AN ASSESSMENT OF HYDROLOGICAL IMPACTS DUE TO CHANGES IN THE URBAN SPRAWL IN BHOPAL CITY AND ITS PERIPHERAL URBAN-RURAL FRINGE

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ABSTRACT

Bhopal district has been developing at a very fast pace with most of the developmental activities being concentrated in the Bhopal city and along its periphery mostly comprising of the urban-rural fringe areas. This has resulted in considerable changes in the land use in the city and its fringes, with substantial areas being converted to semi-pervious and impervious zones owing to the fast pace of urbanization. These drastic changes in the land use pattern, has to a large extent changed the hydrology and drainage aspects of the city. Owing to the changes in the land use and pressures of increasing population, the runoff and drainage aspects have also been altered to some extent. Nowadays it is very common to find large stretches of roads being submerged during small rainfall events, thereby causing hardships to the local population. An effort has therefore been made to identify the land use changes in the city and its surroundings and its possible impacts on the hydrology of the study area. The land use classification has been carried out for 1992, 2000 and 2014 using LANDSAT data with a resolution of 30 m. The changes in the land use/land cover categories were derived for three different time periods by spatial intersection of land use maps pertaining to 1992 & 2000, 2000 & 2014 and 1992 & 2014 using ERDAS Imagine 2011 and ArcInfo/ArcMap 10 software. The area under settlements has increased by 10.66% during the period between 1992 and 2014, whereas the area under wastelands decreased by 18.29% during the same period. However, the forested area initially decreased from 45.64 sq. km (1992) to 40.24 sq. km (2000) but subsequently increased to 48.62 sq. km in 2014. The Soil Conservation Service-Curve Number (SCS-CN) method has been used to compute the surface runoff. The change in the runoff pattern has not been substantial in commensuration to these changes in the land use pattern as the runoff generation mechanism is also dominantly dependent on the rainfall pattern and its distribution and the antecedent moisture condition apart from the curve number.

Keywords: Land use, Change detection, SCS-CN, LANDSAT, GIS.

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INTRODUCTION

The hydrological cycle and stream water quality of any geographical location is highly effected by Land use/land cover (LULC) changes in that particular area. LULC changes also alter climateindirectly and have its impacts on thehydrology of that geographical area. For the environmental change over the globe, LULC changes are counted as major factor and the element which is forcefully driving it is urbanization in that area. However, urbanization provides more employment and economic growth to the community residing in its peripheral fringe areas, the long term effects of the urban sprawl are widespread.Increase in urbanization of any area leads to increase in impervious surfaces which result in relatively higher discharge of surface water and reduction in infiltration, causing more frequent flood incidents. This increased runoff water gets polluted due to urban pollutants and sediments flows towards any stream and degrades the quality of that stream water. hence in case of intense precipitation events, the urban area becomes susceptible to flood hazard.

From previous few decades, in most developing countries, there is a constant acceleration of urban population and urbanization has been experienced, which has become a vital concern for urban environment and ecology.It is Therefore significant to map LULC changes accurately in urban areas as well as to evaluate its impacts on stream water quality anddirect surface runoff.For mapping of LULC changes for a period of more than a decade and accurate detection of urban growth, satellite images are suitable as these are cost effective and easily available for a wide area.

In India, hasty urban sprawl has had anintense impact on direct surface runoff, resulting in frequent and greater flood incidents in urban areas.Bhopal city has recorded a faster growing urban areas during past three decades and therefore, it has sprawled to its peripheral fringe areas significantly and has intense impact on urban direct surface runoff. The main objective of this research paper is to assess the effects of LULC changes on direct surface runoff quantitatively in Bhopal city and its periphery comprising of the urban-rural fringe areas by deriving LULC classification maps. The LULC maps are preparedby using unsupervised classification method for LANDSAT TM/ETM+imageries (1992, 2000 and 2014).To estimate the effects LULC changes on direct surface runoff, the SCS-CNapproach has been used in this research.

