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Effects of Urbanization on Land Use/Land Cover and Stream Flow of a Sub-Tropical River Basin of India

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***Abstract*—**Rapid urbanization changes the land use/land cover pattern of a developing region. Due to these land surface changes, stream flow of the rivers also changes. It is important to investigate the factors affecting hydrological characteristics of the river basin for better river basin management planning. This study is aimed to understand the effect of Land Use/Land Cover (LU/LC) changes on stream flow of Upper Bhima River basin which is highly stressed in terms of water resources. In this study, Upper Bhima River basin is divided into two adjacent sub-watersheds: Mula-Mutha (urbanized) sub-watershed and Bhima (non-urbanized) sub-watershed. First of all, LU/LC changes were estimated over 1980, 2002, and 2009 for both Mula-Mutha and Bhima sub-watersheds. Further, stream flow simulations were done using Soil and Water Assessment Tool (SWAT) for the streams draining both watersheds. Results revealed that stream flow was relatively higher for urbanized sub-watershed. Through Sensitivity Analysis it was observed that out of all the parameters used, base flow was the most sensitive parameter towards LU/LC changes.

***Keywords*—**Land Use/Land Cover, remote sensing, stream flow, urbanization.

I. Introduction

THE urbanization changes LU/LC of a developing river basin. These changes affect the stream flow of the rivers. The present work is an attempt to understand the effects of urbanization and LU/LC changes on stream flow of a sub-tropical river basin of India. Due to urbanization, the natural and pervious ground surfaces change to impervious ground surfaces. During heavy rainfall, large volumes of runoff are generated. All these water flows directly into the nearby streams. Hence, the flow property of the rivers gets altered. Due to increasing impervious surface cover, the infiltration of rain water into the ground also reduces. Therefore, base flows are affected and groundwater in the area declines. Generally, increased stream flow is observed in urban watersheds than in non-urban watersheds [2]. The watershed simulation models are often used for water resources planning and management studies. These models help to understand the behavior of the changing river basin due to urbanization. There are various hydrological models available to study watershed related changes. Semi-distributed model viz. SWAT describes the physical interaction between the different components of the river basin through mathematical equations [1]. In the present work, SWAT model is coupled with ArcGIS software to study the effects of LU/LC changes on stream flow.

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LU/LC distribution map is a basic input used in hydrological models to simulate the effects of LU/LC changes on stream flow. Remote sensing and Geographical Information System (GIS) help to prepare better LU/LC maps. Nowadays, a wide range of satellite datasets are available to study the effect of LU/LC changes on stream flow e.g. Advanced Very High Resolution Radiometer (AVHRR), Landsat Multispectral Scanner/Thematic Mapper (MSS/TM), Enhanced Thematic Mapper (ETM+) [3], [7] and Indian Remote Sensing Linear Imaging Self-Scanning (IRS LISS-III) data [5]. Remote sensing and GIS tools are effective in monitoring and analyzing the LU/LC changes for developmental activities in the study area. Increasing population and urbanization, increase the water demand in the region for domestic, agricultural and industrial activities. Over-exploitation of water resources causes the imbalance in the water budget of the river basins. Based on the background work, the objectives of this study include: (1) Assessment of the urbanization induced LU/LC changes in Upper Bhima river basin and (2) evaluation of the effects of urbanization on the stream flow.

II. Study Area

Fig. 1 shows Upper Bhima river basin which lies in Maharashtra state of India. This study area has a total catchment of 6145.49 km^2. It has latitudinal extent of 18^0 19' to 19^0 15' and longitudinal extent of 73^0 20' to 74^0 26'. Bhima River is a major tributary of the Krishna River. It originates from Western Ghats and flows from west towards east. Upper Bhima River basin is suffering from chronic water shortage due to increased water demands for domestic, industrial and agricultural purposes [4]. The maximum elevation of about 1307 m is observed in Western Ghat mountains region. Minimum elevation of about 451 m is observed in the eastern part of the basin which is comparatively flat. The mean annual rainfall of the basin is 741 mm, with an uneven distribution in space and time [6]. Upper Bhima River basin consists of mainly basalts and black soils.

