



# Impact of Land use Land cover change on Storm Runoff Generation: A case study of suburban catchments of Pune, Maharashtra, India

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## Abstract

Urbanization has evolved as one of the key factors responsible for the environmental health not only for the urban centres, but also for the suburban regions. In the recent years, most of the suburban regions in India are experiencing flash floods during the high intensity low duration rainfall condition. Such situations of flash floods in the urban and suburban areas are referred to as storm runoff. This paper deals with the computation of storm runoff in the suburban catchments of the Pune City. Five catchments, known for flash floods in the recent years, are identified for the present work. Storm runoff estimations in these catchments have been done using LandsatTM data of 1989 and 2011. Population-calibrated impervious surfaces (IS) were extracted for these catchments, and runoff has been calculated using the Soil Conservation Service-Curve Number method. Major changes in the land use land cover pattern in these 22 years have been detected, with a net growth in built-up area of almost 10 times from 1989 to 2011, leading to the increase in IS in the catchment. The impact of increase in built-up area and IS has augmented storm runoff in the catchment. Estimated runoff values increased from 461.8 m<sup>3</sup> to 1068.52 m<sup>3</sup> (Baner), 2026.4 m<sup>3</sup> to 3638.73 m<sup>3</sup> (Kharadi), 2947.5 m<sup>3</sup> to 4736.46 m<sup>3</sup> (Kondhwa Ghorpadi), 1021.1 m<sup>3</sup> to 2039.57 m<sup>3</sup> (Wadgaon Sheri) and 1176.89 m<sup>3</sup> to 3691.18 m<sup>3</sup> (Wadgaon Budruk) from 1989 to 2011. Thus, it is quite evident that the growth in built-up area and impervious surfaces has enhanced the capacity of suburban basins to generate more runoff.

**Keywords** Land use land cover · Suburban catchment · Impervious surface · Storm runoff · SCS-CN method

## 1 Introduction

In recent times, urban flooding has become a major concern with scientists from all over the world, who are working on resolving queries related to climatic change and urban hydrology. It has thus become increasingly important to understand and analyse

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the underlying realities of urban flooding and to offer remedies to resolve it. The shift of land use from rural agricultural to a built-up landscape has been a result of urbanization, which has led to an increase in the Impervious Surface Area (ISA). ISA includes built-up areas such as roads, buildings, pavements, roof tops, etc., that prohibit percolation of water (Schueler 1994). This water, in turn, translates into an increased surface flow leading to channel erosion and degradation of habitat which has an adverse effect on aquatic life (Bird et al. 2002). This spread of water on the surface is known as surface runoff. It depends on a variety of factors such as soil type, rainfall duration, drainage, land use, etc. In the recent past, occurrences of surface runoff within the cities and their peripheries have become a common phenomenon during the situations of low duration high intensity rainfall events. These occurrences of surface runoff are referred to as storm runoff.

Since the growth in impervious surfaces (IS) is a causative factor for increase in surface runoff, their mapping has become extremely important. IS are often mapped by employing the remote sensing data which primarily aid in identifying the land use and land cover types (Ward et al. 2000; Yang 2006). It has been recognized that there is a relationship between the changing hydrological condition and variations in land use over a period of time (Dougherty et al. 2007).

For the prediction of runoff following any rainfall event, the Soil Conservation Service Curve Number (SCS-CN) method has been used widely, which has been documented in the National Engineering Handbook, Sect. 4: Hydrology (NEH-4) (USDA 1956, 1964, 1971, 1985, 1993). It was developed by the United States Department of Agriculture Soil Conservation Service (USDA) and is used for the study of hydrology in small catchments and agricultural watersheds (Mishra and Singh 2006). Over a period of time, its applications have increased to include the study of forested and urbanized catchments and a variety of land use types (Rawls et al. 1981; Mishra and Singh 1999). Long-term hydrological response to an increased urban ISA has been studied by a number of scholars (Lee and Heaney 2003; Weng 2001). Distinctively different spatial patterns of ISA generate varied storm runoff which can be managed by proper urban planning (Ferreira et al. 2018).