STUDY AREA

The study area is a part of Bhopal district of Madhya Pradesh, India and covers an area of 874.51 sq. km.Bhopal city has spectacular views of hilly terrains. the slope of them are towards north and some of them have towards southeast. Hillocks with varying altitude can be sited along the southwest and northwest area of the city, these are the hillocks which form a contiguous belt between two ranges, viz. Singarcholi and Vindhyachal. Near Lalghati the relative height of the city is 625 m above MSL which is maximum in this area. On an average, ground level is nearly 460 m above MSL. The topography of Bhopal city has many panoramic views of the natural scenic beauty. There are immense possibilities for water front development and recreation along the beautiful hills and several lakes spread all over the city. Owing to this Bhopal is also called “The City of Lakes”. The Upper Bhopal Lake is one of the biggest lakes in the country.

In Bhopal city and around its peripheral urban rural fringe areas multiple developmental activities on varying scale are being initialized. The city is getting a modern look owing to the large number of infrastructure projects and it has off-late turned out to be the educational hub in Central India. However, this had led to changes in the land use with agricultural land being converted into housing colonies and recreational parks and malls. The map showing the location of the study area is given in Figure 1.

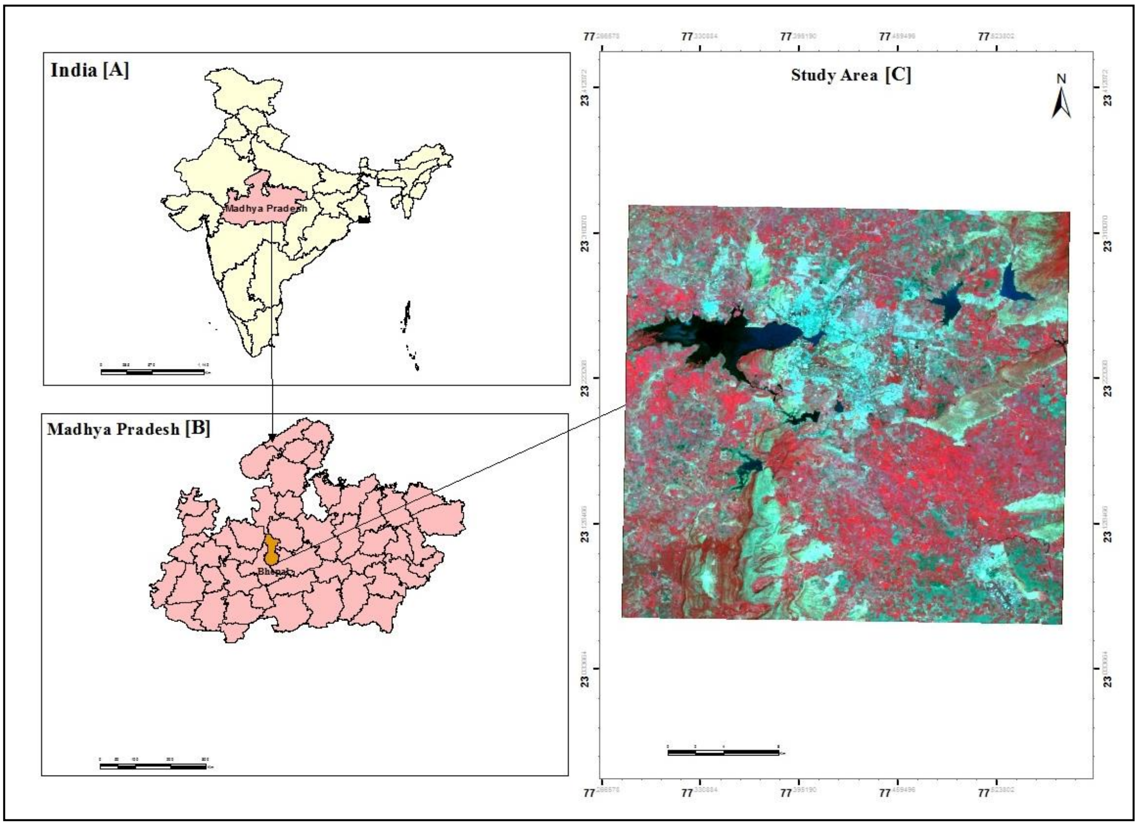

Figure 1. Location map of the study area

METHODOLOGY

The LULC classification maps were derived from LANDSAT TM/ETM+ imagery. The SCS-CN approach was used to assess the impacts of LULC changes on surface runoff due to urbanization. Figure 2 shows the data processing framework of research on hydrological response to LULC changes. The left sideof Figure 2 depicts the data processing for LULC classification and change detection while the right sideshows the flowchart of SCS-CN approach. In this paper, unsupervised classification was used to prepare LULC maps and spatial intersection (overlay analysis) was used to evaluate the temporal change of LULC in study area.

Unsupervised Classification

Visual interpretation technique was used for the mapping of land use/land cover. Prior to interpretation of multi-date satellite data, a reconnaissance survey of the study areawas done to develop a classification scheme based on local knowledge and ancillary information. An interpretation key was also developed based on standard Photo-elements like tone, texture, size, shape, association, pattern, location etc. to identify and map different classes. With the help of interpretation key onscreen preliminary interpretation of satellite data was done using ERDAS IMAGINE 2011 software.

Ground Truth Verification

Entire study area was visited to get an acquaintance of different ground feature and cover type with respect to satellite data. The doubtful area on preliminary interpreted maps from satellite data were carefully verified in the field. After verification, these areas were reconciled on the maps and corrections were made to obtain final maps.