To study the effects of urbanization on LU/LC and stream flow, the Upper Bhima river basin has been divided into two adjacent sub-watersheds: (1) Mula-Mutha sub-watershed (urbanized) (2) Bhima sub-watershed (non-urbanized). Urbanized Mula-Mutha sub-watershed covers an area of 2988.47 km^2 whereas the non-urbanized Bhima sub-watershed covers an area of 3157.02 km^2. Out of the total area of the urbanized Mula-Mutha sub-watershed about 17.29% of its area is having built up lands by the year 2009. On the other hand, out of the total area of the non-urbanized Bhima sub-watershed about 9.12% of its area is having built up lands. Mega city Pune lies in Mula-Mutha sub-watershed. Pimpri-Chinchwad, a rapidly spreading industrial zone is also situated north-west to the Pune city.

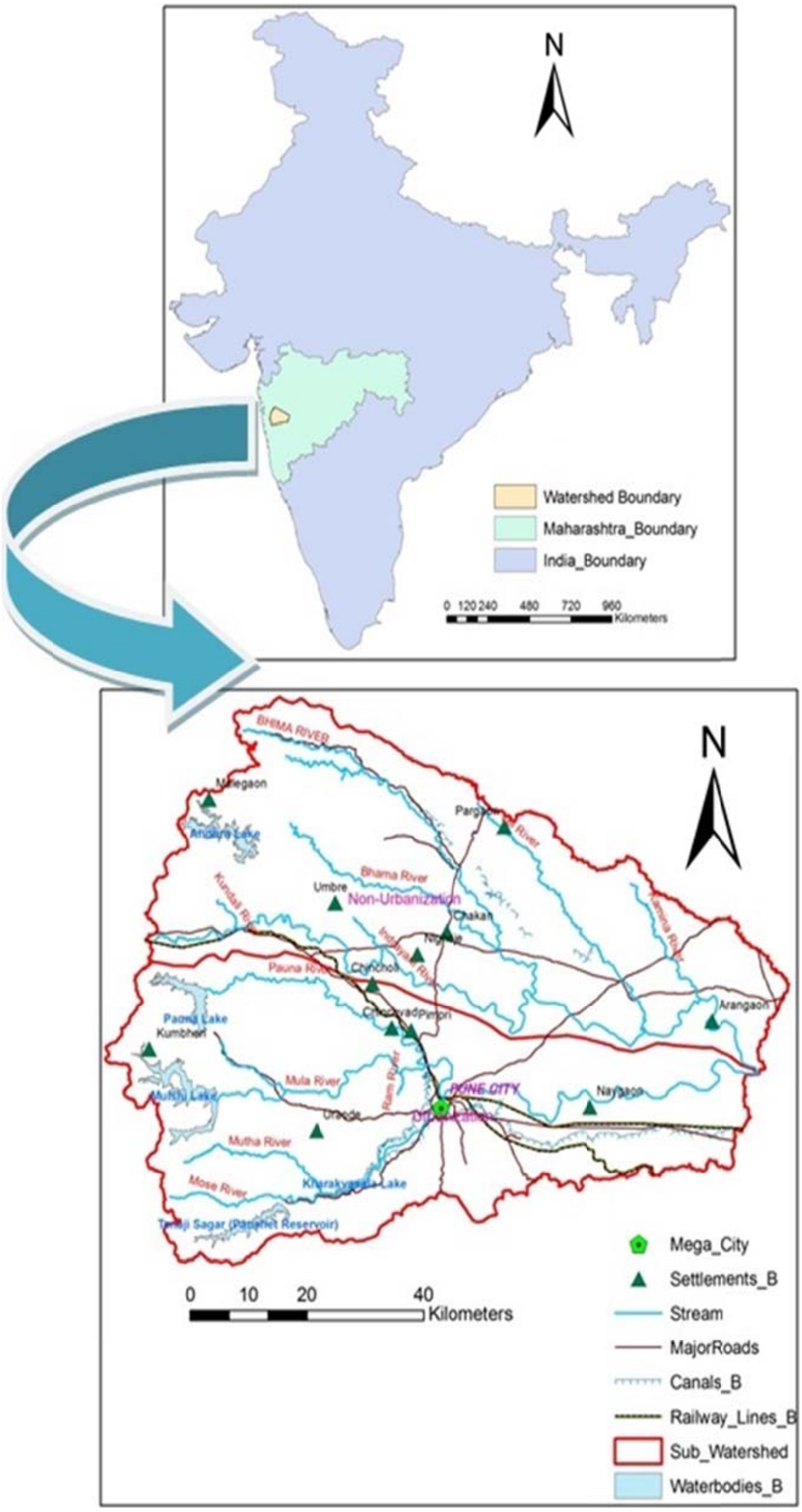


Fig. 1 Location map of Upper Bhima River basin and its sub-watersheds

III. Materials and Methods

A. Data Used

Survey of India (SOI) topographical maps of scale 1:50000 were used to prepare base map of the study area. Satellite datasets viz. time series IRS LISS III satellite data and Advanced Space borne Thermal Emission and Reflectance Radiometer (ASTER) Digital Elevation Model (DEM) were downloaded from United States Geological Survey (USGS) Earth Explorer, National Remote Sensing Centre (NRSC) Bhuvan and Japanese Global DEM websites respectively. Other ancillary datasets required for the study were: Pune census data from census of India, soil map from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur, Maharashtra, India and daily hydro-metrological data such as rainfall, runoff/discharge, evapotranspiration, solar radiation, wind speed, relative humidity and temperature from Hydrology Project Office, Ministry of Water Resources, Government of Maharashtra, Nasik, Maharashtra, India.

First of all, census data of Pune city was analyzed to understand the population growth in Pune city. A base map was prepared for Upper Bhima river basin using the SOI toposheets of 1:50000 scale. The ASTER DEM data was processed on ArcGIS 10.1 to delineate the stream network and Upper Bhima River basin boundary, which is shown in Fig. 3 (a). Based on the topography and the stream network, the Upper Bhima River basin was further divided into two adjacent sub-watersheds: Mula-Mutha sub-watershed (urbanized) and Bhima sub-watershed (non-urbanized). A GIS database was prepared consisting of the base map, DEM, soil map and all the hydro-metrological datasets collected for 1998-2009. The changes in the watershed were updated in the database using the satellite image IRS LISS III of 2009. Ground truthing was done with the help of data collected from field visit, satellite images, toposheets, GPS and Google Earth images. The major LU/LC classes identified were forests, built-up lands, wastelands, agricultural lands and waterbodies.