The present paper deals with the use of satellite imagery to study changes in the Land Use Land Cover (LULC) in the region, thereby leading to an increase in ISA and storm runoff, which is computed using the SCS-CN method. Thus, the goal of the present study is to analyse the response of urban sprawl on storm runoff generation in the suburban catchments of Pune, Maharashtra, India. In order to fulfil this goal, the specific objectives set are, (i) to assess the growth in built-up area and impervious surfaces, (ii) to estimate the storm runoff using Remotely Sensed (RS) data, and (iii) to analyse the impact of built-up area and ISA on storm runoff.

## 1.1 Study area

The study area includes five suburban catchments of Mula Mutha River in Pune, Maharashtra, India (Fig. 1), namely, Baner, Kharadi, Kondhwa Ghorpadi, Wadgaon Sheri and Wadgaon Budhruk. The catchments cover the following area as shown in Table 1.

The elevation of these catchments range from 541 m to 926 m above mean sea level. These catchments are covered by Survey of India toposheet numbers 47F/10, 11, 14 and 15 on 1:50,000 scale. The study area entirely falls in the rain shadow region and receives 741 mm of average annual rainfall.

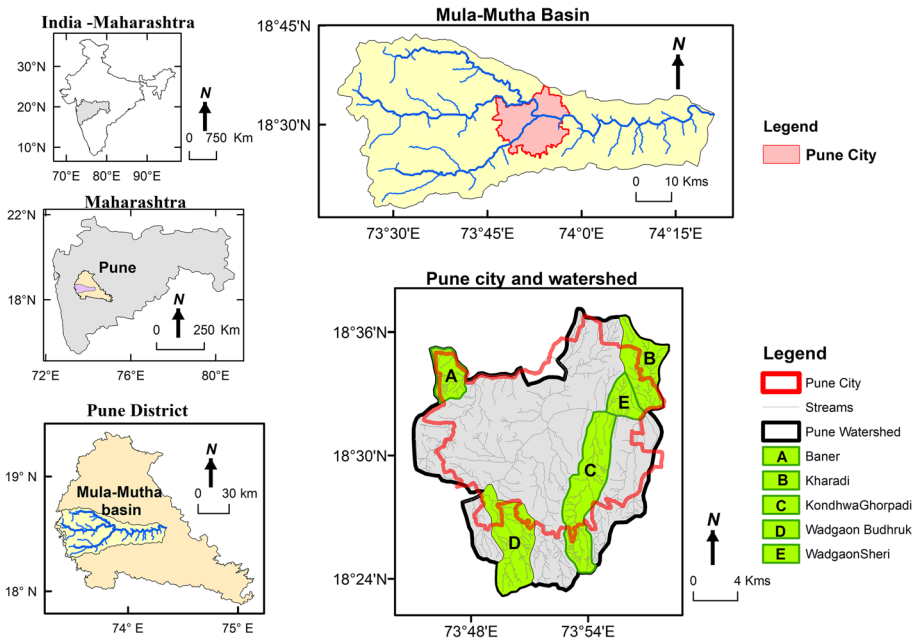


Fig. 1 Location of study area

Table 1 Area covered by catchments for present study

Baner	Kharadi	Kondhwa Ghorpadi	Wadgaon Budhruk	Wadgaon Sheri
11.01 km <sup>2</sup>	20.49 km <sup>2</sup>	34.47 km <sup>2</sup>	28.06 km <sup>2</sup>	8.48 km <sup>2</sup>

## 2 Materials and methods

In order to assess the LULC for the study region as well as estimate the storm runoff for the same, Landsat-5 Thematic Mapper (L-5 TM) images of February 1989 and 2011 were used. Satellite data were obtained from the United States Geological Survey (USGS) Earth-explorer site. Population data for 1991 and 2011 were procured from the Census of India, and the soil data for all the catchments were procured from the National Bureau of Soil Survey and Land use, Nagpur. Rainfall data from 1980 to 2010 were obtained from India Meteorological Department. Figure 2 represents the methodology used for this study. The SCS-CN method has been used for the computation of storm runoff. For this, the aspects of land use and hydrological soil group (HSG) were evaluated first. After the pre-processing including the geometric and atmospheric correction of satellite images, supervised classification was carried out using the maximum likelihood classifier, which generated the LULC maps and subsequently the Normalised Difference Vegetation Index (NDVI) maps. NDVI is a numerical indicator that uses the visible band 3, i.e. red band (0.63–0.69 μm) and near-infrared bands (0.76–0.90 μm) of the electromagnetic spectrum. The NDVI algorithm computes the ratio of the difference between the near-infrared and red reflectance values and their summation, as shown in Eq. 1.