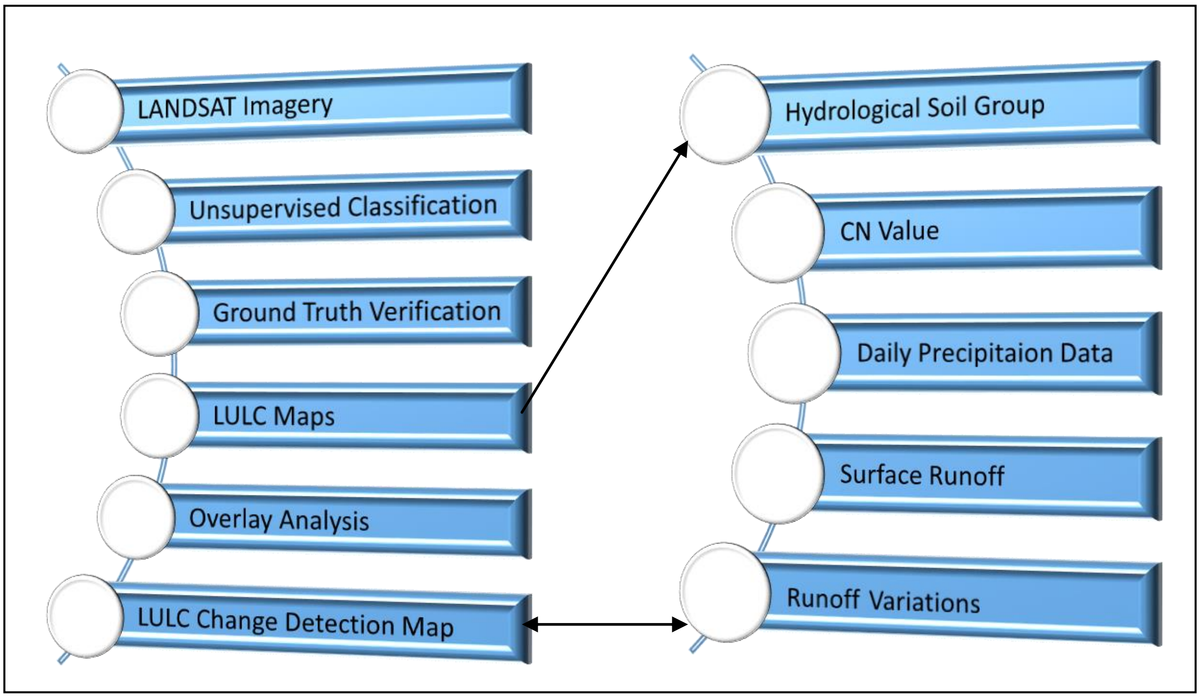

Figure 2. Framework of research on hydrological response to LULC changes.

Overlay analysis, Final Map Preparation and Area Statistics Generation

The spatial intersection method has been used for performing the overlay analysis using Arc info software. The final maps were prepared after reconciliation of doubtful areas observed in preliminary maps. The final maps were prepared/ composed and area statistics were generated using Arc Map 10.0 Software.

SCS-CN Approach Description

The SCS-CN model was used to estimate direct runoff from daily rainfall after deriving the curve number (CN) from LULC, and hydrologic soil group data and thereafter deriving the appropriate CN for the average, wet or dry condition based on the antecedent rainfall condition. For runoff calculation, SCS-CN uses the curve number (CN) method of the US Department of Agriculture (USDA) Soil Conservation Service (SCS, now Natural Resources Conservation Service), which is a core component of many traditional hydrology models (Wang et al., 2005). The runoff equation is

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \tag{1}$$

where Q is the runoff (mm), P is the rainfall (mm), S is the potential maximum retention (mm), and I_a is the initial abstraction (mm) and can be approximately estimated by

$$I_a = 0.2\ \mathrm{S} \tag{2}$$

S, in mm, is related to the soil and LULC conditions and can be described by CN through:

$$S = \frac{25400}{CN} - 254 \tag{3}$$

Where, CN is determined by the combination of LULC and soil (hydrological soil group) information for each cell. Theoretically, CN values are between 0 and 100. However, practically, CN values range between 30 and 100. Then SCS-CN approach uses daily rainfall and the CN to calculate the surface runoff (mm).

RESULTS AND ANALYSIS

LULC Change

