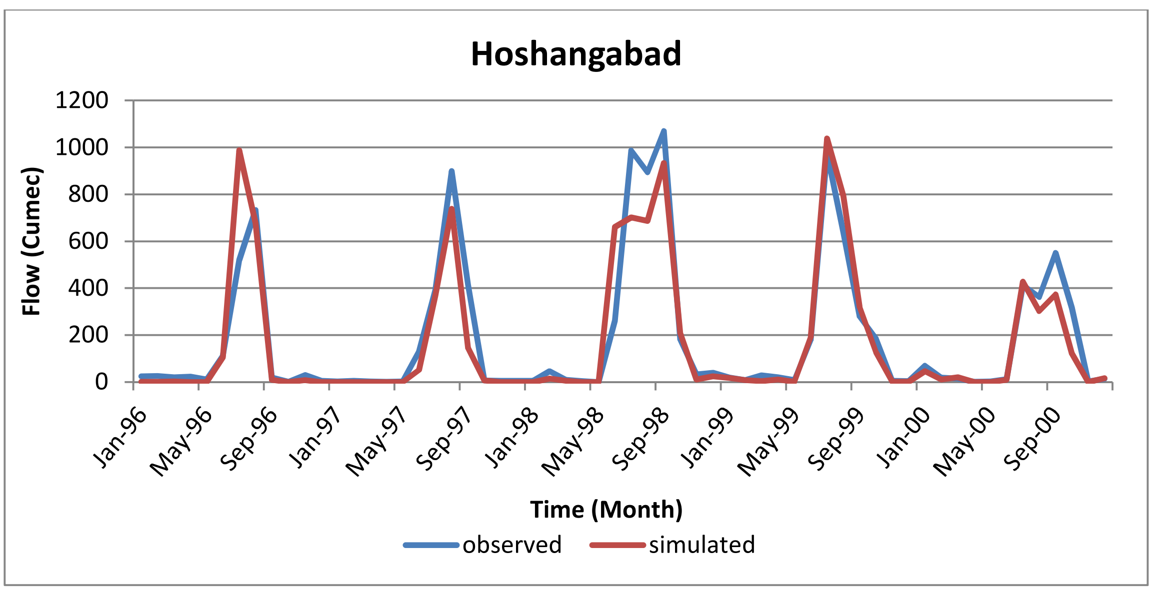

Fig. 4.13 (f): Observed and simulated discharge for period 1996-2000 during validation

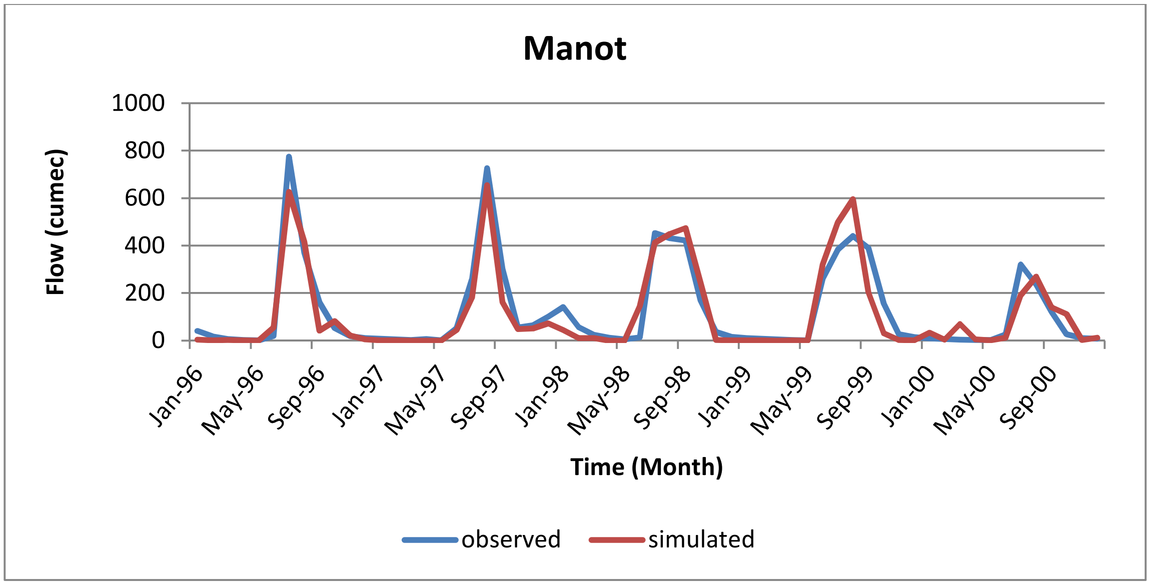

Fig. 4.13 (g): Observed and simulated discharge for period 1996-2000 during validation