B. Methodology

All the time-series satellite datasets of 1980 (Landsat Multi Spectral Scanner), 2002 (Landsat Enhanced Thematic Mapper+) and 2009 (IRS LISS-III) were classified into five major classes viz. forests, built-up lands, wastelands, agricultural lands and Waterbodies. Maximum Likelihood Classifier (MLC) algorithm of supervised classification was used for the classification and 87% accuracy was obtained. In this way, LU/LC maps were prepared for 1980, 2002, 2009 shown in Figs. 3 (d), (e) and (f) respectively. Post-classification LU/LC change detection study was done for both urbanized and non-urbanized sub-watersheds. Further, SWAT 5 model was coupled with ArcGIS 10.1 for spatial analysis and simulations. Major model components included in the study were: LU/LC distribution maps, weather data, hydrological characteristics of the study areas and their soil properties. First of all, SWAT model set up was done. Then entire watershed was divided into multiple Hydrological Response Units (HRUs) which consists of homogeneous LU/LC and soil characteristics. The following weather data were defined in the model for various stations across the sub-watersheds: rainfall, runoff/discharge, evapotranspiration, solar radiation, wind speed, relative humidity and temperature. A total of 10 rainfall stations, 5 temperature, wind speed and relative humidity stations, 2 runoff stations were selected.

The model calibration and validation was done with the data of these stations. Fig. 3 (b) shows slope map having five classes which was generated in SWAT. Based on the soil properties of the basin, a soil map was generated having four major soil classes viz. deep black soil, red sandy soil, shallow black soil and medium black soil. Fig. 3 (c) shows the soil map used in the present study. LU/LC data of all the three years i.e. 1980, 2002 and 2009 were provided as input one after another to simulate the effects of LU/LC changes on stream flow for both the sub-watersheds. The outputs of the model were stream flow changes at Khamgaon station in urbanized sub-watershed and Rakshewadi station in non-urbanized sub-watershed. Further model sensitivity analysis was performed using a SWAT model plug-in viz. Sequential Uncertainty Fitting 2 (SUFI2) SWAT CUP.

IV. Results And Discussion

A. Population Dynamics

The population growth rate was estimated for the Pune district, Maharashtra, India for the years 1981, 1991, 2001 and 2011. The % change from one period to another was calculated using:

$$PGR = \frac{(P_{Present} - P_{Past})}{P_{Past}} \times 100 \quad (1)$$

where: *PGR* is the population growth rate; *Ppresent* is the present population; and *Ppast* is the past population.