In the present study land use/land cover of Bhopal and its peripheral area was mapped for the years 1992, 2000 and 2014. In order to monitor the changes in land use/land cover, proper care was taken in the selection of cloud free multi temporal data. Obtaining the ground truth for the older datasets i.e. LANDSAT 1992, was not possible therefore anapprentice approach utilized to overcome it, followed by mapping for 2000 and using it as template for the analyses of 1992 datasets.

The major land use/land cover categories identified in the study area are built-up, agriculture, forest, scrub, wasteland and water bodies and their areal extent. The details of the various land use classes and the observed changes are presented in Table 1 and Figure 3. In general, major area was occupied by agriculture followed by wasteland, scrub, forest, built-up land and water bodies in the year 1992.In the year 2000 and 2014,built-up land has increased. The built-up area identified in the study area was mainly large city settlements. The total built-up area of 37.51 sq. km in 1992 increased to 130.73 sq. km in 2014.This accounted 4.29% and 14.95% of the total geographical area during 1992 and 2014 respectively. The overall increase was10.66% of total geographical area with annual increment of 4.24sq.km./year.

Agriculture was observed mainly on plain lands and uplands and accounted 403.53 sq. km.and 435.83 sq. km. during 1992 and 2014 respectively and the rate of increase in the agriculture area was 1.47sq.km./year.Wasteland arelocated on the uplands. The total waste land which was 295.3 sq. km in 1992 reduced to 135.36 sq. km in 2014 and registered a decrease of -7.27sq.km./year. However, the decrease of -18.29% was noticed in wastelands during the period between 1992 and 2014. Forests are mainly located in southwest and northwest areas of the city. The total area during 1992 was 45.64 sq. km. which decreased to 40.24sq. km. in 2000 which again increased in 2014 to 48.62sq. km. The scrub which was 58.77 sq. km. in 1992 increased to 116.04 sq. km. in 2000 and thereafter decreased to 79.40 sq. km. in 2014.The area covered by waterbodies was almost same during all the years while area of reservoirs increased by 1.24 % during1992-2014.