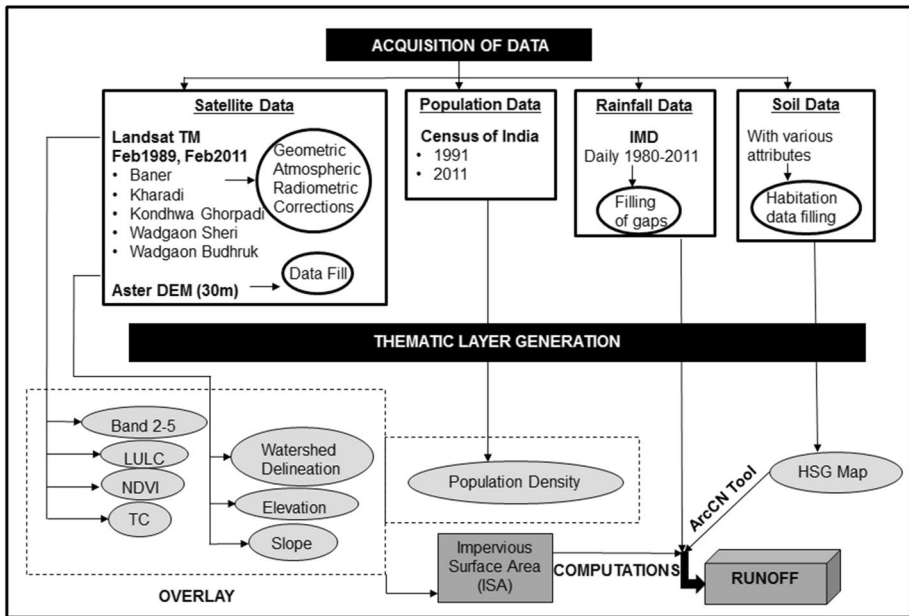


Fig. 2 Methodology

$$\text{NDVI} = \frac{\text{NIR} - \text{IR}}{\text{NIR} + \text{IR}} \quad (1)$$

Eight land use classes were identified including natural vegetation, agricultural land, fallow land, water bodies, barren land, hilly terrain, sparse built up, dense built-up areas, and roads. Elevation and slope values were extracted after the rectification of aster data (30 m resolution) following the standard procedure using the hydrology tool in ArcGIS (Frye 2007). Built-in coefficients values for TC band II (Crist et al. 1986) were employed to obtain the Tasseled cap transformations of Landsat TM data in the ERDAS Imagine environment. Population density maps were obtained from the population data for each administrative unit within the study area. IS were extracted by generating a number of thematic layers followed by complex analyses for model building (Dhorde et al. 2012; Kumar and Dhorde 2013). Regression analysis of nine independent parameters, namely population density, values of band II to band V, TC Band II, NDVI, elevation and slope, was carried out against the dependent variable IS.

## 2.1 Estimation of storm runoff

In order to estimate the storm runoff, thematic layers were generated along with the use of variables like HSG, rainfall data, antecedent moisture condition (AMC), and ISA. These are elaborated in the following section.

### 2.1.1 Watershed delineation

ArcSWAT and Spatial Analyst in ArcGIS were used for the delineation of watersheds in each of the five catchments under consideration. These catchments were identified using Aster DEM 30 m resolution.

### 2.1.2 HSG map

The National Bureau of Soil Survey and Land use, Nagpur, provided the soil map containing attributes like soil taxonomy, texture, depth, temperature conditions, etc., in a digital format on a 1:50,000 scale. HSG map was generated by grouping these attributes according to standard rules given in the National Engineering Handbook, NRCS, 2007, Chapter 7.