From the results it was observed that the population of Pune city increased rapidly from 4.164 million in 1981 to 9.426 million in 2011, which is shown in Table I. Fig. 2 illustrates that the population growth rate of Pune city increased from 31.03% to 32.87% in between 1981 and 1991 and later it slightly decreased from 30.7% to 30.34% in between 2001 and 2011. Therefore, Upper Bhima River basin is a rapidly urbanizing river basin.

TABLE I
POPULATION GROWTH OF PUNE CITY FROM 1981-2011

Year	Population of Pune City			
	1981	1991	2001	2011
Population Growth Rate (%)	31.03	32.87	30.7	30.34
Population (Millions)	4.164	5.533	7.232	9.426

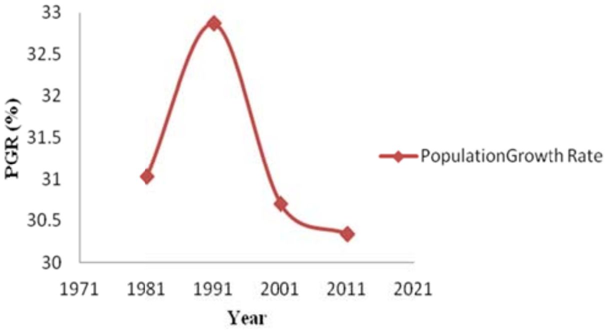


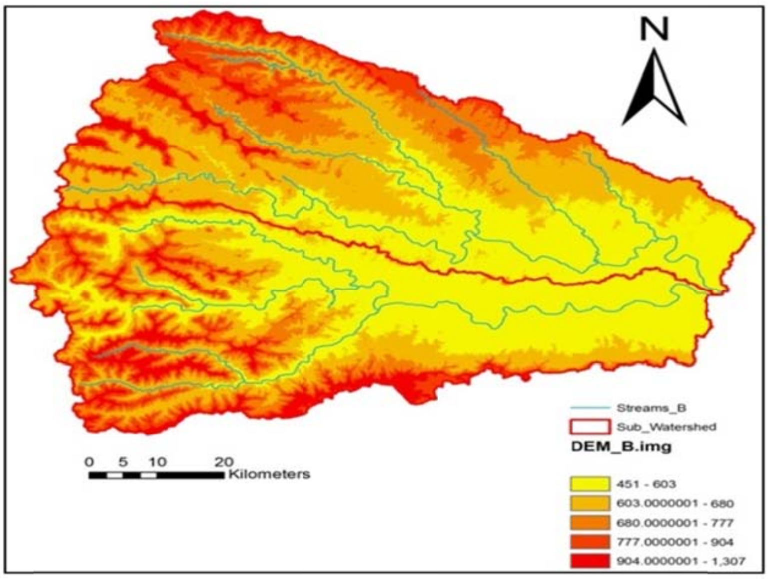
Fig. 2 Population growth rate in Pune city from 1980 to 2011