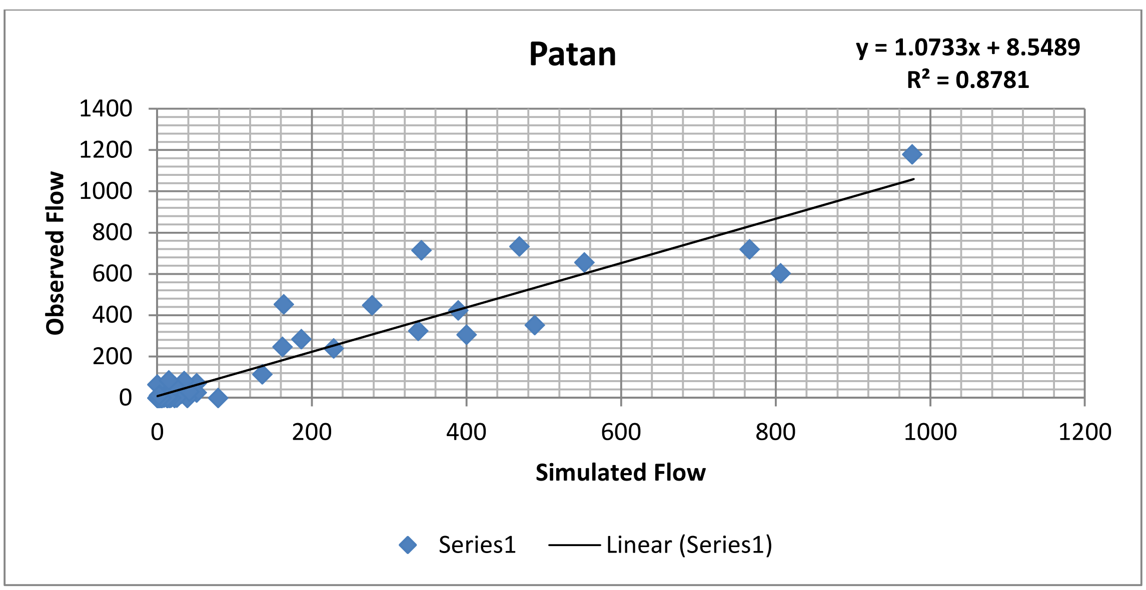

Fig. 4.14(a): Scatter plot of simulated and observed flow for the validation

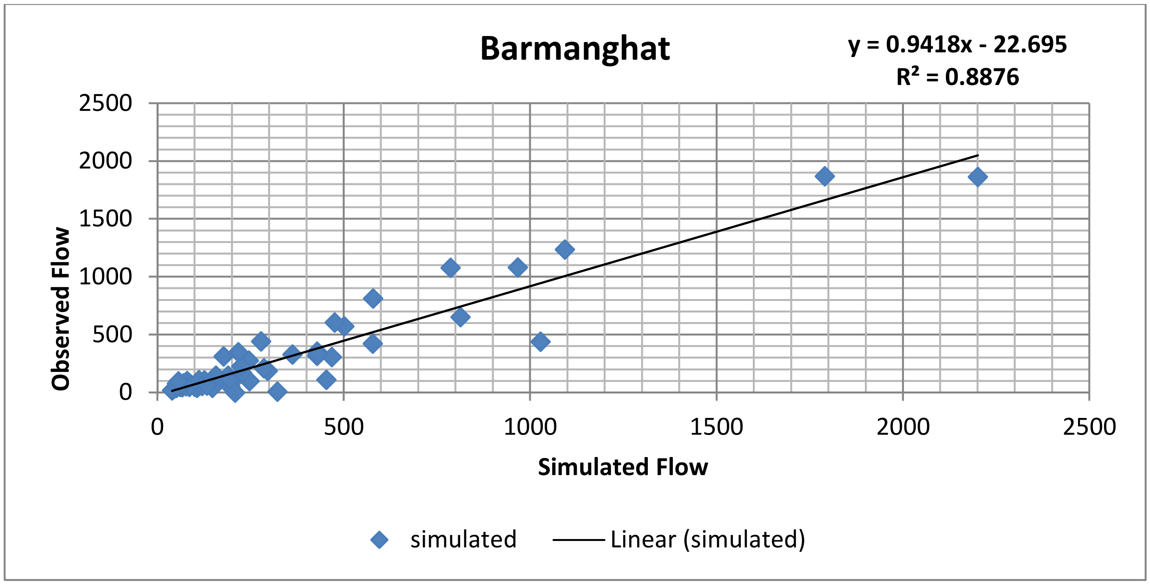

Fig. 4.14 (b): Scatter plot of simulated and observed flow for the validation

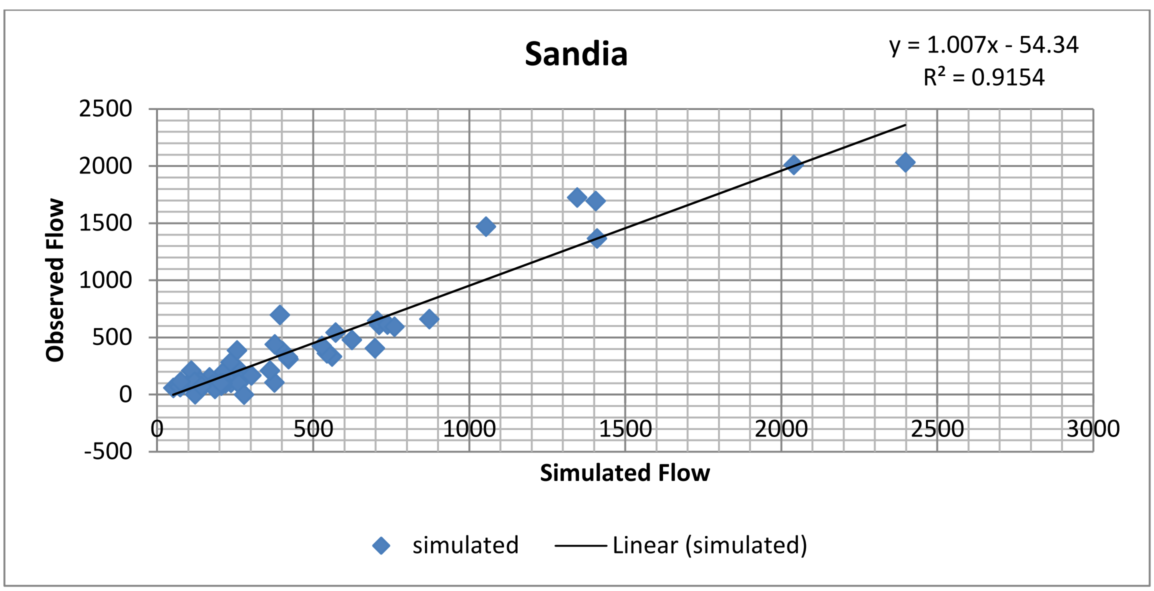

Fig. 4.14(c): Scatter plot of simulated and observed flow for the validation

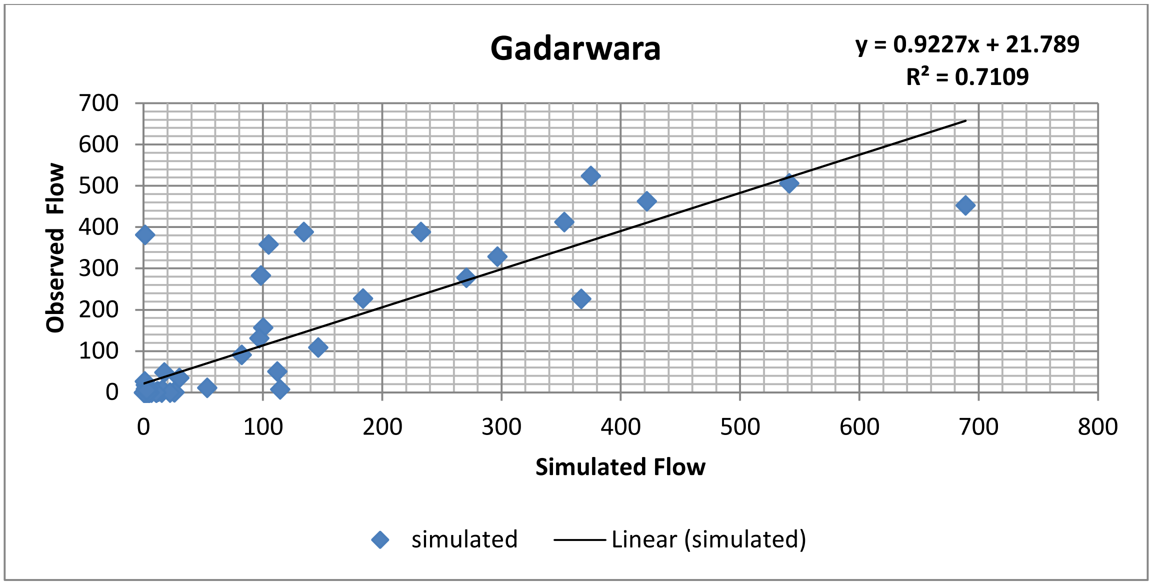

Fig. 4.14(d): Scatter plot of simulated and observed flow for the validation

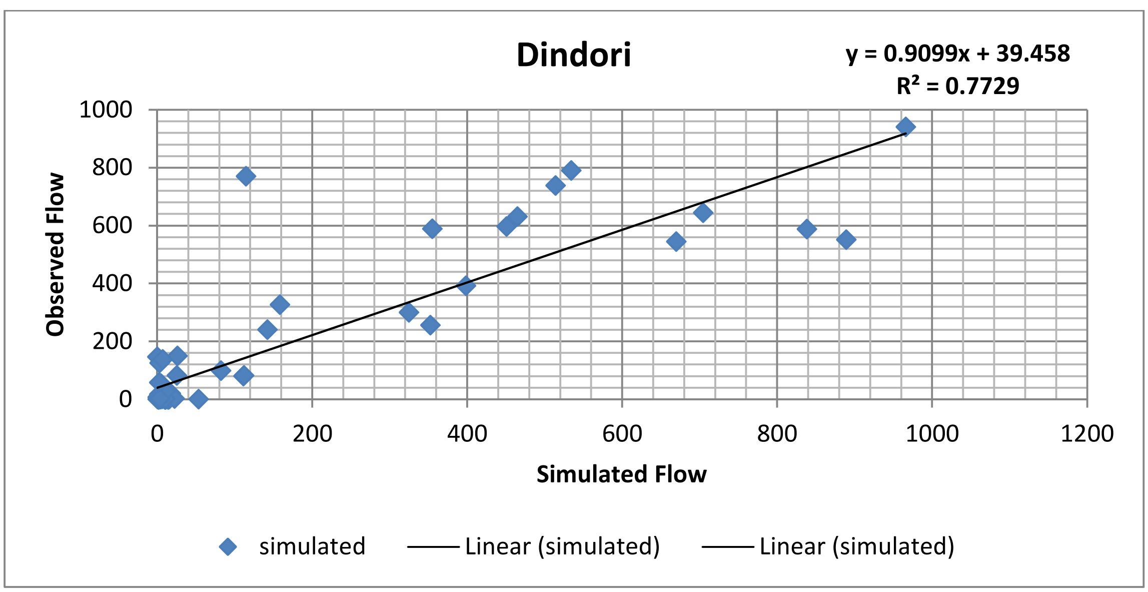

Fig. 4.14 (e): Scatter plot of simulated and observed flow for the validation

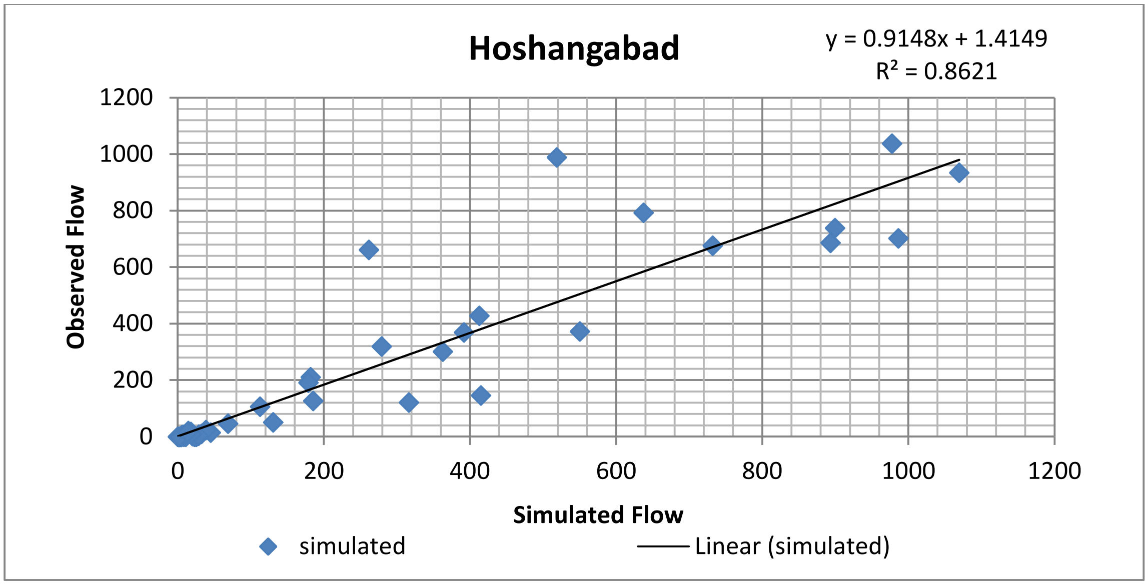

Fig. 4.14 (f): Scatter plot of simulated and observed flow for the validation

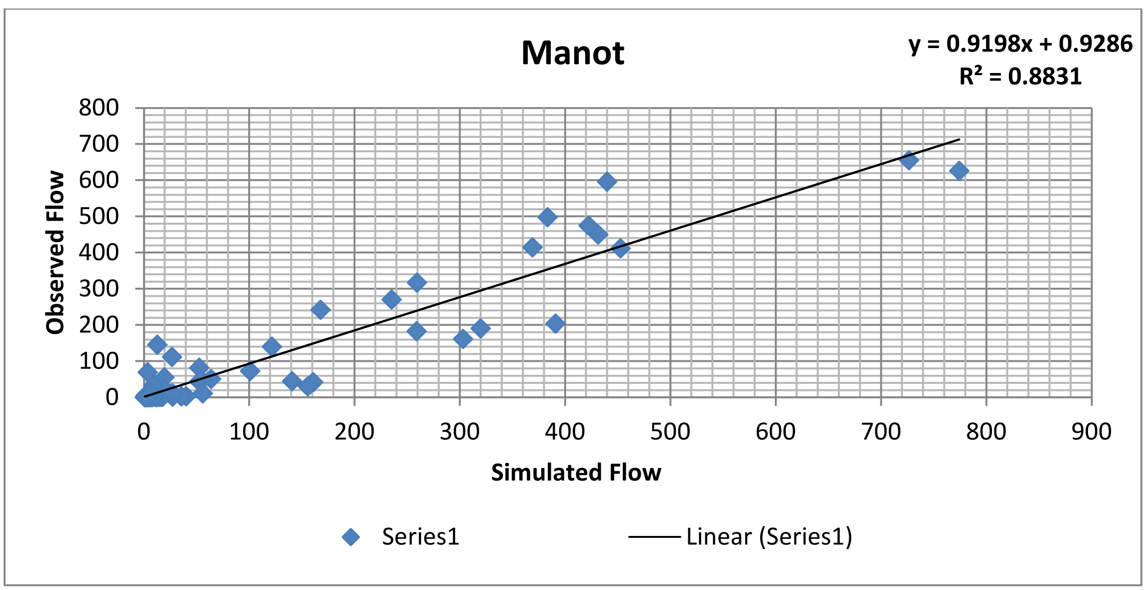

Fig. 4.14 (g): Scatter plot of simulated and observed flow for the validation

4.6 Model Responses to Land use /Land cover change analysis

The SWAT model simulated runoff for the three time periods corresponding to the LULC of 1989, 2000 and 2011. Simulation runs have been conducted on monthly and annual basis to compare the modeling outputs.

Annual output of the SWAT model is presented in Table 4.16 for the study period. The result indicate that the mean annual surface runoff was decreased by 0.73 % from 1989 to 2000, while it decreases by 0.91% from 2000 to 2011.

However overall decrement was found by 1.63% for year 1989 to 2011. The result also indicated that overall evapotranspiration (ET) increased from 1989 to 2011 was 2.21% for 2011 LULC (Also refer Fig. 4.15). Result also analyzed that aquifer recharge and water yield were decreasing rate by 8.13% and 6.87% from 1989 to 2011 year LULC.

Table 4.16: Parameters from annual simulations for 1989, 2000 and 2011 Land use/ land cover

Output (mm)	**Year**		
	1989	**2000**	**2011**
Surface Runoff	418.73	415.68	411.91
Total Aquifer Recharge	168.60	158.10	154.89
Total Water Yield	711.32	689.18	662.44
Evapotranspiration	499.49	503.02	510.54

Average annual stream flows are directly related to LULC type, soil characteristics and annual precipitation. In the study, Built-up area and Fallow/Barren areas have increased between 1989, 2000 and 2011 with most of the increase occurring in previously areas of forest land. Built-up have the highest potential for runoff because the land is impervious cover in and reduces infiltrations.

However, changes from Agriculture/Other Vegetation to Built-up area has been observed in present study. Which result the decrease in water yield, Surface runoff but increase in Evapotranspiration shown in Table 4.16, was also found in other studies (Table 4.10, 4.12(a), (b), and (c)) like in Wagner et al (2013), Im et al (2009) and Wijesekara et al (2012).

While these impact on Water Yield and Evapotranspiration appears to be the pronounced as compared to urbanization rate increases. Also this may be possible due to monsoon –dominant rainfall in basin during study period.

It is well known that response of hydrology of a basin are relatively large due to corresponding effect in basin (Foherer et al, 2001). In large study on the Meuse River basin, Ashagrie et al (2006) conclude that overall impact of land use changes was small to be detected.

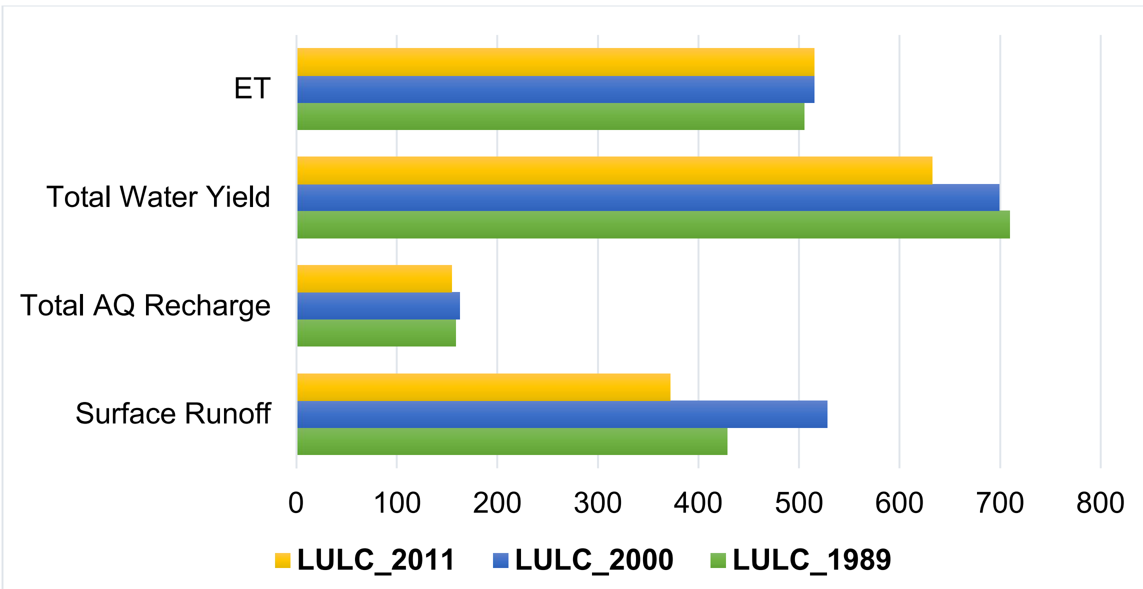

Fig. 4.15: Output parameters from annual simulations for study period

The impacts of land use have received a considerable amount of interest in hydrology. LULC is an important characteristic in the runoff process that affects infiltration, erosion, and evapotranspiration. Understanding of the effects historic LULC changes have had on river flow is required to understand the future effects of LULC on hydrological regimes at a basin level. Along with these changes, considerable consequences are expected in the hydrological cycles and subsequent effects on water resources (Githu, 2007).

To understand the flow processes during different seasons under different LULC conditions, the average monthly stream flows were plotted for the wet and dry season and compared. In Upper Narmada basin, there are two different months: the wettest and driest months. Wettest are June, July, August, September and October while driest months are March, April and May. The average dry monthly stream flow shows differences between simulations.

There are significant differences in stream flow during wet and dry months. Month's variations predicted from the three land cover classifications 1989, 2000 and 2011 are presented in (Fig. 4.16).

The result indicates that the wet mean monthly flow for declined by 2.32% between 1989 to 2000, while from 2000 to 2011 LULC it was lowered by 1.40%. On the other hand dry mean monthly flow was decreased by 7.31% and 10.71% between 1989-2000 and 2000-2011 LULC respectively. However, it is observed that in mean monthly flow rate was declined by 17.24% for dry month and 3.69% for wet month.

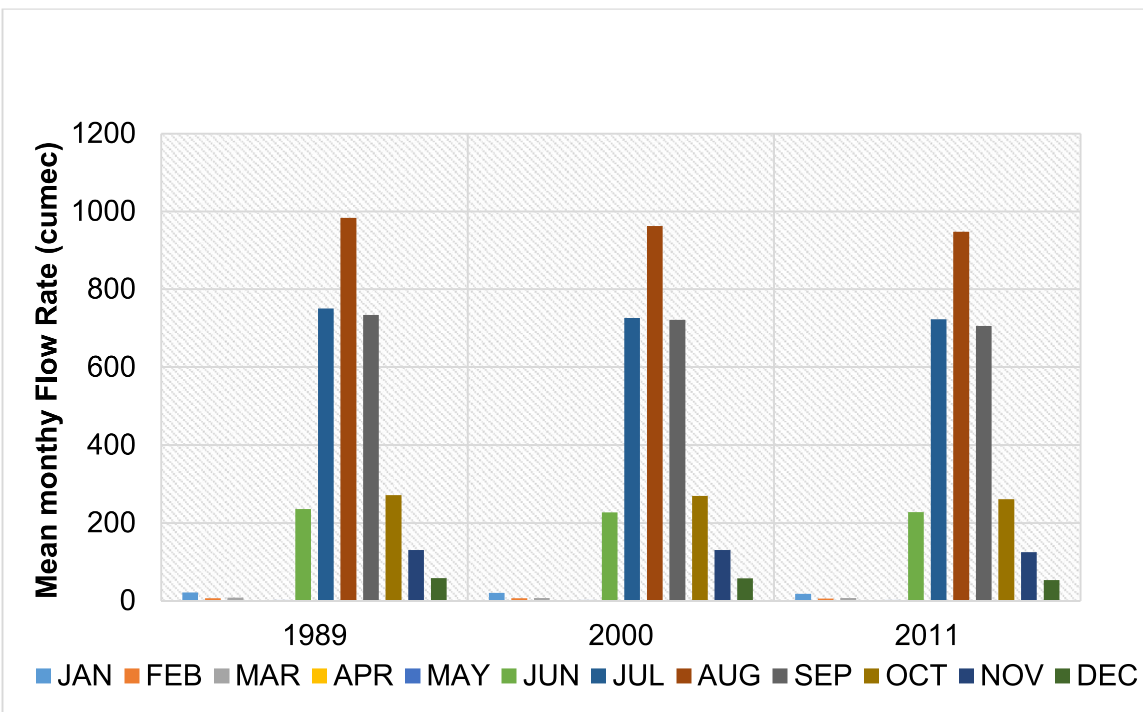

Fig. 4.16: Simulated monthly basin stream flow for study period

4.6.1 Trend analysis

For the available observed data, plots are made for summer, monsoon and winter periods to show the trend using Mann Kendall test and the magnitude of the trend using Sen's slope estimator. The plots provide an indication of increasing or decreasing trend in the time series.

4.6.1.1 Trend analysis of rainfall and temperature

The results of Mann Kendall analysis of rainfall and temperature (Min. and Max.) data at seven stations (Patan, Barmanghat, Sandia, Gadarwara, Dindori, Hoshangabad, and Manot) in the upper Narmada basin for or the period 1979–2013 were summarized in Table 4.17 and 4.18(a), 4.18(b) and shown in Fig. 4.17 and 4.18(a), 4.18(b).The trend analysis for rainfall data on the basis of season, shown in summer month (March, April and May) there is general negative trend in almost all stations except that two gauge stations Sandia and Gadarwara ,during the winter season (November, December, January and February) Test z value shows in all station in decreasing trend. While in monsoon season (June, July, August, September and October) there is an overall positive trend at all selected gauge stations except Manot station (showing negative trend).

Table 4.17: Z and Q values for all observed rainfall data (1979-2013)

Station	Summer		Monsoon		Winter	
	Test Z	Q	Test Z	Q	Test Z	Q
Patan	-14.2	-0.05	1.14	1.54	-1.93	-0.26
Barmanghat	-1.31	-0.02	0.57	0.66	-1.91	-0.23
Sandia	0.44	0.01	1.70	1.56	-1.19	-0.10
Gadarwara	0.40	-0.01	0.88	1.56	-1.56	-0.22
Dindori	-1.96	-0.11	0.23	0.49	-1.70	-0.37
Hoshangabad	-0.04	0.01	1.31	1.25	-1.68	-0.13
Manot	-2.05	-0.06	-0.31	-0.41	-1.76	-0.26

The Seasonal Kendall trend analysis performs on the monthly totals (Table 4.17). The annual Kendell slope of the upper Narmada basin stations shows a negative slope with a decreases in summer -18.72 mm per year and in winter it decreases -11.73 mm per year, while it shows some increase in monsoon season at rate 5.52 mm per year. This is due to an increase temperature and resulting increase of evapotranspiration.