The wasteland was observed to be 295.30 sqkm in 1992 which was reduced to 89.15 sqkm in 2000. The reason behind this transformation is because of increase in agricultural activities at those places. However, the wasteland further increased to 135.36 sqkm in 2014 because of lesser utilization of land in agricultural activities.

The transformation of a particular land use/land cover category into different categories was derived by spatial intersection of 1992 - 2000, 2000 - 2014 and 1992 -2014. The built-up area increased from 37.51 sq. km. in 1992 to 77.20 sq.km in 2000 which further increased to 130.73 sq. km. in 2014 as a result of conversion of crop lands and wasteland existing around settlements. One may expect suchchange in the study area on account of increase in population over a period of almost two decades.

The aerial extent of agriculture registered an increase of 12.72 % of total geographical area from 1992 to 2000 and further decreased -9.03% during 2000 to 2014. The overall increase was 3.69% oftotal geographical area during 1992 to 2014. During these periods, major area under wasteland and small area under Reservoir was transformed into cropland. However, conversion of wasteland into cropland was more during 1992-2000 than the year 2000-2014. In case of forest, the land transformation in dense, open and scrub was observed for the period 1992 – 2000 and 2000-2014. During this period dense forest converted into scrub forest and at a few places the scrub lands got converted into forest.

Table 1. Area statistics of land use/land cover distribution in Bhopal during 1992, 2000, 2014

S.L.	Landuse/ Land cover Categories	1992 Area (in sq km)	2000 Area (in sq km)	2014 Area (in sq km)	Change 1992-2000 (%)	Change 2000-2014 (%)	Change 1992-2014 (%)
1	Agriculture	403.53	514.78	435.83	12.72	-9.03	3.69
2	Builtup	37.51	77.20	130.73	4.54	6.12	10.66
3	Forest	45.64	40.24	48.62	-0.62	0.96	0.34
4	Scrub	58.77	116.04	79.40	6.55	-4.19	2.36
5	Wasteland	295.30	89.15	135.36	-23.57	5.28	-18.29
6	Waterbody	33.76	37.09	44.57	0.38	0.86	1.24