B. LU/LC Changes in Urbanized Mula-Mutha Sub-Watershed

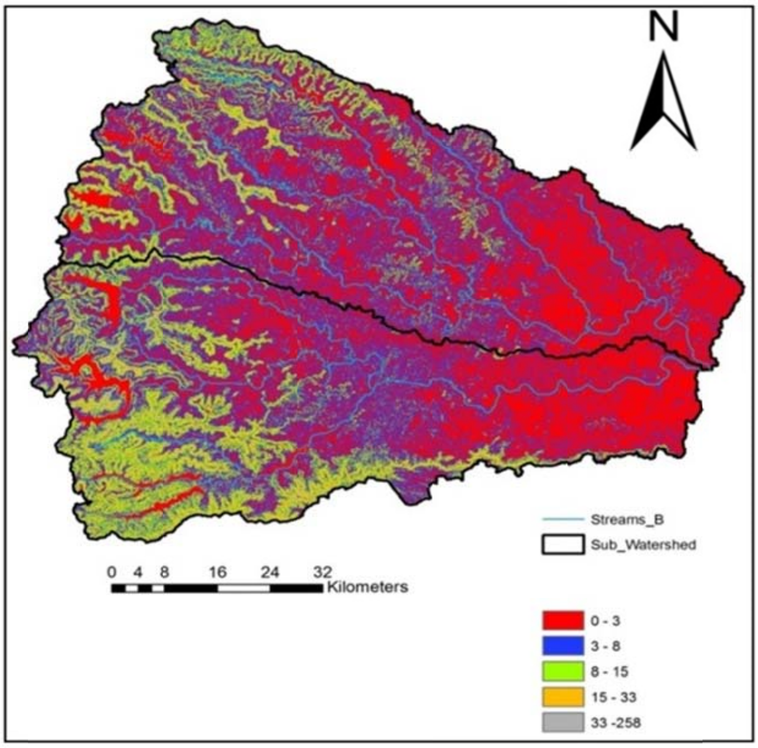
First, the LU/LC change study was done for urbanized Mula-Mutha sub-watershed. This sub-watershed has mega city Pune and Pimpri-Chinchwad industrial zone which is growing constantly. As it is a rapidly urbanizing sub-watershed, built-up lands increased from 3.31% in 1980 to 17.29% in 2009. Waterbodies also increased from 2.65% in 1980 to 4.03% in 2009. This indicates that the water resources development in this watershed is closely associated with the increasing urbanization. The waterbodies increased to meet the water requirements of increasing population for irrigation, industrial and domestic purposes in this sub-watershed. Newly constructed reservoirs in the sub-watershed increased the irrigation therefore agricultural lands also increased. Agricultural lands increased from 11.84% in 1980 to 40.04% in 2009. Agricultural lands increased to meet the increasing food demands of the population residing in Mula-Mutha sub-watershed. From Fig. 4, it can be observed that increase in built-up lands, waterbodies and agricultural lands in urbanized Mula-Mutha sub-watershed occurred on the expense of forests and waste lands. Therefore, forests decreased from 21.18% in 1980 to 10.38% in 2009 and waste lands also decreased from 61.26% in 1980 to 29.11% in 2009. The increase in built up lands, waterbodies and agricultural lands also occurred due to wasteland developments and encroachments of the forest lands in the sub-watershed.

C. LU/LC Changes in Non-Urbanized Bhima Sub-Watershed

LU/LC change study was done for non-urbanized Bhima sub-watershed. This part of the basin is mainly dominated by agricultural lands and waste lands but small towns and waterbodies are also present. In this sub-watershed, built-up lands increased from 2.45% in 1980 to 9.12% in 2009. The increase in built-up lands occurred due to the increase of population in the small towns and sprawl of the mega city Pune towards this sub-watershed. Waterbodies also increased from 1.14% in 1980 to 2.60% in 2009. Waterbodies also increased due to the newly constructed reservoirs in the river basin to fulfil the agricultural and domestic water demands of the increasing population in this sub-watershed. Agricultural lands increased from 2.35% in 1980 to 31.65% in 2009. A number of reservoirs were constructed to meet the irrigation demands of the agricultural lands.