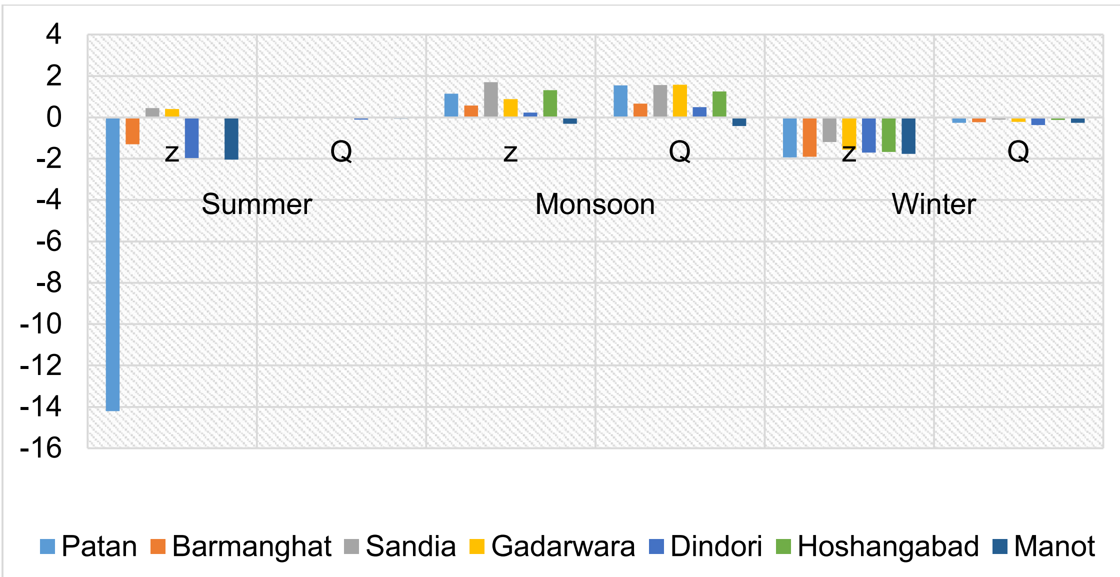

Fig. 4.17: Slope and trend for rainfall

Similarly trend analysis was done for max. and min. temperature for the period 1979-2013. In this all seven stations were situated high altitude to low altitude area. It is observed that in analysis in max. temperature shows positive trend means increasing trend in both summer and winter season. Whereas in monsoon season temperature trend showing declined trend except two station Dindori and Manot (Table 4.18(a) and Fig.4.18 (b)).

The minimum temperature trend analysis Table 4.19(b), it can be seen that Test z value for both monsoon and winter season in decreasing trend for almost all stations. While in summer season minimum temperature is positively increasing trend shown in Fig.4.18 (b).

Table 4.18(a): Z and Q values for all observed Maximum Temperature (1979-2013)

Station	Summer		Monsoon		Winter	
	Test Z	Q	Test Z	Q	Test Z	Q
Patan	2.64	0.04	-0.71	-0.01	2.30	0.04
Barmanghat	2.57	0.04	-0.53	-0.01	2.88	0.05
Sandia	2.36	0.04	-1.02	-0.03	2.27	0.04
Gadarwara	2.53	0.05	-1.90	-0.04	1.99	0.03
Dindori	2.39	0.04	0.04	0.01	2.36	0.04
Hoshangabad	3.10	0.05	-0.71	-0.02	3.04	0.05
Manot	3.69	0.05	0.68	0.01	3.24	0.06

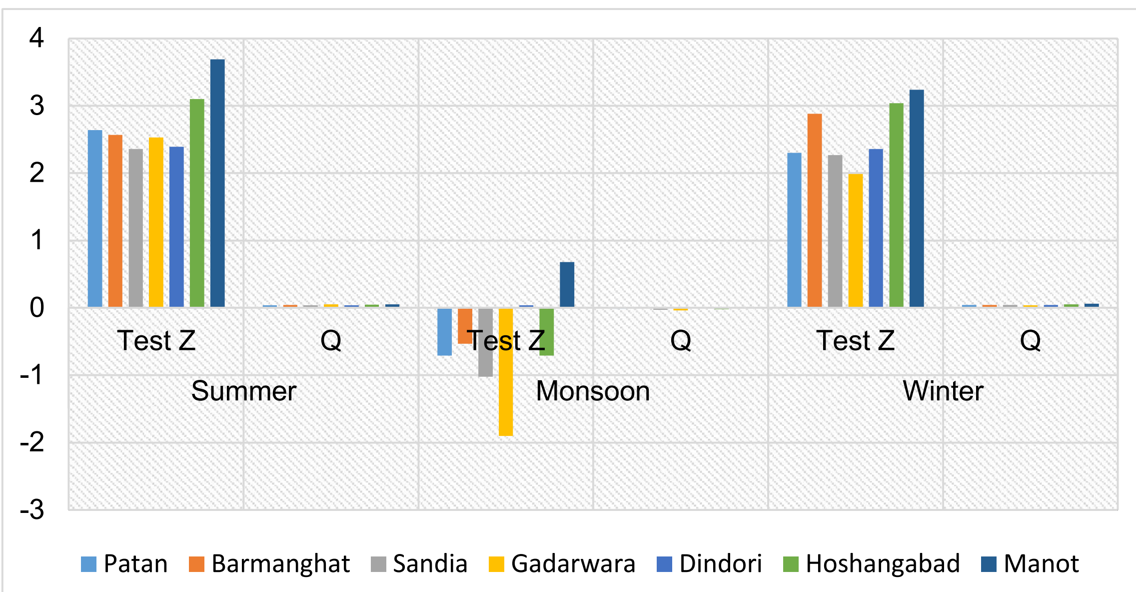

Fig.4.18 (a): Slope and trend for Maximum Temperature

Table 4.18(b): Z and Q values for all observed Minimum Temperature (1979-2013)

Station	Summer		Monsoon		Winter	
	Test Z	Q	Test Z	Q	Test Z	Q
Patan	1.59	0.02	-0.31	-0.03	-1.19	-0.02
Barmanghat	2.16	0.02	-0.57	-0.05	-1.14	-0.02
Sandia	1.14	0.01	-0.85	-0.06	-0.88	-0.02
Gadarwara	0.45	0.01	-0.74	-0.07	-0.99	-0.03
Dindori	2.93	0.04	-0.20	-0.07	0.07	0.01
Hoshangabad	1.05	0.02	-0.20	-0.01	-0.23	-0.04
Manot	1.16	0.01	-0.11	-0.01	-0.65	-0.11

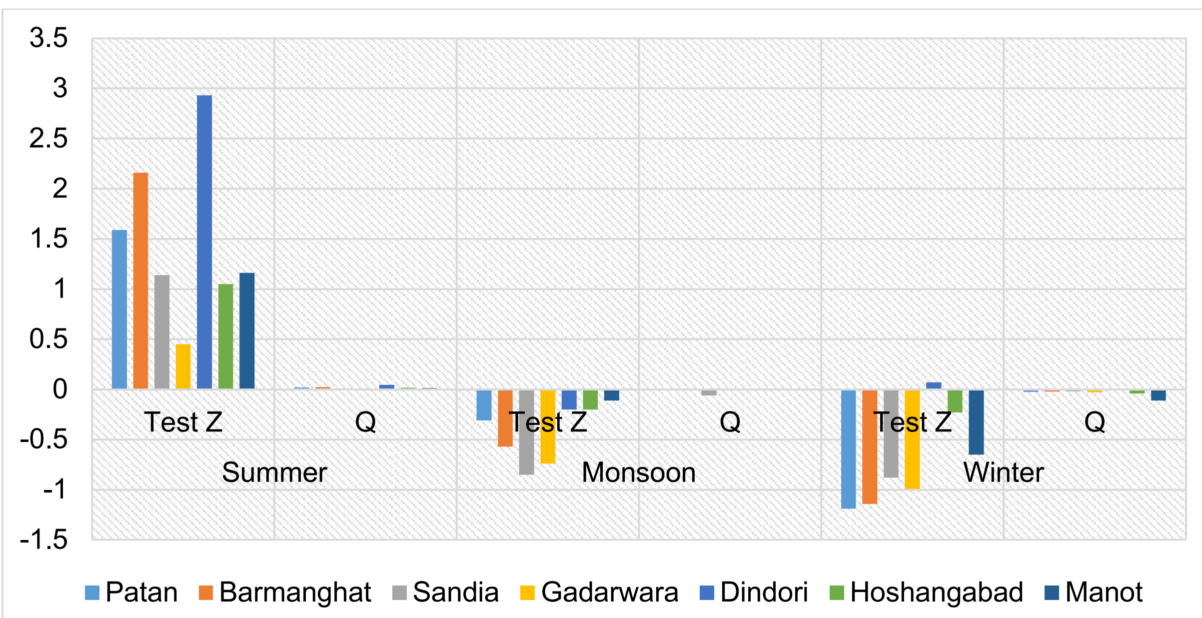

Fig.4.18 (b): Slope and trend for Minimum Temperature

Singh et al (2008) also reported that Narmada basin experienced warming trend in maximum temperature and minimum temperature based on 100 years of data analyzed. Also Sananda et al (2015) analysis on variation in spatial distribution of annual and monsoon rainfall was observed, which shows decreasing trend during 1979 to 2011.

4.6.1.2 Trend analysis of stream flow

The stream flow data from the gauging stations of upper Narmada basin was trend analyzed using the data of the period 1989–2011 shown in Table 4.19 with Fig. 4.19. The descriptive statistics (mean, maximum, minimum, standard deviation (SD), Skewness, kurtosis and Coefficient of variation (CV)) are given in Table 4.20 and Fig. 4.20.

Table 4.19: Z and Q values for stream flow data UNB gauging station (1989-2011)

Station	Summer		Monsoon		Winter	
	Test Z	Q	Test Z	Q	Test Z	Q
Patan	0.26	-0.01	-0.21	-0.30	1.21	0.10
Barmanghat	0.74	1.29	-0.90	-9.89	0.95	1.97
Sandia	0.16	0.44	-1.11	-4.71	0.90	2.56
Gadarwara	-2.93	-0.07	0.69	0.88	-0.85	-0.05
Dindori	1.80	0.07	-0.85	-1.31	1.53	0.19
Hoshangabad	0.42	0.72	-1.27	-3.57	0.48	1.36
Manot	-1.80	-0.05	-0.79	-2.41	-0.26	-0.04

Seasonal trend analysis of seven stream flow gauging station showed that decreasing trend in summer season i.e. on an average -0.19 m^3/s per year, and in monsoon season it decreases up to -0.63 m^3/s per year while in winter it shows increasing trend 0.56 m^3/s per year. Climate may be the major contributor to the seasonal variability of streamflow trends as warmer winter temperature reported and may lead to early spring snowmelt, resulting in higher streamflow in winter and spring (USEPA 1998).

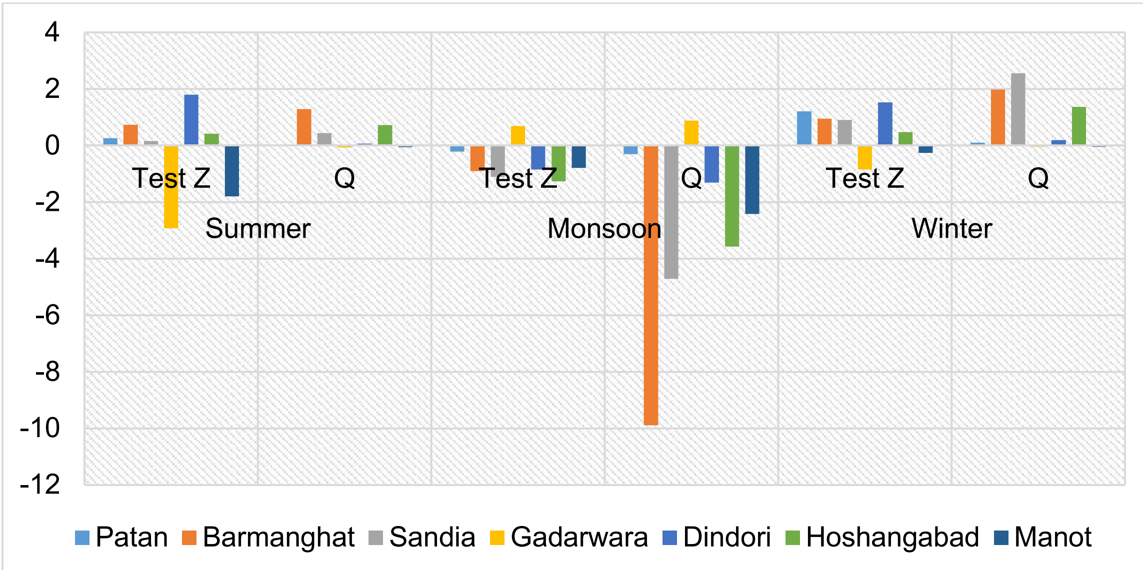

Fig. 4.19: Slope and trend for Stream flow

Table 4.20: Annual mean stream flow statistics for UNB gauging station (1989-2011)

	Patan	Barmanghat	Sandia	Gadarwara	Dindori	Hoshangabad	Manot
Mean	96.64	87.90	86.24	104.52	56.09	82.14	96.79
Max	287.06	245.66	271.73	281.18	204.28	283.48	265.94
Min	17.25	14.55	13.93	19.56	21.78	10.18	21.79
Stdev	62.02	55.68	61.76	64.99	48.17	62.48	58.56
Skew	1.65	1.67	1.76	1.63	2.15	1.77	1.67
Kurtosis	2.17	2.13	2.45	2.01	5.06	2.51	2.21
CV	0.64	0.63	0.71	0.62	85.8	0.76	0.60

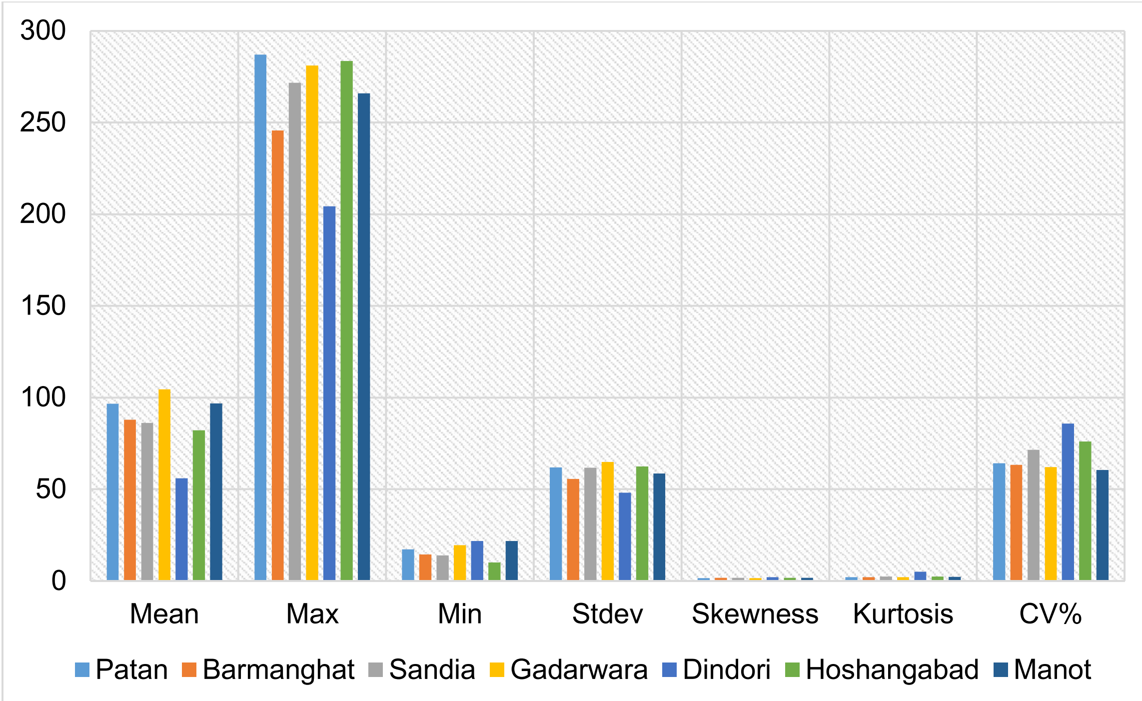

Fig. 4.20: Annual mean stream flow statistics

4.7 Simulation of surface runoff with changing scenario of land use /land cover

To simulate surface runoff due to change in land use/ land cover (LULC) hypothetical changes consideration was given to differences in quantity of surface runoff resulting from the replacement of land use/ land cover. The hypothetical scenarios for LULC were adopted by simulating an arbitrary LULC change.

This analysis was carried out to provide possible causes and effects if such developments were observed in the future in the study area. Increase in urbanization and reduction of agriculture and other vegetation area was taken as the key factor of LULC change hypothetical scenario as it was observed to be happening in the study area.

Four scenarios of change in LULC (detailed in section 3.17) have been used to simulate surface runoff (SQ), aquifer recharge (AR), water yield (WY) and evapotranspiration (ET).