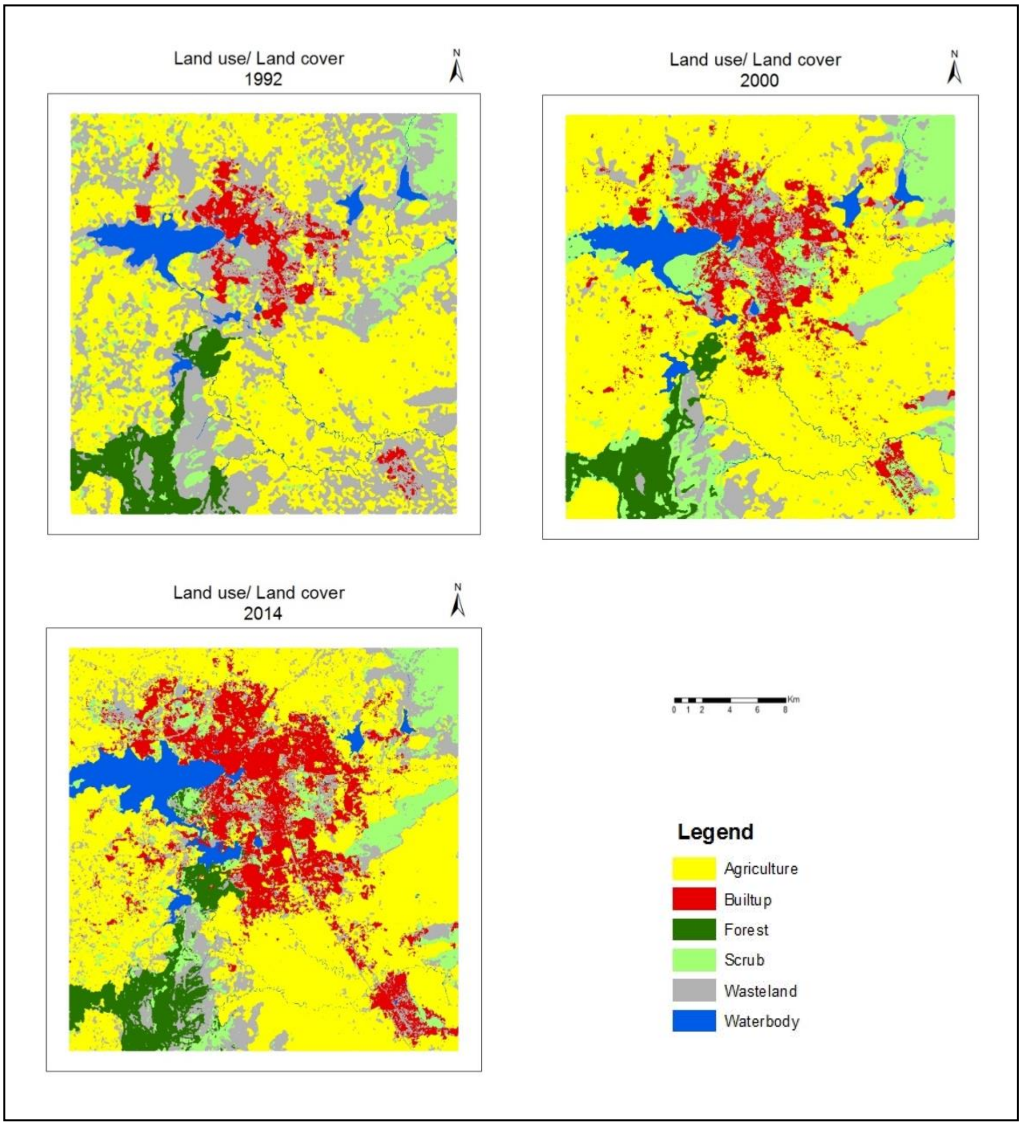

Figure 3. LULC maps of study area in 1922, 2000 and 2014.

Estimation of SCS-CN

The direct surface water runoff has been estimated by the Soil Conservation Service Curve Number (SCS-CN) methodat the outlet of the watershed. The SCS-CN methodis based on the single parameter Curve Number (CN), which depends on the land use, land cover, soil type and the antecedent moisture conditions prevailing in the watershed. The LULC types were derived from LANDSAT TM/ETM+ imagery as described earlier. According to soil classification categories, the study area comes in very low infiltration category which is categorized by type 'D' in Hydrological Soil Group (HSG) classification. Based on this hydrological soil group and LULC, the CNs have been determined for the various combinations of land use and soil type combinations.The composite curve number (CCN) for the watershed is estimated as 78 using hydrologic soil group and land use for the AMC-II condition (average). The AMC changes to dry or wet conditions depending on the 5-day antecedent rainfall.

Estimation of Direct Surface Runoff by SCS-CN

The simulated annual surface runoff of the study area estimated by SCS-CN method is 252.8mm for the year 1992, 298.39mm for the year 2000 and 245.24mm for the year 2014. The ratio of annual surface runoff to that of annual rainfall calculated is 31.71%, 33.98% and 27.75% for the years 1992, 2000 and 2014, respectively.