(a)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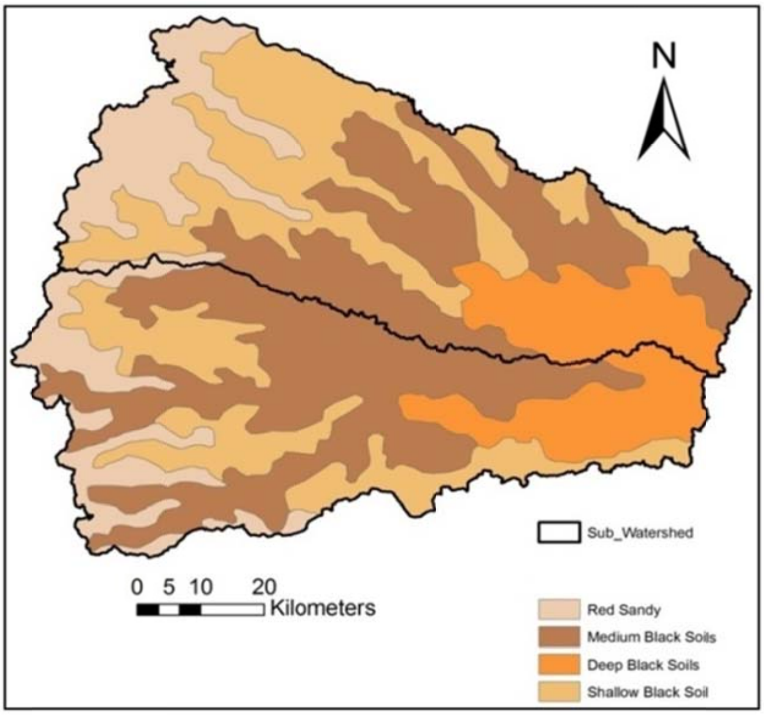
(b)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Red Sandy
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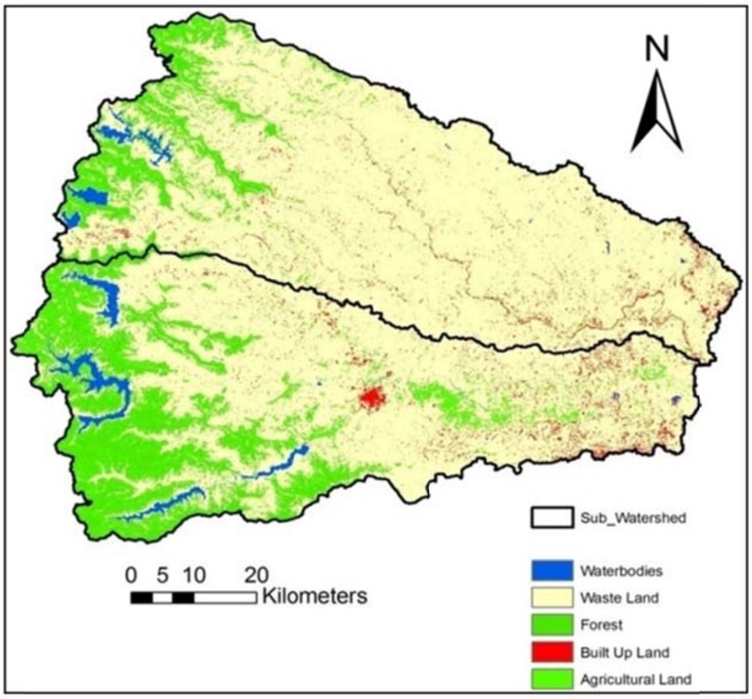
Deep Black Soils
Shallow Black Soil

(c)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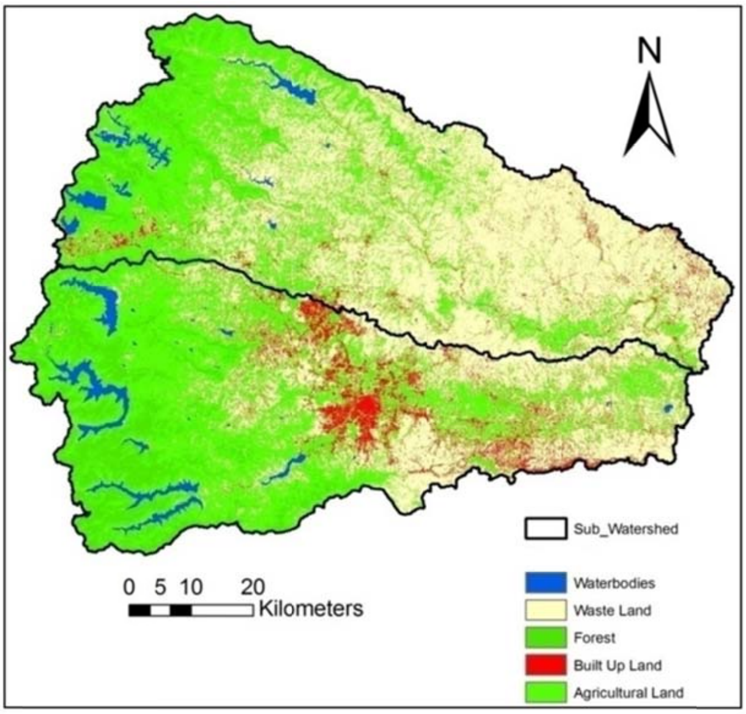
Kilometers
Waterbodies
Waste Land
Forest
Built Up Land
Agricultural Land