In terms of scenario generation, the first scenario was the Built-up area change scenario (i.e. conversion of agriculture/other vegetation and fallow/barren land to Built-up land at given percentage). Second scenario was forest development (forestation). The third scenario was Agriculture /other vegetation land increment where the fallow/barren and wasteland were reclaimed to agriculture. Fourth scenario was performed on assessing combined Built-up land and Agriculture/other vegetation land increment.

The hydrological simulation of the entire Upper Narmada basin was carried out using Arc SWAT model. Initial run was carried out for the base year 2011. The result of these scenarios were analyzed with the baseline period i.e. LULC of year 2011.

Scenario I: increase in Built-up area

Urbanization and industrial development is expected due to increase with the increase in population in the basin. To simulate the effect of increase in built-up area, five levels i.e. increase by 5%, 10%, 15%, 20% and 25% were considered using the base year 2011.

Table 4.21 represents the increase in built-up area which has come from Agriculture and Fallow land. The results of this scenario (Table 4.21 and Fig. 4.21) indicate that change in generated runoff was from 412.63 mm/year to 421.71 mm per year with respect to 5 to 25 percent increment in built-up area respectively. The generated runoff was 411.91 mm per year for the base period 2011 LULC. Increase in urban area or settlement area had strong effect on rapid surface runoff and thereby reduced percolation and also reduced ground water storage that is aquifer recharge which decreased from 154.46 mm per year to 151.12 mm per year on increasing urbanization from 5 to 25 percent respectively (Fig. 4.22).

In the basin the water yield increased from 662.44 to 690.13 mm per year which directly contributed to the stream flow (Fig. 4.23). Evapotranspiration (ET) was decreased from 510.54 to 507.89 mm /year with increase in urbanization (Fig. 4.24). The scenario level of decreasing ET represents the decrease in the cropland area in the basin.

Water yield i.e the net amount of water provided by the sub-basin that contributes to stream flow (SWAT output parameter WY) (Wagner et al, 2013) was also assessed in the study. As per Zongxue Xu and Gang Zhao, 2016, rapid urbanization has an adverse impact on the urban rainfall-runoff processes, which may result in the increase of urban flood risk.

Table 4.21: **Land use/ Land cover for scenario-increase in Built-up area and its hydrological response at increase in Built-up land.**

LULC Class	Area (Km^2)					
	Base 2011	**5%**	**10%**	**15%**	**20%**	**25%**
Forest	13377.82	13377.82	13377.82	13377.82	13377.82	13377.82
Waterbody	752.96	752.96	752.96	752.96	752.96	752.96
Wasteland	229.03	229.03	229.03	229.03	229.03	229.03
Built-up	225.08	236.334	247.58	258.84	270.09	281.35
Agriculture/Oth.Veg.	15792.1	15786.45	15782.11	15776.71	15771.83	15760.94
Fallow/Barren	14909.51	14903.91	14897.00	14891.14	14884.77	14884.40
Total	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**
Simulated Hydrological Parameters (mm)						
Surface Runoff	411.91	412.34	413.78	416.32	418.49	421.71
Aquifer Recharge	154.89	154.66	154.46	154.07	153.69	151.1
Water yield	662.44	666.31	669.31	676.45	681.37	690.13
Evapotranspiration	510.54	510.54	509.64	509.12	508.52	507.89

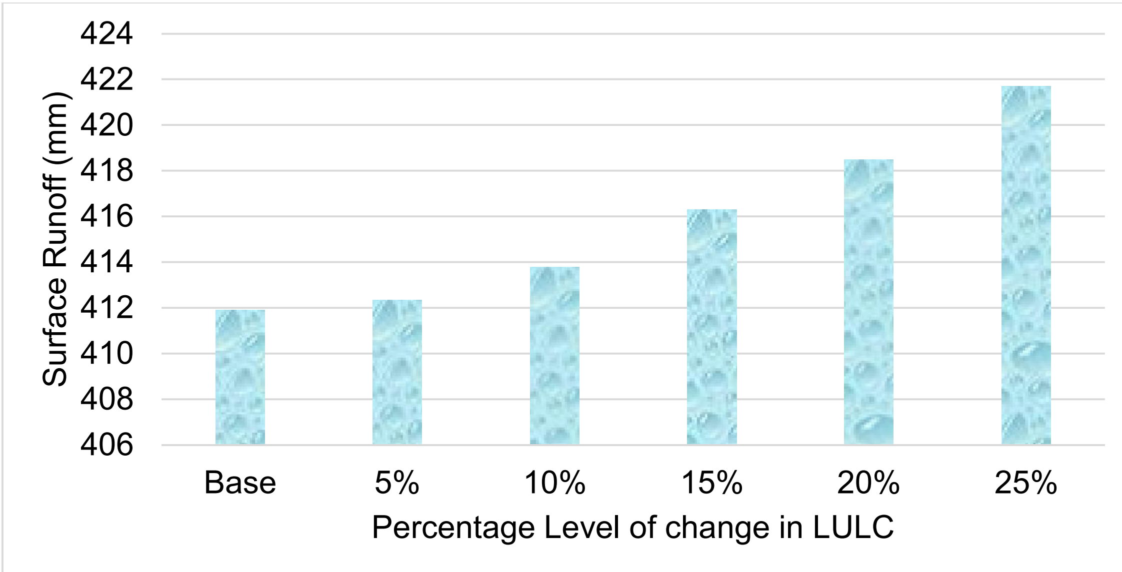

Fig. 4.21: Simulated Surface runoff at changing Built-up area

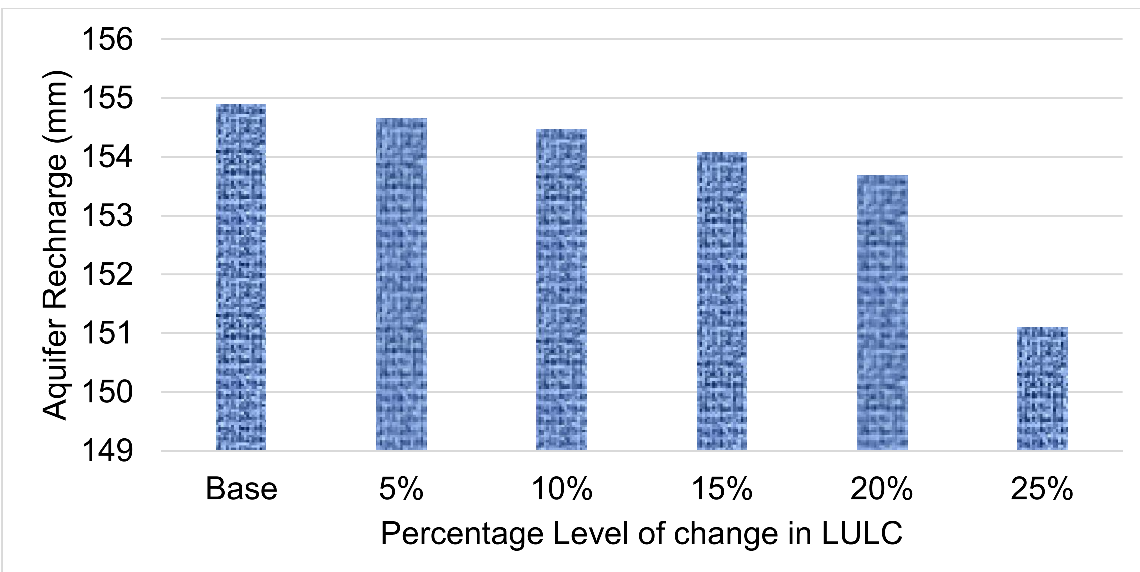

Fig. 4.22: Simulated Aquifer recharge at changing Built-up area

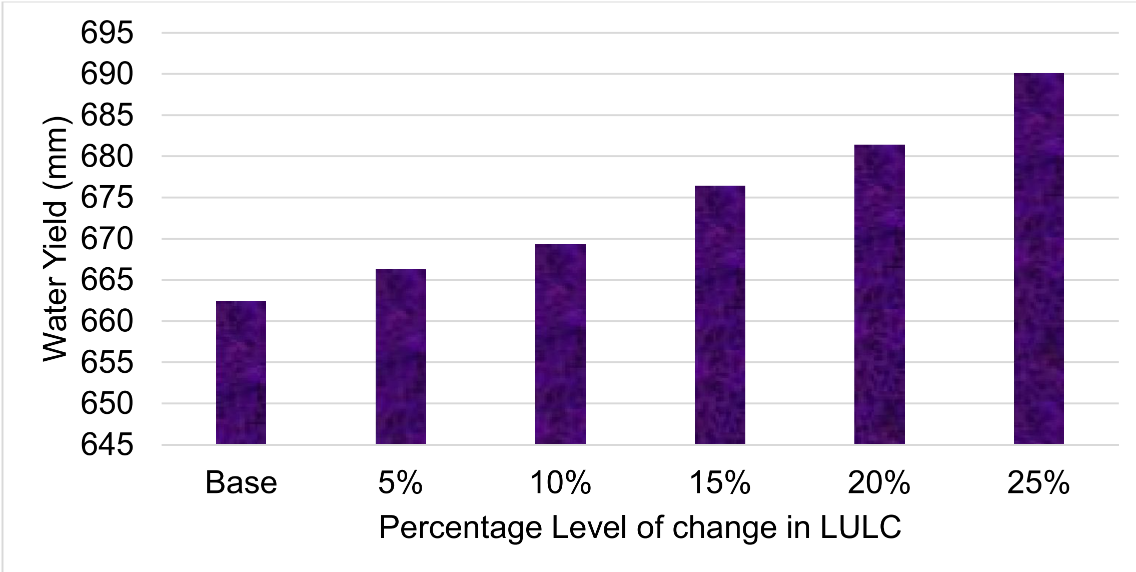

Fig. 4.23: Simulated Water yield at changing Built-up area

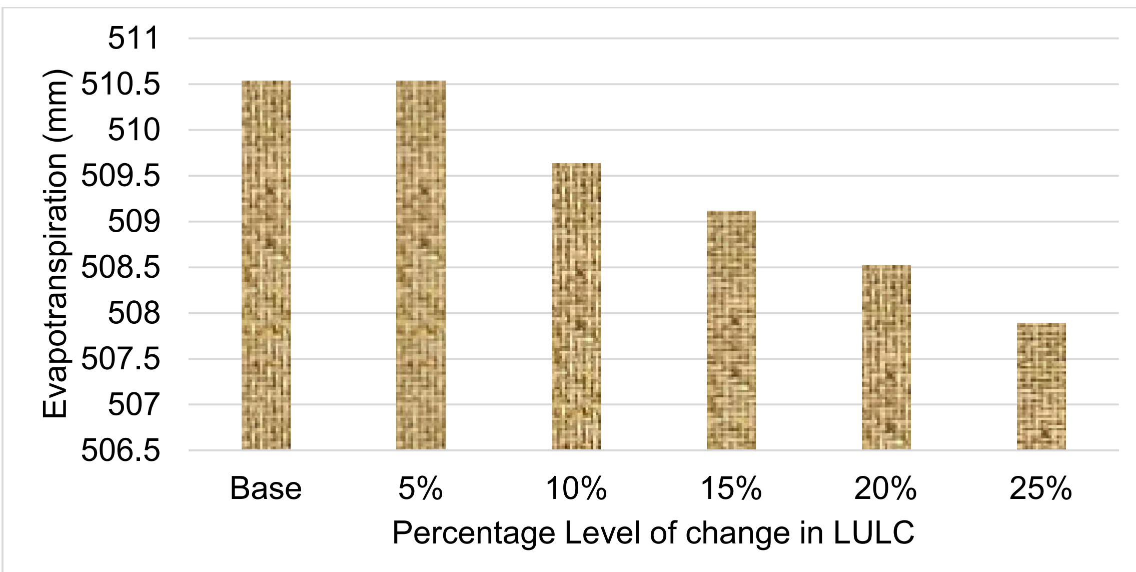

Fig. 4.24: Simulated Evapotranspiration at changing Built-up area

Scenario II: Increase in Forest area

Second scenario i.e forest area development wherein wasteland, fallow/barren land and such forest area occupied by agriculture area are converted as forest land is presented in Table 4.22. Conversion of wasteland and agricultural lands within the forest area into forest land lead to marked decline in surface runoff from 411.01 to 399.40 mm per year (Fig. 4.25). Consequently the aquifer recharge (Fig. 4.26) increased from 154.89 to 181.51 mm per year. This reflected that the afforestation may increase the ground water storage. Water yield and Evapotranspiration prediction based on forest scenario is presented in Fig. 4.27 and 4.28 respectively. It was observed that the water yield declined from 662.44 to 645.87 mm per year and ET declined from 510.54 to 484.53 mm per year with increase in forestation. Forests absorb most of the precipitation hence there is increased interception, percolation and reduced evapotranspiration, rather than prompt streamflow.

Table 4.22: **Land use/ Land cover for scenario-increase in Forest area and its hydrological response at increase in Forest area.**

LULC Class	Area (Km^2)					
	Base 2011	**5%**	**10%**	**15%**	**20%**	**25%**
Forest	13377.82	14046.71	14715.68	15384.49	16053.38	16722.27
Waterbody	752.96	752.96	752.96	752.96	752.96	752.96
Wasteland	229.03	Nil	Nil	Nil	Nil	Nil
Built-up	225.08	225.08	225.08	225.08	225.08	225.08
Agriculture/Oth.Veg.	15792.10	15792.10	15691.90	15687.12	15659.1	15654.54
Fallow/Barren	14909.50	14469.65	13900.70	13236.85	12595.98	11931.64
Total	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**
	Simulated Hydrological Parameters (mm)					
Surface Runoff	411.91	411.01	409.32	405.45	404.61	399.4
Aquifer Recharge	154.89	159.98	165.43	170.78	179.33	181.51
Water yield	662.44	662.44	660.23	659.37	651.09	645.87
Evapotranspiration	510.54	510.15	509.67	500.19	491.34	484.53