Although the change in urban area from 1992 to 2014 is very vast, which is 10.66% of the total area but the computed surface runoff has not increased in a similar proportion. The main reason of this exception is the rainfallpattern and its distribution. As the SCS-CN runoff estimation depends on the previous 5 days AMC (Antecedent Moisture Condition), and as distribution of rainfall in 2014 had been quite different from that during 2000 and 1992. The comparison of the daily rainfall and daily computed runoff for 1992, 2000 and 2014 is given in Figure 4-6, respectively.From these figures it is clear that the rainfall events in the year 2014 are in scattered manner (non-continuous) and hence the direct surface runoff peak values are smaller as compared to that during the years 1992 and 2000. Therefore, the simulated annual surface runoff had decreased even though there is a drastic increase in urban area.

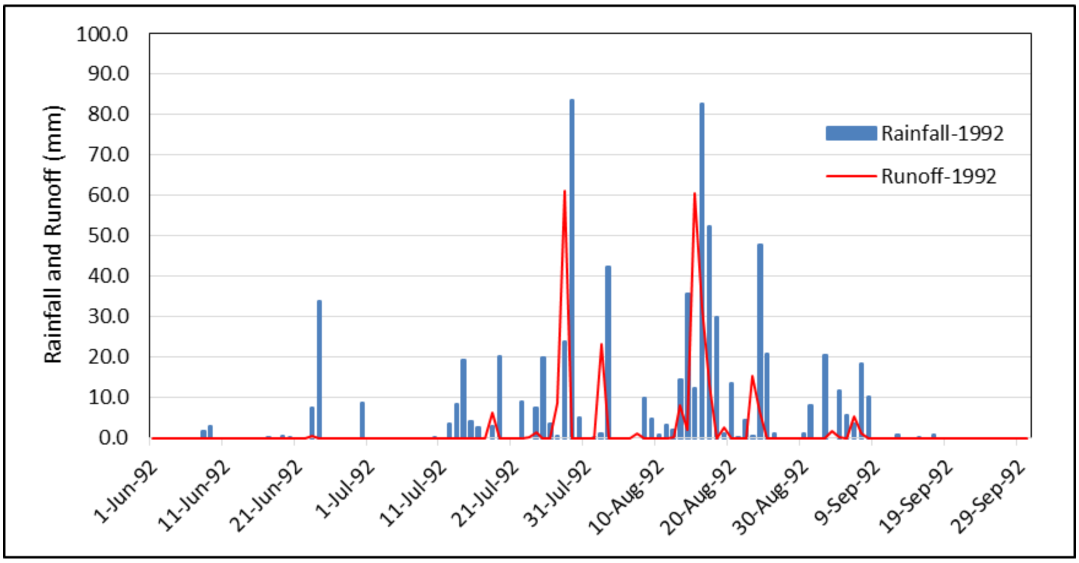

Figure 4. Comparison of rainfall and runoff during 1992

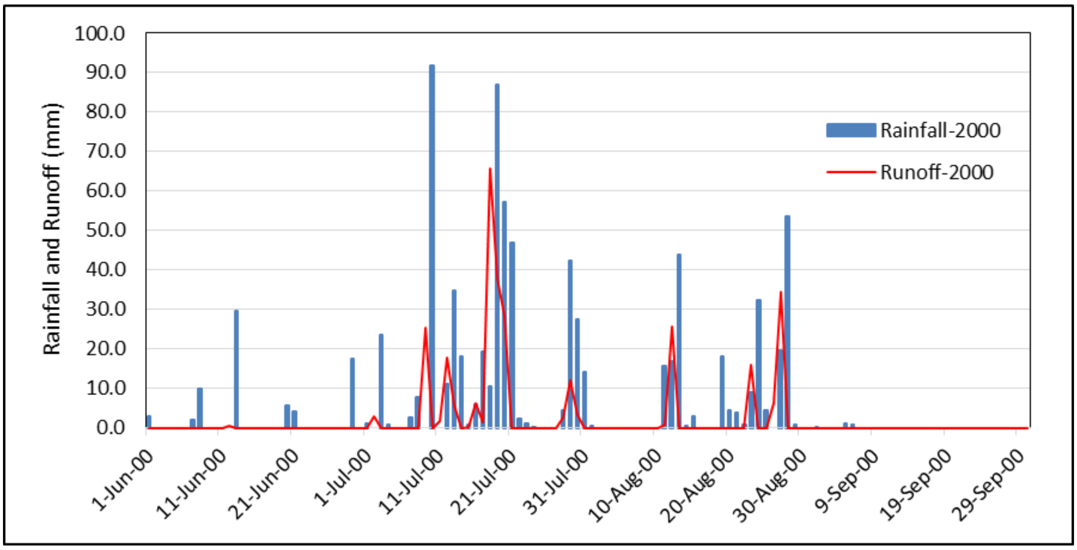

Figure 5. Comparison of rainfall and runoff during 2000

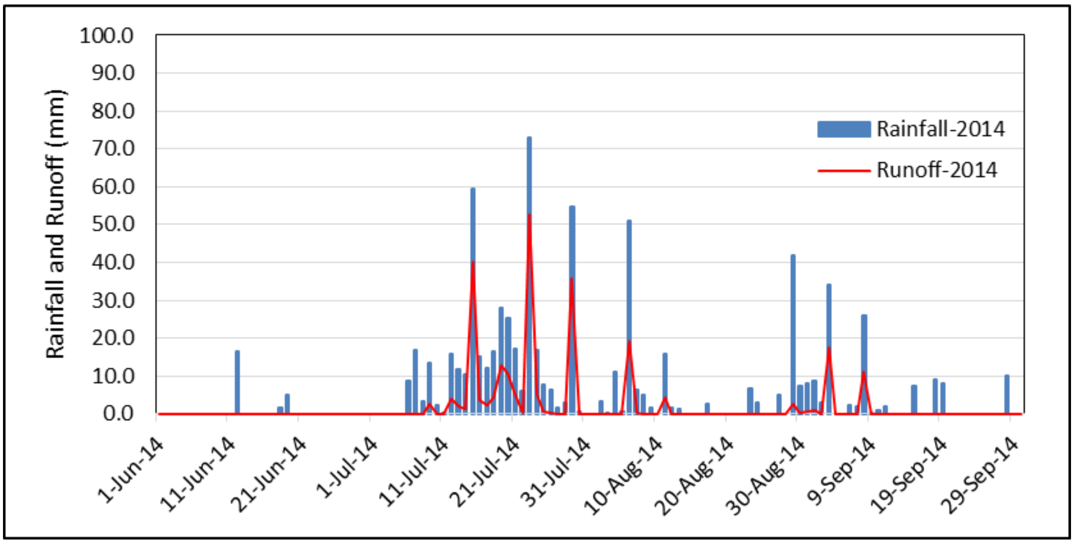

Figure 6.Comparison of rainfall and runoff during 2014

CONCLUSIONS

This paper presents a case study to investigate the impact of LULC change on surface runoff in the fast urbanizing Bhopal city, the capital of Madhya Pradesh. The LULC maps were derived from LANDSAT TM/ETM+ imagery (acquired in 1992, 2000 and 2014 respectively) using support unsupervised classification. Results indicated that the selected study area experienced rapid urbanization from 1992 to 2014. The overall increase in built-up area was 10.66% during 1992 to 2014. The increase was more during 2000-2014 (6.12%) than 1992-2000 (4.54%). The increase in built-up area was due to transformation of agriculture and wasteland.The SCS-CN approach was applied to simulate surface runoff variations in the study area during1992, 2000 and 2014. As a direct result of the urbanization from 1992 to 2014, the surface runoff increased for the whole area. However due to scattered rainfall pattern in the year 2014, changes in the runoff do not seem to be significant. This research paper is an attempt to assess potential hydrological impact of developmental and urbanization activities for a better planning of the Bhopal city and its peripheral urban rural fringe areas.

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