(d)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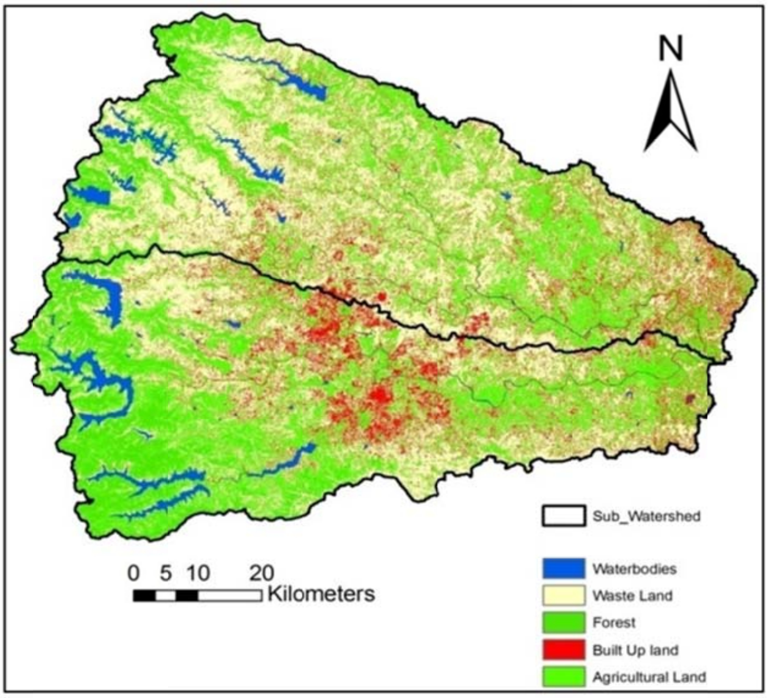
(e)



(f)

Fig. 3 Spatial maps of Upper Bhima river basin showing (a) DEM of study area with extracted stream network, (b) Classified slope map in SWAT, (c) Soil types observed in study area, (d) LU/LC map of 1980, (e) LU/LC map of 2002, (f) LU/LC map of 2009

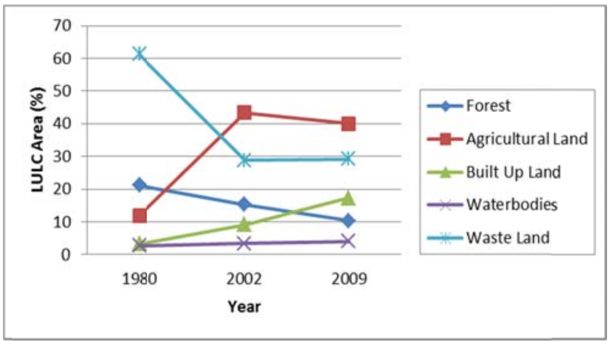


Fig. 4 Land use land cover changes in 1980, 2002 and 2009 for urbanized Mula-Mutha sub-watershed

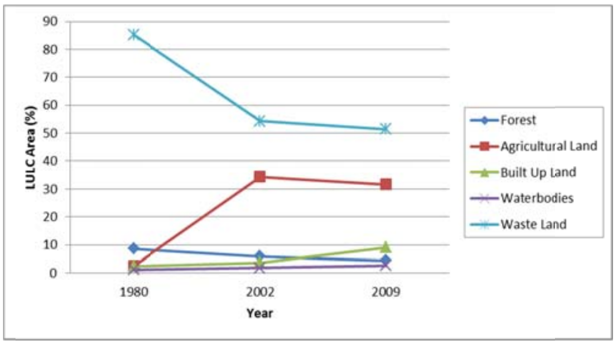


Fig. 5 Land use land cover changes in 1980, 2002 and 2009 for non-urbanized Bhima sub-watershed

From Fig. 5 it can be observed that the increase in built-up lands, waterbodies and agricultural lands in the non-urbanized Bhima sub-watershed occurred on the expense of wastelands and forest lands. Therefore, forests decreased from 8.56% in 1980 to 4.38% in 2009 and wastelands also decreased from 85.24% in 1980 to 51.40% in 2009. It is observed from the study that both the watersheds are changing. But the change is more rapid in urbanized Mula-Mutha sub-watershed than in non-urbanized Bhima sub-watershed. In urbanized Mula-Mutha sub-watershed, the forest lands and wastelands decreased to about 10.79% and 32.14% respectively. On the other hand, in non-urbanized Bhima sub-watershed the forest lands and wastelands decreased to 4.18% and 33.83% respectively. The built-up lands, agricultural lands and waterbodies increased to 13.98%, 28.19% and 1.37% in urbanized Mula-Mutha sub-watershed. On the other hand, the built-up lands, agricultural lands and waterbodies increased to 6.67%, 29.29% and 1.46% in non-urbanized Bhima sub-watershed respectively. This concludes that LU/LC changes occur not only due to urbanization but also due to related infrastructure developmental activities.