Nil= if complete wasteland convert to forest

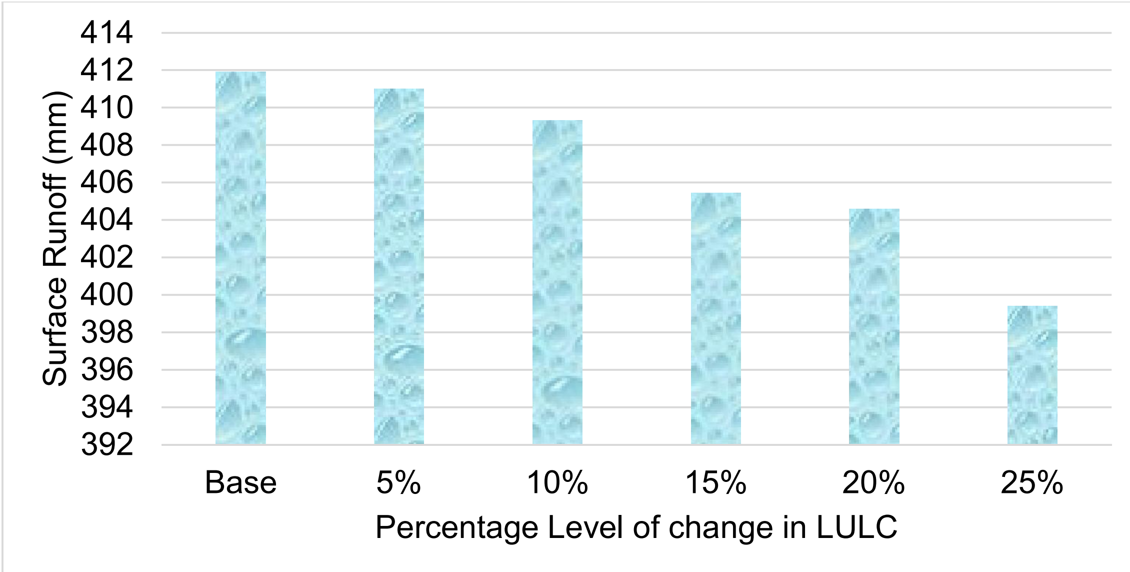

Fig. 4.25: Simulated Surface runoff at changing Forest area

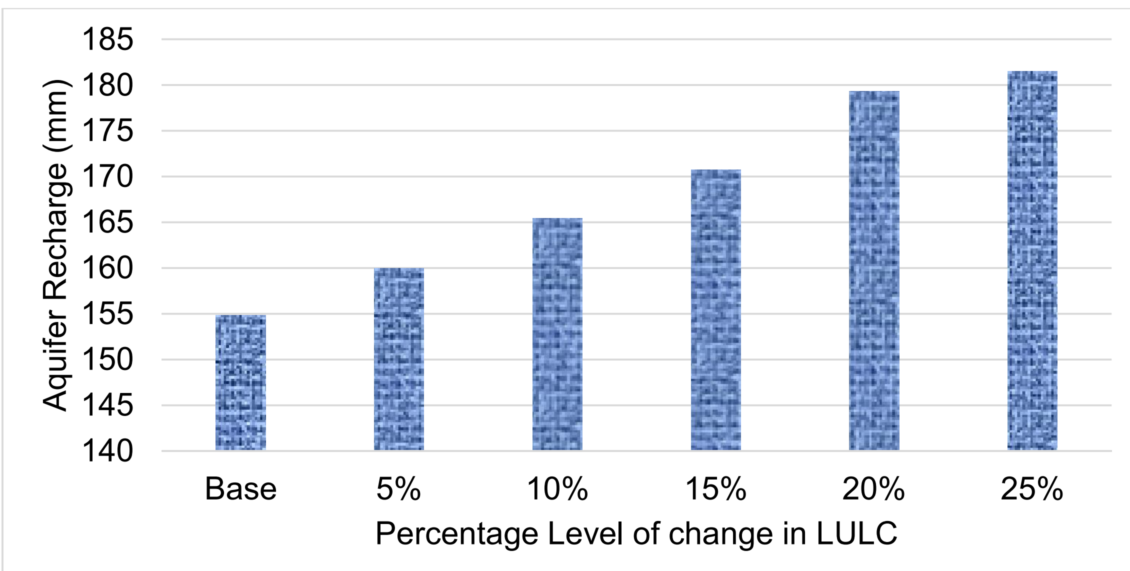

Fig. 4.26: Simulated Aquifer recharge at changing Forest area

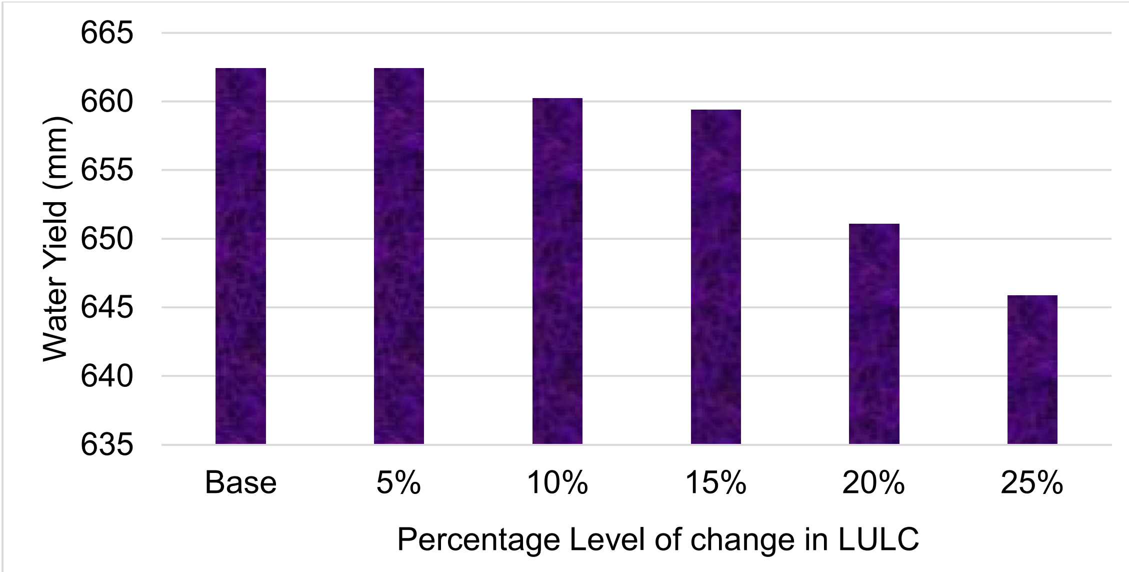

Fig. 4.27: Simulated Water yield at changing Forest area

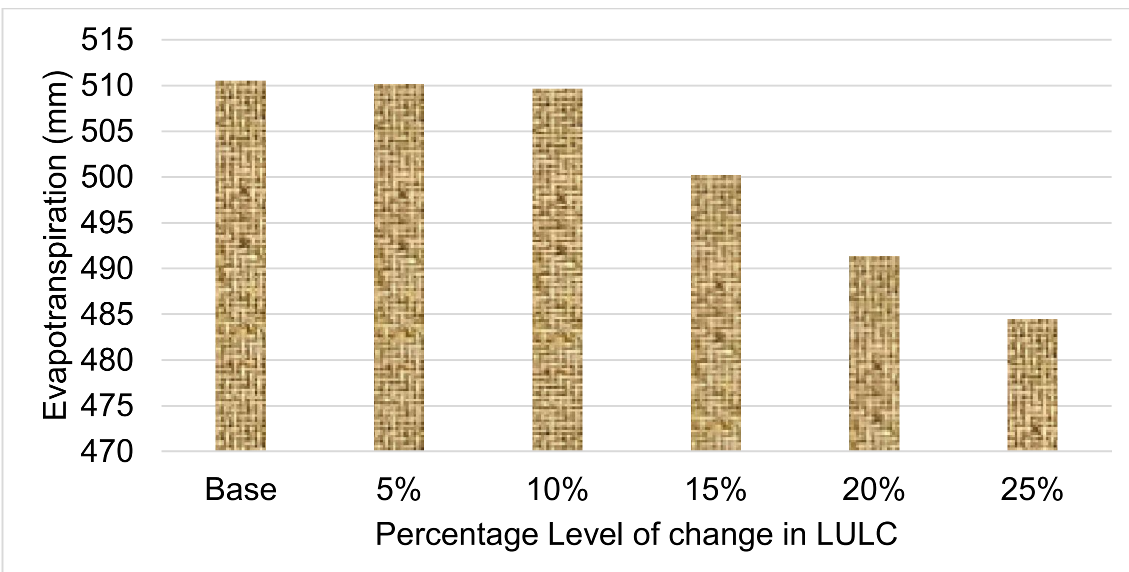

Fig. 4.28: Simulated Evapotranspiration at changing Forest area

Scenario III: Increase in Agriculture / other vegetation area

In the ***third scenario*** effect of increasing of agriculture/other vegetation land (Fallow/Barren and wasteland reclaimed to agriculture) is presented in Table 4.23. The LULC changes were simulated for each level of scenario which resulted in changes in hydrological parameters. The results showed a slight increment in surface runoff at 1.14 percent from 5 to 25 percent of level of scenario (Fig. 4.29).

However, Aquifer recharge, Water Yield and ET increased at the rate of 1.76 percent, 4.24 percent and 0.97 percent mm per year respectively from 5 to 25 percent level of scenario (Fig. 4.30, 4.31 and 4.32 respectively). Several studies confirm that the agriculture expansion results the reduction of infiltration causing increase in surface runoff (Githui 2009; Mengistu 2009; Trimble et al, 1989; and Swank et al, 1988).

Table 4.23: **Land use/ Land cover for scenario-increase in Agriculture/Other Vegetation area and its hydrological response at increase Agriculture/other Vegetation area.**

LULC Class	Area (Km^2)					
	Base 2011	**5%**	**10%**	**15%**	**20%**	**25%**
Forest	13377.82	13377.82	13377.82	13377.82	13377.82	13377.82
Waterbody	752.96	752.96	752.96	752.96	752.96	752.96
Wasteland	229.03	229.03	216.12	212.72	209.13	200.45
Built-up	225.08	225.08	225.08	225.08	225.08	225.08
Agriculture/Oth. Veg.	15792.1	16581.70	17371.31	18160.91	18950.52	19740.12
Fallow/Barren	14909.51	14119.9	13343.21	12557	11770.99	10990.07
Total	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**
	Simulated Hydrological Parameters (mm)					
Surface Runoff	411.91	412.01	412.32	413.86	414.57	416.73
Aquifer Recharge	154.89	155.21	155.39	156.01	156.29	157.95
Water yield	662.44	662.89	665.03	670.54	679.34	691.01
Evapotranspiration	510.54	510.71	511.19	512.09	512.45	514.68

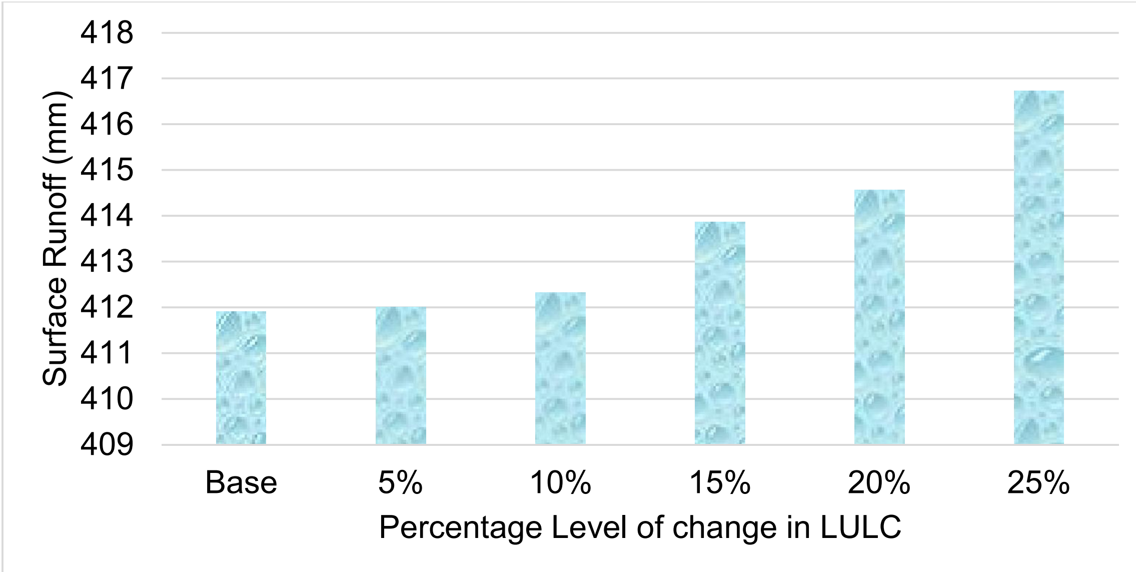

Fig. 4.29: Simulated Surface runoff at changing Agriculture/Other Vegetation

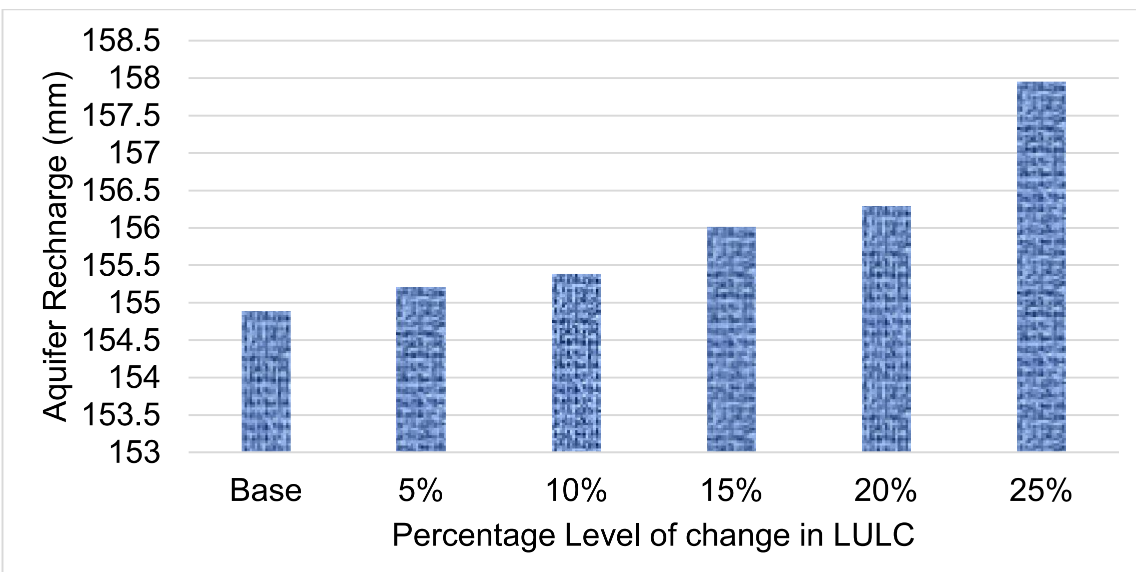

Fig. 4.30: Simulated Aquifer recharge at changing Agriculture/Other Vegetation

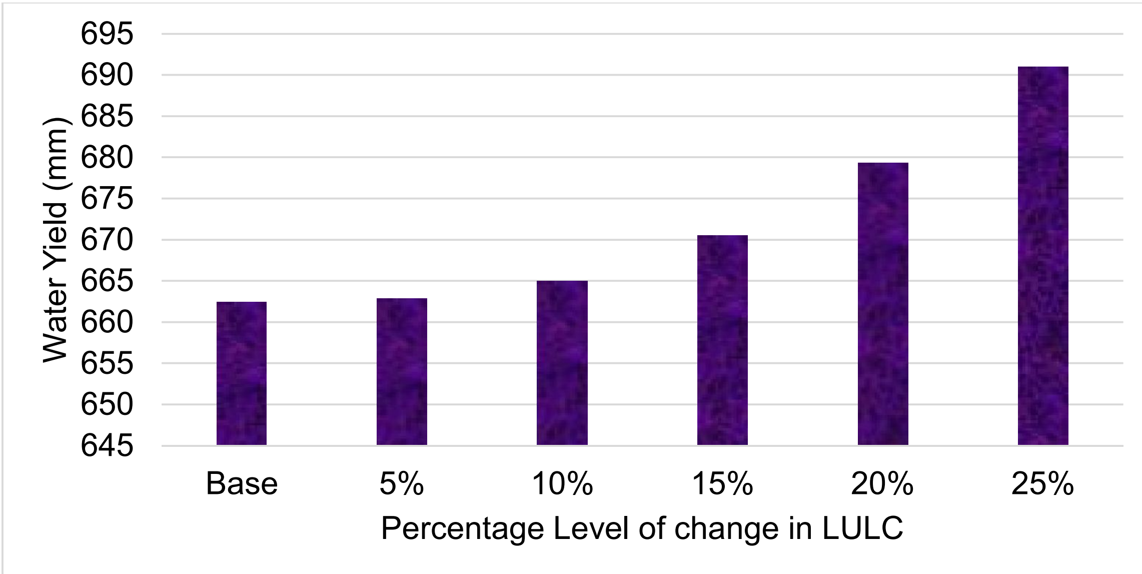

Fig.4.31: Simulated Water yield at changing Agriculture/Other Vegetation

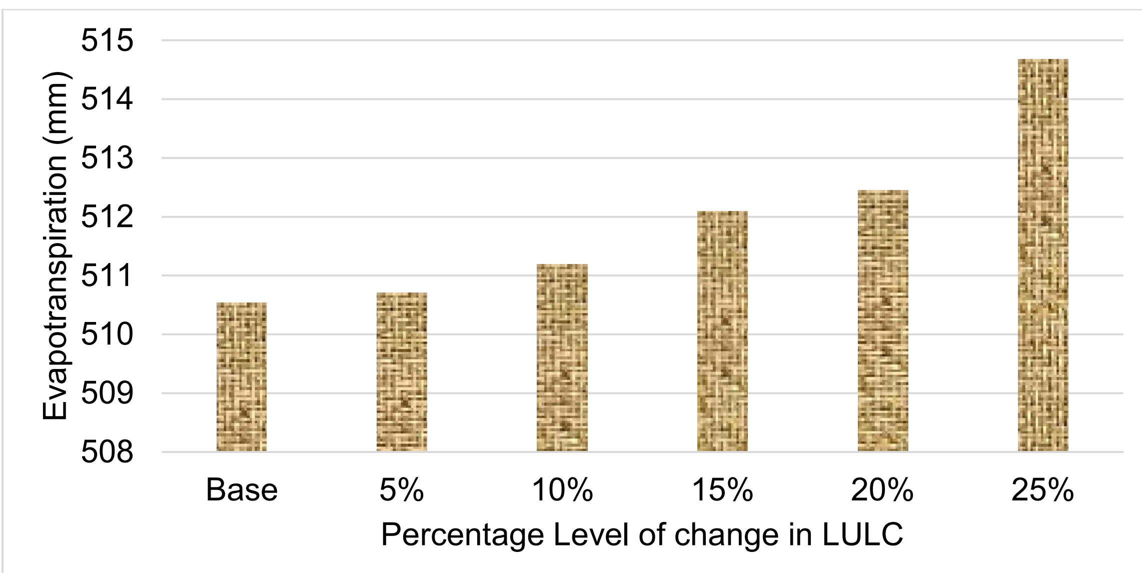

Fig. 4.32: Simulated Evapotranspiration at changing Agriculture/Other Vegetation

Scenario IV: Increase combined of Built-up as well as Agriculture /other vegetation area

The **forth *scenario*** depicts the combined effect of increase of Built-up as well as Agriculture/other vegetation (Table 4.24). From Table 4.24 and Fig. 4.33 it was observed that the surface runoff increased from 412.19 to 430.66 mm per year with increase in levels of scenario.