### 2.1.3 Curve number (CN) matrix

The HSG data along with land use was used to generate CN values according to the table provided by USDA (1986). Runoff curve numbers were determined using the classification of soils into hydrologic groups A, B, C, D based on minimum infiltration rate on wetting of dry soils.

### 2.1.4 Rainfall computation

Daily rainfall data procured from the Indian Meteorological Department (IMD), Shivajinagar, for the study area are used for the present work. Though desirable, due to the lack of multiple rain gauges precipitation data from a single station were employed. The actual precipitation value used to generate storm runoff for this study is a decadal average, i.e. 2.35 inches for 1981–1990 and 2.87 inches for 2001–2010. For the application of the SCS-CN method, an assumption is made that rainfall with a uniform depth of 2.35 inches in 1989 and 2.87 inches in 2011 occurred over the entire watershed including all catchments in the study area.

## 2.2 SCS-CN method

Since rainfall data from a single gauging station has been used for the present study, the computation of runoff has been done using the SCS-CN method. The SCS equation governing the excess rainfall ' $P_e$ ' can be written as,

$$P_e = \frac{(P - KS)^2}{(P + (1 - K)S)} \quad (2)$$

where, ' $P$ ' = cumulative precipitation and ' $S$ ' = land use parameter related to the Curve Number (CN). It is defined as

$$S = \frac{1000}{CN} - 10(\text{in inches}) \quad (3)$$

$$S = \frac{25400}{CN} - 10(\text{in mm}) \quad (4)$$

' $K$ ' = 0.2, as determined from observations, is an arbitrary coefficient (SCS 1972).

CN is an indirect reflection of IS cover whereby a completely impervious surface has a curve number of 100 ( $S=0$ ).

The ArcCN tool following the guidelines as mentioned in the SCS-CN 1972 manual, was used for the estimation of potential maximum retention ( $S$ ) and storm runoff, by employing Eqs. 2, 3 and 4. The runoff in cubic metres and millimetre was computed by giving the intersect layer of LULC, HSG and subbasin boundaries, along with rainfall value as the input. Separate simulations were run for the 1989 and 2011 situations, using the respective rainfall intensity for each decade.

### 3 Results and discussion

Land use changes for 22 years span along with the changes noted in the impervious surface area and surface runoff are discussed in this section.