D.Effects of LU/LC Changes on Stream Flow

To study the impact of LU/LC changes on two different sub-watersheds, two different discharge stations were selected in each of the two sub-watersheds. The discharge station in the urbanized sub-watershed was selected on the Mula-Mutha river just before its confluence with the Bhima river. This discharge monitoring station is located near Khamgaon village. The discharge station in the non-urbanized sub-watershed was selected on the Bhima River just before its confluence with the Bhima River. This discharge monitoring station is located near Rakshewadi village. From the results, it was observed that the population increased from 4.164 million in 1981 to 9.426 million in 2011. Therefore, due to urbanization LU/LC changes took place in both the sub-watersheds of Upper Bhima river basin. In urbanized Mula-Mutha sub-watershed, the built-up lands increased from 3.31% to 17.29% between 1980 and 2009. As a result, the average stream flow increased from 179.14 m^3/s to 185.23 m^3/s. In non-urbanized Bhima sub-watershed, the built-up lands increased from 2.45% to 9.12% between the years 1980 to 2009. As a result, the average stream flow increased from 128.40 m^3/s to 129.83 m^3/s.

TABLE II
CHANGES IN THE AVERAGE STREAM FLOW OF URBANIZED AND NON-URBANIZED SUB-WATERSHEDS OF UPPER BHIMA RIVER BASIN

Station	Stream Flow (m^3/s)		
	1980	2002	2009
Khamgaon (Urbanized)	179.14	181.32	185.23
Rakshewadi (Non-Urbanized)	128.40	128.32	129.83

From Table II, it can be noticed that with increase in built-up lands the average stream flow increased in both the sub-watersheds. But, comparatively the increase was higher in urbanized Mula-Mutha sub-watershed than in the non-urbanized Bhima sub-watershed. Due to urbanization, the impervious surface covers increase and in turn the surface runoff increased. The increase in impervious land cover decreased the infiltration of the water to the ground. During heavy rainfall, the sudden excess amount water due to increased runoff is often discharged into the nearby streams, either directly or passing through storm water drains. Hence, it results in increased average stream flow into the rivers. Fluctuations in the average stream flow reduces and thus causing less variability in the flow patterns. Generally, a river is supposed to be healthy if it has more flow variability because it helps the river to maintain its structure and function.

E. Sensitivity Analysis

Sensitivity analysis was done to estimate the rate of change in the output of a model with respect to changes in watershed characteristics. In this study, parameter sensitivity was determined using SUFI2 SWAT CUP program linked to SWAT model. The sensitivity analysis was performed for 15 different parameters and simulation results were evaluated at two different stream flow stations i.e. Khamgaon and Rakshewadi stations. Some parameters used for sensitivity analysis were: base flow, SCS curve number, groundwater delay time, soil evaporation, mean air temperature, effective hydraulic conductivity, etc. It was observed that base flow is the most sensitive parameter to LU/LC changes in Upper Bhima river basin.

V. CONCLUSION

Due to urbanization and infrastructure development activities in sub-tropical river basins the land use land cover has changed rapidly. Most of the pervious open spaces are gradually turning into impervious built-up areas due to developmental activities. Increase in impervious land cover reduces the infiltration of rain water into the ground hence affecting the ground water recharge in the region. During heavy rainfall, the increase in impervious surface cover causes the increase in surface runoff and peak discharges which sometimes causes floods. Therefore, it has become important to study the effects of urbanization and LU/LC changes on stream flow. Stream flow increase occurs due to increasing urbanization in a river basin. The changes in LU/LC pattern affect the hydrological parameters of the basin e.g. rainfall, infiltration, peak flow and ground water recharge, etc. Base flows are the most sensitive parameter to LU/LC changes in the river basins. Non-urbanized Bhima sub-watershed is found to be healthier than urbanized Mula-Mutha sub-watershed. Controlled and planned urbanization, implementation of best management practices, practicing sustainable town planning and agriculture, conservation of the forests, etc. are some highly recommended measures to be taken towards sustainable development of the river basins. SWAT model in conjunction with remote sensing and GIS emerged as very efficient tools for monitoring and assessing effects of urbanization on LU/LC and hydrological components of river basins.

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