Table 4.24: Land use/ Land cover for scenario-increase in combine (Built-up+ Agri. /Other Vegetation) Area and its hydrological response at increase combine (Built-up +Agriculture /Other Vegetation).

LULC Class	Area (Km^2)					
	Base 2011	5%	10%	15%	20%	25%
Forest	13377.82	13377.82	13377.82	13377.82	13377.82	13377.82
Waterbody	752.96	752.96	752.96	752.96	752.96	752.96
Wasteland	229.03	229.03	229.03	216.12	212.72	209.13
Built-up	225.08	230.12	236.33	240.37	247.58	261.65
Agriculture/oth.veg.	15792.10	16186.90	16581.76	16976.50	17371.72	17780.11
fallow/Barren	14909.51	14509.67	14108.6	13722.73	13321.7	12904.83
Total	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**	**45286.50**
Simulated Hydrological Parameters (mm)						
Surface Runoff	411.91	412.19	412.73	415.45	420.39	430.66
Aquifer Recharge	154.89	154.99	155.51	156.18	158.23	160.81
Water yield	662.44	662.91	663.45	667.37	670.29	680.32
Evapotranspiration	510.54	510.54	510.78	511.89	512.01	512.07

However, LULC change showed slight increase in aquifer recharge from 154.99 to 160.81 mm per year (Fig. 4.34), slight increase in water yield from 662.91 to 680.32 mm per year (Fig. 4.35), and increase in ET from 510.54 to 512.07 mm per year (Fig.4.36) with increase in level of scenario. From the above results it can be inferred that the effect of increase in built-up area nullified the effect of increase of agriculture land and vice - versa. In contrast, other studies show that, when agriculture land is plowed, compaction of lower soil horizon occurs, causing decreasing infiltration capacity that results into more surface runoff, increasing water yield and decreasing aquifer recharge (Ankenys et al. 1990; logsdon et al 1990; Abu Hamden 2013).

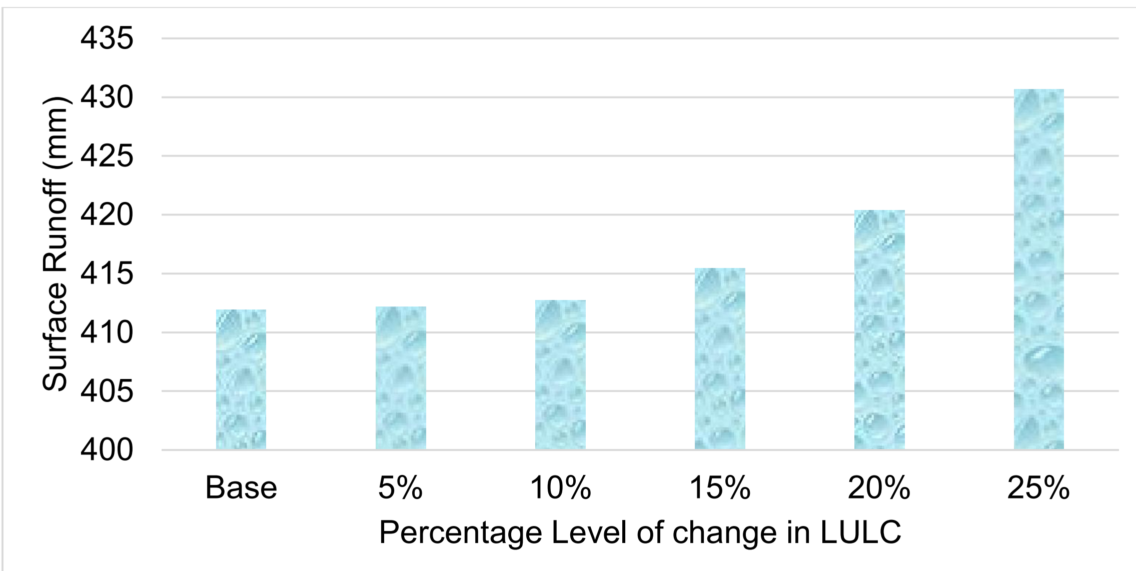

Fig. 4.33: Simulated Surface runoff at changing combined Built-up area and Agriculture area

Arc SWAT model was utilized to explore the hydrological characteristic of the upper Narmada basin. The analysis provided valuable information on hydrological response towards Land use/ land cover change in the basin.

The recent changes in land use/ land cover conditions have brought significant impact on surface runoff, water yield and aquifer recharge and thus threaten the eco-hydrology of the basin. The rapid growth in urbanization has increased the demand for land for development purposes. Consequently Agriculture/other vegetation, forest and water resources are coming under enormous pressure.

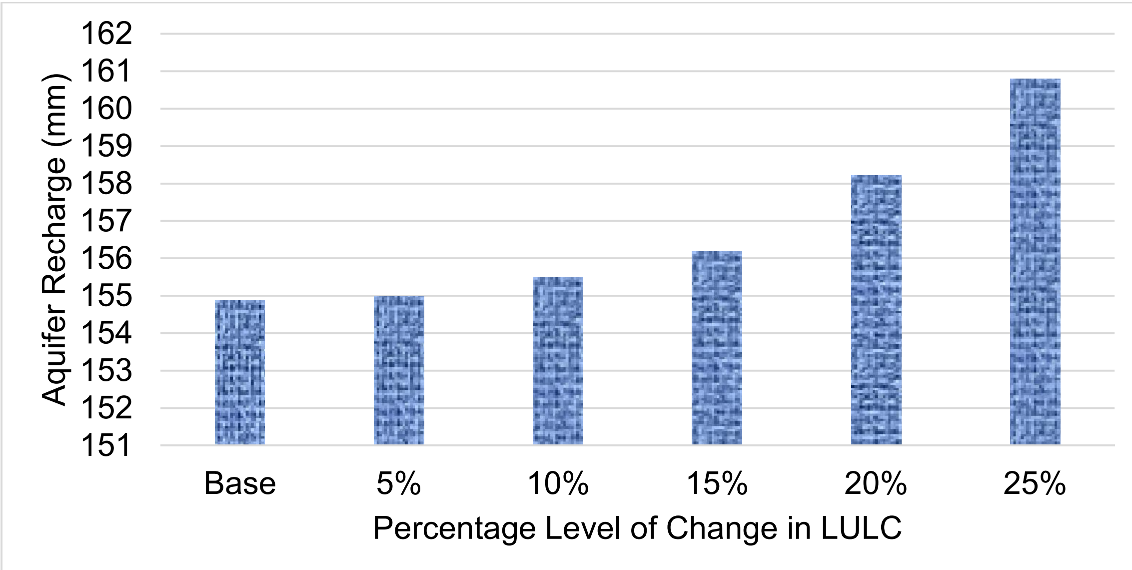

Fig. 4.34: Simulated Aquifer recharge at changing combined Built-up area and Agriculture area

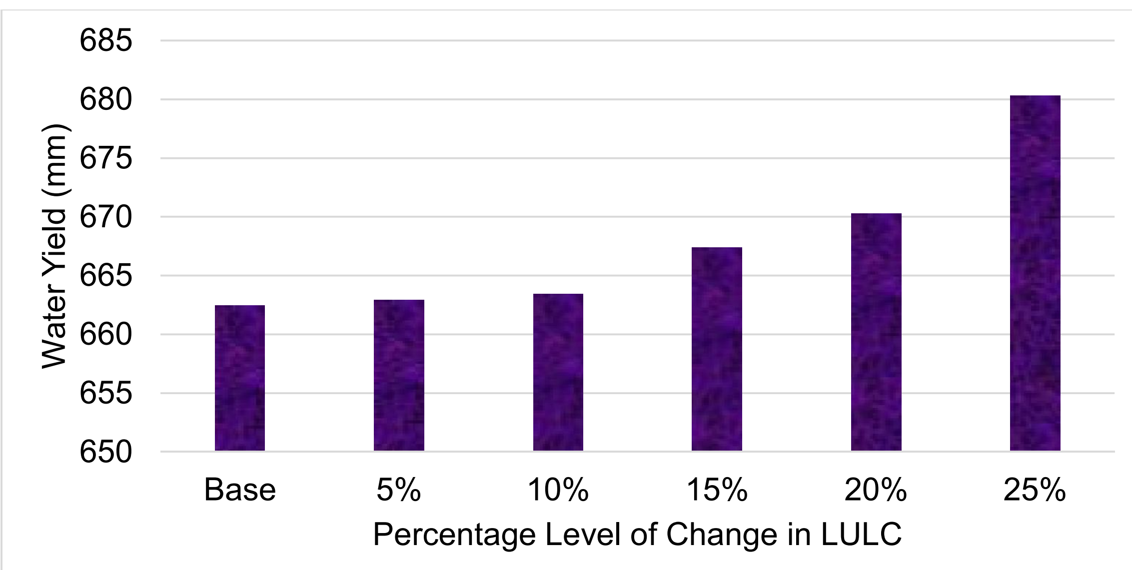

Fig. 4.35: Simulated Water yield at changing combined Built-up area and Agriculture area

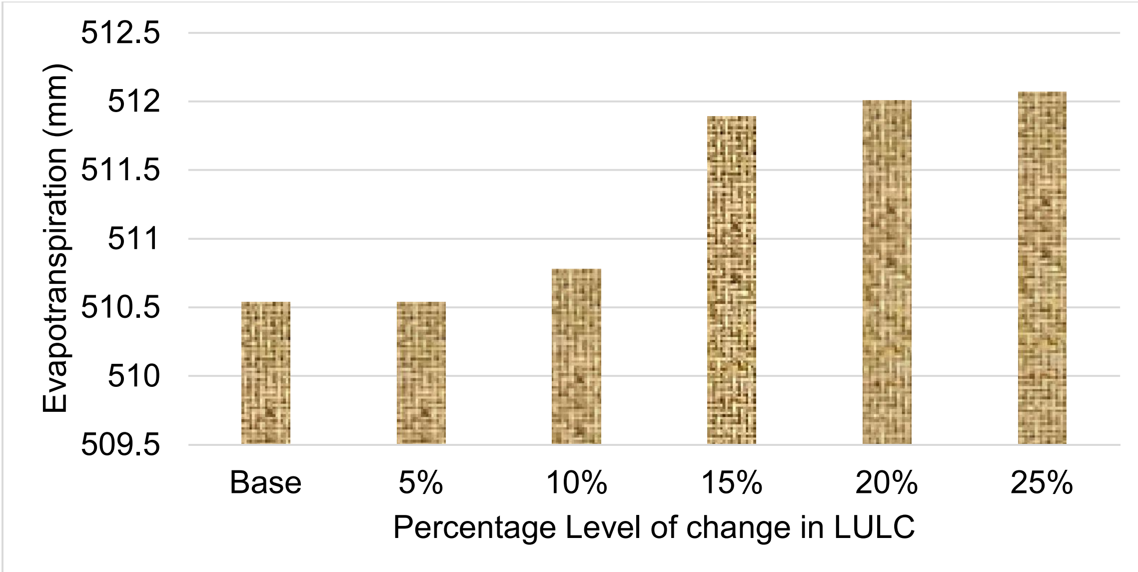

Fig. 4.36: Simulated Evapotranspiration at changing combined Built-up area and Agriculture area

The general trends of land use change are gradual decline in coverage of forest, increase in urban development and somewhere in agriculture area. The increase in built-up land in the valley has reduced the recharge source of groundwater which needs to be protected through controlling unplanned growth of urbanization. The rise in global warming accompanied with high variability in precipitation projects extreme changes in water balance and ultimately deterioration of the land quality. It is essential to regulate the urban development properly; affordable substitute fuels for household use should be made available and an extensive community programme should be undertaken to improve the fragile system of the basin. An integrated adaptation strategy needs to be developed to cope with future implications of hydrological changes through focusing key policy areas and improving adaptive capacities of the communities at risk. Existing knowledge and data gaps need to be filled by systematic observations and enhanced capacities for research since these will be fundamental for developing climate change adaptation and mitigation programmes for the Upper Narmada basin in future.

5. Summary, Conclusion and Suggestions for Further Work

5.1 Summary

In recent years, considerable efforts have been put into the development of computer-based models that are powerful tools for investigating the impacts of LULC on hydrological responses and optimization of water resources utilization that support integrated water resources management. Remote sensing provided useful information on LULC changes since its capability of viewing and repetitive coverage. Step-by-step evaluations of the satellite images have allowed us to better understand the cause and effect relationship regarding the LULC over time. Accordingly, in the present study, spatial databases were developed and analyzed using satellite image and intensive LULC mapping using ERDAS IMAGINE 10 and ArcGIS 9.3 with SWAT 2009 software for upper Narmada Basin of state Madhya Pradesh of India.

The study showed that GIS tools and remote sensing application are helpful analyze and evaluate spatio-temporal land use/cover dynamics. It also showed that SWAT2009 is an effective tool in analyzing the impacts of land use/cover changes on hydrology in areas with limited readily available data. In the study, it was observed the calibrated model adequately exposed the phenomena that take place in the hydrological regime.

The statistical result of model performance assessment also showed that the trend agreements between the calibrated and simulated model were good. The Nash efficiency and coefficient of determination result showed that the model has a good performance. It was observed that the model was effective in simulating the stream flow of the catchment.

The result showed significant change in land use/cover that has occurred in the study area. The forest land, built-up area, agriculture/other vegetation and fallow/barren land has shown a significant change in twenty three year time period under study.

The increase in the built-up-land and fallow/barren land areas has resulted in decrease in agriculture/other vegetation area. This is due to the continued population growth of the area. The result also showed that the increase in forest cover caused the increase in forest conservation practices.

Systematic data preparation, calibration, validation and simulation analysis were performed on the selected models before they were further used for scenario analysis in the study. Application of distributed hydrological models for the aforementioned purpose is challenging when used in areas where there is limited data available. This is due to the fact that hydrological models use different spatial, temporal, time series data to predict flow components and hydrologic characteristics over the basin.

Given that SWAT2009 require detailed description of the distribution of physical parameters affecting the surface runoff , water yield, aquifer recharge and evapotranspiration at the land surface, the method is facilitated by use of GIS. The use of GIS environment provides a powerful platform for processing of DEM, land use and land cover soil data layers and other topographic attributes and displaying model results in a spatial way, so that it becomes possible to capture local complexities of a basin. Information generated on sensitivity analysis, calibration and validation, analysis helps to identify and characterize hydrologic parameters that can assist in developing and achieving management goals.

5.2 Conclusions

Based on the results for LULC change and change scenario in the study obtained, the following conclusions are drawn:

- Overall accuracy of the classified images for year 1989, 2000 and 2011 was found to be 81.64 % and 78.13 % and 83.20 % respectively with the kappa coefficient being 0.75, 0.70 and 0.76 for respective years. This reflect that classification of satellite image was very good.
- The analysis of the LULC classification and change detection using integrated geospatial technology over a period of years both spatially, quantitative way in Upper Narmada Basin revealed that there was a slight increment in forest area (+0.78 %) caused due to afforestation activity. The agriculture /Other Vegetation area in the basin decreased from 40.68 % to 34.87 % (i.e. -14.28 % decline). And also Built-up area

was found to increase from 0.21% to 0.51% during 1989 to 2011 (which is a +138.1 % increases).

- Hydrologic response was analyzed using the observed time series hydrological data corresponding to the LULC change period. The result indicated that surface runoff declined by 0.73% during the period 1989 to 2000 and by 0.91% during 2000 to 2011. Overall decrease from 1989 to 2011 was 1.63%. Result showed increasing trend of the ET by 0.71% and 1.50 % during 1989-2000 and 2000-2011 respectively. Overall it increased by 2.21% during 1989 to 2011. This means that somewhere climate change and LULC change is affecting the study area. Total water yield showed a decreasing trend viz. 3.11 % from1989-2000 and 3.88% from 2000 to 2011. Overall decrease in water yield was 6.87% during 1989 to 2011. Hence, it is clear that a lot of measures need to be taken to sustain the water resource and to maintain a balanced stream flow aimed at reducing the magnitudes of surface runoff generation and increasing water recharge in the basin area.
- The response of hydrological parameters was studied under probable future changes in LULC in the basin. The conversion scenario based on taking into account of baseline case i.e. LULC of 2011.Four hypothetical scenario were developed and following conclusions were drawn-
    - **i.** First scenario (viz. increase in Built-up area) resulted in rapid increment of surface runoff and water yield i.e. 0.45 to 2.38% and 1.04 to 4.18% respectively. Whereas Aquifer recharge and ET also showing decreasing trend i.e. 0.28 to 2.45% and 0.18 to 0.52% w.r.t to baseline LULC 2011 hydrologic response.
    - **ii.** Second Scenario (viz. increase in Forest area) showed that aquifer recharge in increasing direction i.e. 6.80 % to 17.19 %, while increasing forest area by 5% to 25%. However surface runoff, water yield and ET declined by 0.63-3.04%, 0.33-2.50% and 0.17-5.09% respectively.
    - **iii.** Third scenario (viz. increase in agriculture area) resulted in slight increment in surface runoff, aquifer recharge,

water yield and ET by 0.10-1.17%, 0.32-1.98%, 0.39-4.31% and 0.13-0.81% respectively.

iv. Forth scenario (viz. increase both built-up and agriculture area) result resulted in increase in surface runoff, aquifer recharge, water yield, and ET by 0.20-4.55%, 0.40-3.82%, 0.15-2.70% and 0.05-0.30% respectively.

Considerable hydrologic response to LULC change in the study area was observed. Overall it may be said that the increase in urbanization is adversely affecting the ground water recharge. To counter this it is necessary to promote the activities of afforestation, convert waste land, fallow/ barren land into agriculture or forest lands. This would help in sustained ground water recharge.

It is concluded that the SWAT model resulted in idealistic hydrology as it took into account a large number of parameter influencing LULC change. It was realized that to study such hydrological simulation between land use/ land cover and atmosphere over large area, it requires qualitative and quantitative data, in this regard; remote sensing data played an important role.

5.3 Suggestions for further work

Following suggestions for future work would be helpful in expanding the present study.

- The model simulation in this study considered only LULC change effect by assuming all other things as constant. But change in climate and soil management activities and other LULC variables will also contribute great impact on rainfall runoff process of the catchment.
- Comparative study can done with climate change future predication with GCM models.
- Model comparative study for best fit for data availability would be useful.
- Further study can be conducted for crop performance.
- As only stream flow were calibrated and validated, it has to be emphasized that other outputs presented in this study, such as sediment dynamics in response to LULC change should be treated with caution and hence its impact on UNB should considered for future studies. The model could be further tested when data on sediment load is available.
- Further study can be conducted for watershed performance changing indicator.

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Appendix-A

Meteorological information of Upper Narmada basin selected station during 1979-2013

Temperature (°C), Precipitation (mm), Wind (m/s), Relative Humidity (fraction), Solar (MJ/m^2)

Hoshangabad 226778

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	34.72	19.43	583.70	2.15	0.44	19.29
1980	33.82	19.41	762.66	2.16	0.47	18.47
1981	32.68	19.02	728.22	2.13	0.52	18.74
1982	33.05	19.73	901.52	2.17	0.53	18.20
1983	33.16	18.65	1011.34	2.12	0.49	19.56
1984	33.17	18.61	854.44	2.22	0.48	18.68
1985	33.93	18.92	793.06	2.13	0.47	19.26
1986	33.40	19.21	1045.79	2.26	0.49	18.40
1987	34.48	19.53	479.28	2.20	0.45	19.16
1988	33.87	19.49	1366.44	2.12	0.49	18.66
1989	33.70	18.34	1067.51	2.09	0.46	18.70
1990	32.30	19.49	1874.50	2.21	0.55	17.06
1991	34.25	19.14	700.99	2.20	0.46	18.71
1992	34.35	18.78	677.62	2.10	0.44	19.61
1993	33.33	19.12	1343.86	2.19	0.51	18.83
1994	32.83	19.07	1036.51	2.14	0.53	17.89
1995	33.89	19.41	578.44	2.13	0.49	19.14
1996	33.47	19.47	927.38	2.13	0.50	18.89
1997	32.58	19.27	848.87	2.23	0.54	18.72
1998	33.43	19.72	836.61	2.09	0.53	18.96
1999	34.49	19.55	704.58	2.13	0.48	19.25
2000	34.85	18.09	701.56	2.12	0.41	19.60
2001	34.96	18.72	456.40	2.05	0.45	19.67
2002	35.09	19.47	969.48	2.26	0.43	19.35
2003	34.02	19.51	1053.04	2.14	0.50	19.50
2004	34.67	19.13	493.28	2.08	0.46	19.70
2005	33.91	18.71	743.81	2.06	0.48	19.71
2006	34.20	19.51	663.95	2.04	0.49	18.68
2007	34.35	19.45	1058.23	2.00	0.48	19.17
2008	34.09	18.71	929.00	2.07	0.48	19.36
2009	34.81	20.07	929.89	2.09	0.48	19.59
2010	34.49	20.04	786.85	2.05	0.51	20.17
2011	33.66	18.49	2382.52	1.87	0.52	19.00
2012	33.51	18.35	1901.07	2.00	0.49	18.24
2013	33.08	19.11	1764.39	1.93	0.54	18.36

Gadarwara 226791

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	32.15	18.51	933.48	2.29	0.47	18.90
1980	31.48	18.64	1109.12	2.37	0.50	17.78
1981	30.57	17.98	953.07	2.27	0.54	18.20
1982	30.54	18.64	1228.65	2.26	0.56	17.48
1983	30.62	17.52	1702.87	2.26	0.52	19.21
1984	30.70	17.72	1021.28	2.43	0.50	18.40
1985	31.39	17.82	927.41	2.36	0.50	19.27
1986	30.98	18.37	1397.98	2.42	0.53	18.32
1987	31.86	18.46	829.13	2.31	0.48	18.38
1988	31.79	18.54	1463.78	2.28	0.50	18.22
1989	31.39	17.51	1865.34	2.29	0.48	18.47
1990	29.88	18.53	2264.23	2.37	0.58	15.93
1991	31.83	18.06	884.68	2.38	0.49	18.14
1992	32.03	17.73	797.82	2.31	0.46	19.28
1993	30.96	18.18	2115.25	2.33	0.53	18.46
1994	30.63	18.13	1408.38	2.30	0.54	17.02
1995	31.26	18.32	916.47	2.26	0.53	18.56
1996	31.24	18.31	1439.27	2.26	0.52	18.49
1997	30.24	18.23	1258.50	2.44	0.57	18.11
1998	31.03	18.78	1333.42	2.26	0.57	18.38
1999	31.97	18.58	861.85	2.41	0.51	19.18
2000	32.29	17.10	803.77	2.38	0.44	19.49
2001	32.24	17.48	687.60	2.27	0.47	19.40
2002	32.59	18.39	1305.34	2.46	0.46	19.03
2003	31.69	18.49	1335.46	2.31	0.53	19.05
2004	32.19	18.00	627.15	2.24	0.49	19.48
2005	31.37	17.72	1105.23	2.26	0.50	19.40
2006	31.91	18.52	784.92	2.22	0.50	18.41
2007	31.83	18.23	1352.94	2.19	0.50	18.86
2008	31.57	17.75	1263.68	2.24	0.51	18.83
2009	32.07	19.01	1397.10	2.26	0.51	18.77
2010	31.91	19.16	1395.65	2.16	0.54	19.40
2011	31.07	16.98	1508.09	2.04	0.54	19.00
2012	30.72	16.77	1628.33	2.09	0.53	18.76
2013	30.45	17.59	1574.18	2.01	0.57	18.58

Manot 226806

Year	Max Temperature	Min Temperature	Precipitation	Wind	Relative Humidity	Solar
1979	32.09	18.40	810.84	2.24	0.48	19.53
1980	31.17	18.54	1503.99	2.35	0.51	18.29
1981	30.69	18.06	812.89	2.30	0.53	19.15
1982	30.32	18.45	1272.28	2.20	0.57	18.00
1983	30.52	17.89	1183.58	2.32	0.52	19.40
1984	30.53	17.97	1008.20	2.41	0.51	18.70
1985	30.97	17.92	907.34	2.36	0.50	19.51
1986	30.66	18.11	1201.75	2.27	0.54	18.86
1987	31.61	18.20	646.39	2.24	0.49	18.85
1988	31.67	18.46	1407.19	2.26	0.50	19.11
1989	31.27	17.79	1625.21	2.31	0.49	19.29
1990	29.56	18.49	2000.44	2.37	0.59	16.13
1991	31.48	18.47	1289.02	2.39	0.50	18.42
1992	31.80	18.07	979.80	2.34	0.46	19.50
1993	30.93	18.42	1406.33	2.31	0.53	18.76
1994	30.46	18.16	1485.76	2.26	0.55	17.59
1995	30.93	18.43	953.68	2.24	0.54	18.71
1996	31.17	18.37	1102.70	2.30	0.51	19.08
1997	29.83	18.04	1519.60	2.36	0.57	18.34
1998	30.68	18.82	1442.39	2.26	0.58	18.85
1999	31.81	18.88	898.15	2.34	0.51	19.47
2000	32.05	17.26	945.41	2.33	0.44	19.59
2001	31.87	17.86	888.46	2.28	0.47	19.91
2002	32.33	18.42	986.85	2.41	0.45	19.50
2003	31.35	18.60	1469.85	2.31	0.54	19.41
2004	31.81	18.02	695.55	2.21	0.49	19.74
2005	31.29	18.14	1116.85	2.29	0.50	19.66
2006	31.84	18.45	682.51	2.24	0.50	18.57
2007	31.75	18.57	1087.97	2.32	0.50	19.41
2008	31.32	18.08	1347.19	2.23	0.52	19.15
2009	32.16	19.08	1291.33	2.25	0.50	19.48
2010	32.03	19.16	1034.20	2.18	0.53	19.80
2011	32.02	17.12	1606.19	1.79	0.54	19.69
2012	31.74	16.87	951.65	1.82	0.53	19.55
2013	31.75	17.64	688.04	1.81	0.55	19.49

Sandia 229781

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	34.91	19.67	547.43	2.13	0.43	18.91
1980	34.08	19.65	856.63	2.13	0.46	18.26
1981	32.96	19.24	759.85	2.09	0.50	18.43
1982	33.17	19.93	1140.69	2.18	0.52	17.95
1983	33.23	18.89	1063.80	2.07	0.48	19.23
1984	33.38	18.87	779.42	2.21	0.46	18.44
1985	34.08	19.14	750.81	2.11	0.47	19.05
1986	33.53	19.37	1016.47	2.22	0.49	18.26
1987	34.61	19.62	598.74	2.17	0.45	18.81
1988	34.14	19.70	1425.67	2.11	0.48	18.43
1989	34.04	18.62	1209.30	2.07	0.45	18.55
1990	32.48	19.68	2029.62	2.21	0.54	16.78
1991	34.51	19.49	760.18	2.20	0.45	18.47
1992	34.51	19.09	682.16	2.08	0.44	19.47
1993	33.58	19.37	1413.22	2.17	0.50	18.65
1994	33.09	19.30	1145.81	2.10	0.52	17.68
1995	34.00	19.69	610.86	2.12	0.48	18.76
1996	33.63	19.61	890.77	2.11	0.49	18.55
1997	32.54	19.47	980.91	2.23	0.54	18.31
1998	33.49	19.89	896.07	2.08	0.53	18.63
1999	34.66	19.87	569.91	2.12	0.47	19.02
2000	35.05	18.28	836.97	2.09	0.41	19.41
2001	35.03	18.91	583.72	2.02	0.44	19.37
2002	35.31	19.61	900.93	2.23	0.42	19.14
2003	34.18	19.66	1172.33	2.12	0.50	19.26
2004	34.89	19.34	617.14	2.03	0.45	19.27
2005	34.11	18.88	897.87	2.04	0.47	19.55
2006	34.43	19.67	597.12	2.02	0.48	18.34
2007	34.50	19.68	1173.64	2.00	0.47	19.00
2008	34.11	18.91	1310.67	2.03	0.48	18.95
2009	34.85	20.30	905.50	2.06	0.48	19.28
2010	34.47	20.20	902.25	2.02	0.50	19.93
2011	33.38	18.24	2272.30	1.83	0.52	18.63
2012	33.31	18.11	1754.90	1.95	0.49	17.99
2013	32.73	18.88	1679.65	1.88	0.54	17.94

Barmanghat 229794

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	33.61	18.98	755.65	2.14	0.45	19.20
1980	32.72	19.10	1206.39	2.23	0.49	18.61
1981	31.86	18.44	921.57	2.12	0.52	18.87
1982	31.70	19.12	1146.61	2.13	0.55	17.97
1983	31.69	17.94	1366.56	2.07	0.52	19.49
1984	31.86	18.18	796.88	2.25	0.49	18.65
1985	32.50	18.33	728.51	2.19	0.49	19.49
1986	32.02	18.66	1181.81	2.24	0.52	18.63
1987	33.12	18.93	586.57	2.16	0.47	18.86
1988	33.01	18.91	1355.39	2.14	0.49	18.90
1989	32.68	17.95	1403.02	2.14	0.46	19.03
1990	31.12	18.96	1923.53	2.25	0.56	16.69
1991	32.97	18.41	792.45	2.22	0.48	18.62
1992	33.16	18.26	774.91	2.15	0.46	19.67
1993	32.15	18.63	1656.28	2.16	0.53	18.81
1994	31.78	18.49	1392.98	2.14	0.54	17.81
1995	32.46	18.91	791.16	2.12	0.51	18.99
1996	32.33	18.68	1031.07	2.11	0.51	18.84
1997	31.24	18.69	1035.30	2.28	0.56	18.28
1998	32.23	19.30	1044.07	2.15	0.56	18.95
1999	33.20	19.27	814.73	2.24	0.50	19.53
2000	33.46	17.63	710.79	2.22	0.43	19.77
2001	33.37	17.86	640.98	2.10	0.47	19.81
2002	33.79	18.89	954.26	2.31	0.45	19.42
2003	32.79	18.87	1085.09	2.14	0.52	19.29
2004	33.35	18.51	533.46	2.08	0.48	19.72
2005	32.49	18.11	956.86	2.08	0.50	19.80
2006	33.20	18.98	669.30	2.06	0.49	18.83
2007	32.98	18.68	1104.05	2.04	0.49	19.10
2008	32.63	18.13	1266.67	2.09	0.51	19.11
2009	33.30	19.52	1144.81	2.10	0.50	19.39
2010	33.10	19.69	1086.74	2.03	0.52	19.75
2011	32.89	17.87	1298.76	1.95	0.52	19.60
2012	32.62	17.70	1291.11	2.03	0.50	19.17
2013	32.38	18.46	1073.60	1.97	0.55	19.52

Patan 229800

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	33.20	18.72	714.85	2.04	0.46	19.39
1980	32.26	18.88	1304.83	2.13	0.50	18.55
1981	31.53	18.27	924.39	2.07	0.52	19.29
1982	31.23	18.97	1175.60	2.04	0.56	18.03
1983	31.26	17.91	1389.05	2.04	0.52	19.38
1984	31.48	17.97	853.48	2.16	0.50	18.81
1985	31.89	18.10	754.64	2.10	0.50	19.63
1986	31.59	18.47	1165.92	2.11	0.53	18.76
1987	32.65	18.75	612.29	2.06	0.47	18.88
1988	32.57	18.79	1416.99	2.07	0.50	19.13
1989	32.35	17.90	1383.97	2.08	0.47	19.38
1990	30.60	18.77	2082.26	2.19	0.57	16.52
1991	32.57	18.41	1125.57	2.15	0.49	18.63
1992	32.71	18.13	833.41	2.08	0.46	19.70
1993	31.78	18.56	1509.53	2.08	0.53	19.02
1994	31.38	18.43	1382.69	2.08	0.54	17.96
1995	31.99	18.77	880.77	2.06	0.52	18.90
1996	31.97	18.56	1075.11	2.08	0.51	19.00
1997	30.67	18.54	1257.18	2.17	0.56	18.21
1998	31.60	19.12	1263.07	2.08	0.57	18.94
1999	32.81	19.01	922.40	2.10	0.50	19.63
2000	33.10	17.39	756.39	2.10	0.43	19.90
2001	32.79	17.75	847.98	2.00	0.47	19.96
2002	33.33	18.72	953.66	2.20	0.45	19.49
2003	32.26	18.82	1274.46	2.08	0.53	19.51
2004	32.92	18.31	578.33	1.99	0.48	19.83
2005	32.12	18.02	1019.55	2.02	0.50	19.92
2006	32.82	18.78	741.03	2.02	0.49	18.84
2007	32.59	18.64	1111.76	2.04	0.49	19.27
2008	32.19	18.09	1392.18	2.01	0.51	19.28
2009	32.92	19.18	1176.64	2.00	0.50	19.54
2010	32.86	19.42	1105.13	1.95	0.52	19.83
2011	32.22	17.58	2274.90	1.87	0.53	18.83
2012	31.87	17.46	1638.14	1.95	0.51	18.69
2013	31.64	18.16	1248.93	1.92	0.55	18.63

Dindori 229809

Year	Max Temp.	Min Temp.	Precipitation	Wind	Relative Humidity	Solar
1979	31.15	17.05	995.00	2.24	0.50	19.23
1980	30.44	16.91	1645.36	2.35	0.52	17.78
1981	29.86	16.47	942.83	2.33	0.54	18.72
1982	29.42	17.35	1537.00	2.18	0.57	17.48
1983	29.66	16.11	1443.20	2.27	0.54	18.89
1984	29.69	16.13	1235.68	2.42	0.53	18.40
1985	30.25	16.23	1099.17	2.36	0.52	19.30
1986	29.87	16.60	1427.13	2.30	0.55	18.46
1987	30.62	16.79	836.71	2.25	0.50	18.39
1988	30.96	17.00	1528.39	2.29	0.52	18.73
1989	30.41	15.94	1956.18	2.34	0.51	19.07
1990	28.83	17.37	2424.90	2.41	0.60	15.79
1991	30.71	16.59	1560.54	2.40	0.53	18.06
1992	30.99	16.06	1113.41	2.31	0.50	18.99
1993	30.26	16.69	1751.41	2.32	0.55	18.55
1994	29.83	16.56	1822.14	2.25	0.57	17.21
1995	29.99	17.27	1211.11	2.26	0.55	18.20
1996	30.31	16.74	1396.38	2.27	0.54	18.64
1997	28.91	16.62	1895.70	2.38	0.59	17.56
1998	29.83	17.74	1706.22	2.28	0.59	18.47
1999	31.08	17.24	1076.36	2.33	0.53	19.13
2000	31.21	15.52	1298.89	2.35	0.48	19.24
2001	31.05	16.08	1167.07	2.29	0.50	19.57
2002	31.50	16.69	1217.76	2.41	0.48	19.28
2003	30.58	17.15	1950.42	2.32	0.55	19.00
2004	31.03	16.67	852.05	2.21	0.51	19.30
2005	30.63	16.43	1221.23	2.28	0.52	19.32
2006	31.03	17.11	822.98	2.26	0.52	18.13
2007	30.97	17.05	1375.60	2.33	0.52	18.82
2008	30.65	16.34	1662.01	2.24	0.54	18.81
2009	31.36	17.48	1610.53	2.24	0.52	19.26
2010	31.35	17.75	1392.37	2.16	0.54	19.45
2011	30.46	16.56	1887.41	1.96	0.55	19.01
2012	30.23	16.18	1265.54	1.99	0.54	19.11
2013	30.20	16.79	969.46	1.95	0.57	18.86

Appendix-B

Gauge Discharge and Gauge level information of Upper Narmada basin selected station during 1989-2012

Hoshangabad 226778

Year	Discharge (m^3/sec)	Gauge (m)
1989	378.86	2.77
1990	994.67	3.57
1991	717.24	3.35
1992	523.05	3.06
1993	648.69	3.33
1994	1690.85	4.03
1995	580.22	3.20
1996	364.06	2.95
1997	675.04	3.29
1998	595.39	3.38
1999	1400.35	3.87
2000	384.17	2.97
2001	505.07	3.04
2002	542.93	3.03
2003	938.14	3.53
2004	515.26	3.14
2005	937.27	3.50
2006	654.94	3.23
2007	411.46	2.96
2008	376.22	2.90
2009	465.48	2.92
2010	383.99	3.00
2011	799.86	3.45
2012	188.83	2.66

Gadarwara 226791

Year	Discharge (m^3/sec)	Gauge (m)
1989	34.78	2.14
1990	69.49	2.41
1991	23.63	2.16
1992	36.22	2.21
1993	44.28	2.29
1994	97.06	2.54
1995	29.33	2.22
1996	21.89	2.03
1997	42.06	2.19
1998	27.96	2.29
1999	116.58	2.41
2000	23.58	2.15
2001	19.15	1.99
2002	38.67	2.06
2003	50.77	2.34
2004	21.12	2.10
2005	44.52	2.36
2006	73.78	2.41
2007	52.36	2.38
2008	26.72	2.19
2009	115.98	2.47
2010	47.73	2.24
2011	54.91	2.26
2012	0.95	1.91

Manot 226806

Year	Discharge (m^3/sec)	Gauge (m)
1989	44.94	1.47
1990	136.40	1.87
1991	104.70	1.71
1992	81.22	1.64
1993	90.04	1.71
1994	174.48	2.11
1995	107.56	1.80
1996	73.62	1.75
1997	104.62	1.81
1998	90.19	1.90
1999	130.72	1.87
2000	64.97	1.64
2001	118.18	1.82
2002	63.70	1.57
2003	140.71	1.89
2004	108.50	1.80
2005	156.65	1.88
2006	91.74	1.66
2007	45.74	1.56
2008	70.26	1.61
2009	38.73	1.42
2010	64.30	1.46
2011	121.15	1.86
2012	6.85	1.18

Sandia 229781

Year	Discharge (m^3/sec)	Gauge (m)
1989	228.61	2.99
1990	716.65	3.96
1991	549.92	3.64
1992	409.64	3.28
1993	445.51	3.53
1994	1196.53	4.44
1995	506.21	3.62
1996	275.27	3.21
1997	488.40	3.58
1998	466.11	3.58
1999	1013.51	4.07
2000	315.48	3.30
2001	425.48	3.56
2002	376.74	3.39
2003	690.68	3.81
2004	436.65	3.50
2005	761.41	4.02
2006	455.99	3.62
2007	308.71	3.51
2008	302.01	3.49
2009	382.10	3.34
2010	280.31	3.27
2011	687.12	4.59
2012	165.53	2.76

Barmanghat 229794

Year	Discharge (m^3/sec)	Gauge (m)
1989	133.10	11.53
1990	556.39	3.92
1991	462.27	3.63
1992	299.44	3.08
1993	316.06	2.56
1994	925.79	86.80
1995	398.38	3.50
1996	224.28	3.12
1997	357.27	3.48
1998	358.58	3.61
1999	728.23	3.88
2000	264.41	3.02
2001	380.80	3.34
2002	280.31	3.02
2003	542.72	3.83
2004	374.71	3.34
2005	641.69	3.93
2006	317.28	3.27
2007	204.83	2.83
2008	260.57	2.97
2009	196.21	2.50
2010	246.09	3.00
2011	550.17	3.85
2012	146.85	2.59

Patan 229800

Year	Discharge (m^3/sec)	Gauge (m)
1989	15.94	1.31
1990	98.46	2.28
1991	58.57	1.78
1992	57.84	1.67
1993	45.62	1.71
1994	112.72	2.14
1995	49.29	1.59
1996	19.60	1.30
1997	60.95	1.72
1998	27.55	1.64
1999	93.97	1.92
2000	27.47	1.16
2001	46.24	1.43
2002	53.69	1.51
2003	92.92	2.03
2004	35.45	1.45
2005	97.45	2.13
2006	21.09	1.55
2007	19.74	1.02
2008	56.40	1.30
2009	26.42	0.85
2010	56.20	1.23
2011	90.86	1.60
2012	3.67	0.45

Dindori 229809

Year	Discharge (m^3/sec)	Gauge (m)
1989	24.84	2.80
1990	50.69	2.95
1991	39.87	2.84
1992	35.94	2.82
1993	39.43	2.87
1994	86.40	3.03
1995	42.00	2.87
1996	41.27	2.88
1997	39.71	2.92
1998	42.59	2.95
1999	49.89	2.93
2000	23.46	2.81
2001	46.50	2.88
2002	27.43	2.79
2003	69.96	2.97
2004	44.25	2.88
2005	55.20	2.93
2006	40.21	2.85
2007	20.89	2.79
2008	26.38	3.09
2009	22.24	267.22
2010	36.87	276.31
2011	57.11	3.50
2012	6.50	3.23

Appendix-C

C-1:Weather Generator parameters (WGEN) used by the SWAT model

OBJECTID	STATION	WLATITUDE	WLONGITUDE	WELEV	RAIN_YRS
1					
2					
3					
4					
5					
6					
7					

Where

OBJECT ID : One to N number of station

STATAION : Station Name

WLATITUDE: Latitude in decimal degree

WLONGITUDE: Longitude in decimal degree

WELEV : Elevation in meter

RAIN_YRS : Total no. of year

TMPMX1	TMPMX2	TMPMX3	TMPMX4	TMPMX5	TMPMX6	TMPMX7	TMPMX8	TMPMX9	TMPMX10	TMPMX11	TMPMX12
TMPMN1	TMPMN2	TMPMN3	TMPMN4	TMPMN5	TMPMN6	TMPMN7	TMPMN8	TMPMN9	TMPMN10	TMPMN11	TMPMN12

TMPSTD MX1	TMPSTD MX2	TMPSTD MX3	TMPSTD MX4	TMPSTD MX5	TMPSTD MX6	TMPSTD MX7	TMPSTD MX8	TMPSTD MX9	TMPSTD MX10	TMPSTD MX11	TMPSTD MX12

TMPSTD MN1	TMPSTD MN2	TMPSTD MN3	TMPSTD MN4	TMPSTD MN5	TMPSTD MN6	TMPSTD MN7	TMPSTD MN8	TMPSTD MN9	TMPSTD MN10	TMPSTD MN11	TMPSTD MN12

PCPMM1	PCPMM2	PCPMM3	PCPMM4	PCPMM5	PCPMM6	PCPMM7	PCPMM8	PCPMM9	PCPMM10	PCPMM11	PCPMM12

PCPSTD 1	PCPSTD 2	PCPSTD 3	PCPSTD 4	PCPSTD 5	PCPSTD 6	PCPSTD 7	PCPSTD 8	PCPSTD 9	PCPSTD 10	PCPSTD 11	PCPSTD 12

PCPSKW 1	PCPSKW 2	PCPSKW 3	PCPSKW 4	PCPSKW 5	PCPSKW 6	PCPSKW 7	PCPSKW 8	PCPSKW 9	PCPSKW 10	PCPSKW 11	PCPSKW 12

PR_W1_1	PR_W1_2	PR_W1_3	PR_W1_4	PR_W1_5	PR_W1_6	PR_W1_7	PR_W1_8	PR_W1_9	PR_W1_10	PR_W1_11	PR_W1_12

PR_W2_1	PR_W2_2	PR_W2_3	PR_W2_4	PR_W2_5	PR_W2_6	PR_W2_7	PR_W2_8	PR_W2_9	PR_W2_1 0	PR_W2_1 1	PR_W2_1 2

PCPD1	PCPD2	PCPD3	PCPD4	PCPD5	PCPD6	PCPD7	PCPD8	PCPD9	PCPD10	PCPD11	PCPD12

RAINHHM X1	RAINHHM X2	RAINHHM X3	RAINHHM X4	RAINHHM X5	RAINHHM X6	RAINHHM X7	RAINHHM X8	RAINHHM X9	RAINHHM X10	RAINHHM X11	RAINHHM X12

SOLARAV 1	SOLARAV 2	SOLARAV 3	SOLARAV 4	SOLARAV 5	SOLARAV 6	SOLARAV 7	SOLARAV 8	SOLARAV 9	SOLARAV 10	SOLARAV 11	SOLARAV 12

DEWPT1	DEWPT2	DEWPT3	DEWPT4	DEWPT5	DEWPT6	DEWPT7	DEWPT8	DEWPT9	DEWPT10	DEWPT11	DEWPT12

WNDAV1	WNDAV2	WNDAV3	WNDAV4	WNDAV5	WNDAV6	WNDAV7	WNDAV8	WNDAV9	WNDAV10	WNDAV11	WNDAV12

C-2: Description and Symbols of Weather Generator parameters (WGEN) used by the SWAT model

S. No	Symbol	Description
1	TMPMX	Average or mean daily maximum air temperature for month (° C).
2	TMPMN	Average or mean daily minimum air temperature for month (°C).
3	TMPSTDMX	Standard deviation for daily maximum air temperature for month (°C).
4	TMPSTDMN	Standard deviation for daily minimum air temperature for month (°C).
5	PCPMM	Average or mean total monthly precipitation (mm H2O).
6	PCPSTD	Standard deviation for daily precipitation for month (mm H_2O/day).
7	PCPSKW	Skew coefficient for daily precipitation in month.
8	PR_W1	Probability of a wet day following a dry day in the month.
9	PR_W2	Probability of a wet day following a wet day in the month.
10	PCPD	Average number of days of precipitation in month.
11	SOLARAV	Average daily solar radiation for month (MJ/m2/day).
12	DEWPT	Average daily dew point temperature in month (°C).
13	WNDAV	Average daily wind speed in month (m/s).

Appendix-D

Hydrological Soil group (HSG's)

Soils are classified into hydrologic soil groups (HSGs) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSGs are A, B, C and D. The four groups are defined by Soil Conservation Service (SCS) soil scientists as follows:

Group A -Soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 0.30 in/hr).

Group B -Soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C -Soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D -Soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

(Source: Das G, 2000)