#### 3.1 Changes in LULC

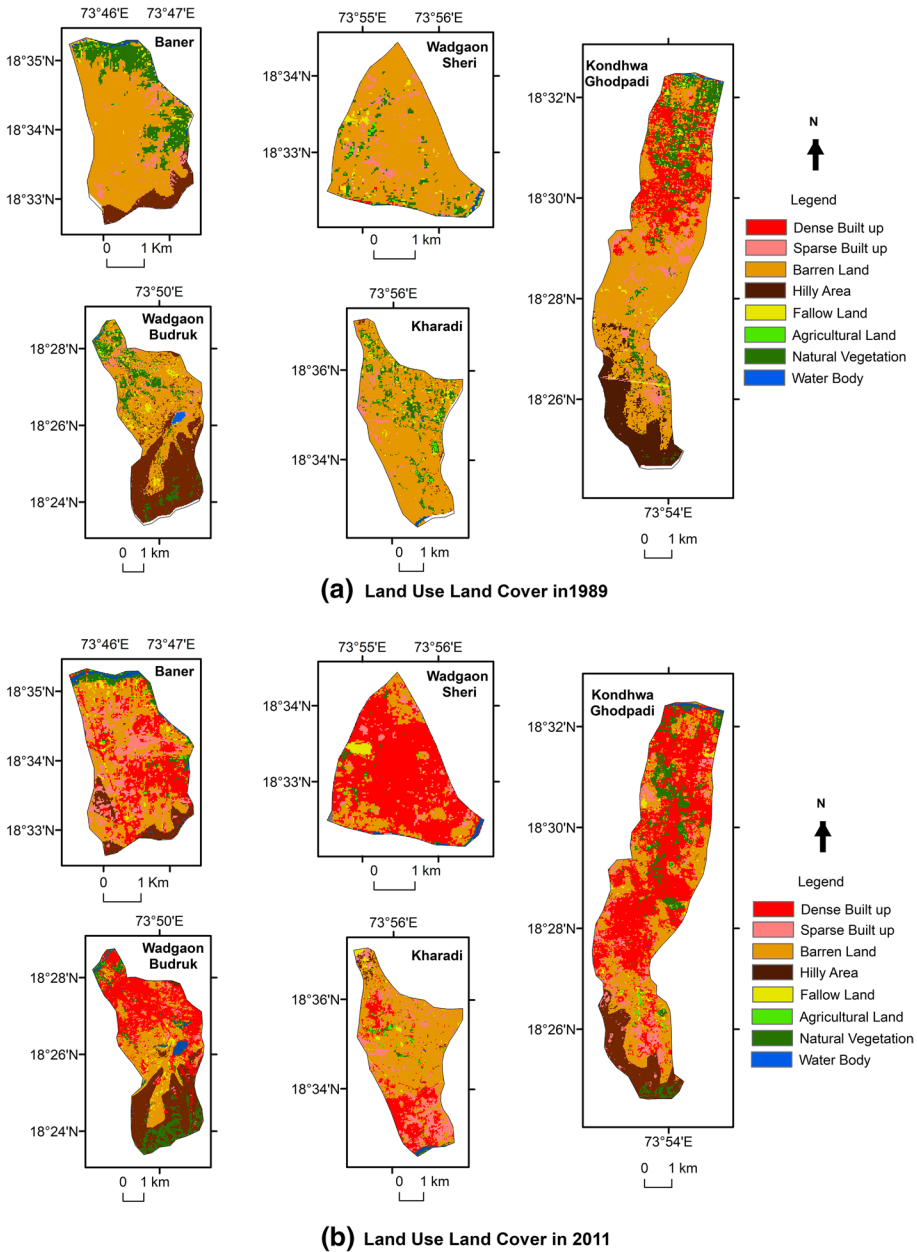
There has been a visible change in the LULC from 1989 to 2011. All the five catchments have seen a considerable increase in the built-up area (Fig. 3a, b).

In *Baner*, majority of barren land is replaced by dense built-up area indicating a rapid increase in urbanization. Areas in the northern part of Baner, close to Mula riverbed, which were earlier covered by natural vegetation, are observed to be under agriculture in 2011. Overall built-up area has increased 10 times from 4.45% in 1989 to 45.85% in 2011. *Kharadi* too has seen a shift from barren land to dense built-up areas in the southern and north-western part of the region. In northern Kharadi, clearing of natural vegetation has given rise to visible hilly areas in the satellite imagery. Kharadi has also experienced more than 10 times increase in built-up area, from 3.76% in 1989 to 33.75% in 2011. Rapid urban growth in *Kondhwa Ghorpadi*, especially in the central part of the catchment, can be observed from 1989 to 2011. Patches of barren land have mostly been replaced by dense built-up areas in 2011. Hilly patches in the southern region are covered with natural vegetation in 2011. Overall, built-up area in this catchment has almost doubled from 24.69 to 53.11% in a span of 22 years. The most remarkable change in the LULC is seen in the case of *Wadgaon Sheri*. Earlier in 1989, majority of the area was under barren land with a few dispersed patches of natural vegetation. 2011 has witnessed a dramatic shift of all the other land uses to dense built-up cover indicating urban sprawl. The built-up area has increased from 6.04 to 76.61% in a span of 22 years. *Wadgaon Budruk* also experienced urban growth mainly in the northern and eastern parts. The southern areas of the catchment continue to remain under hilly cover even in 2011. The total built-up area in this catchment is seen to increase from 4.15% in 1989 to 38.33% in 2011.

Thus, overall, the LULC analysis of satellite images for 1989 and 2011 validate that there has been a substantial increase in built-up area at the cost of natural vegetation, barren land, and hilly terrain within a span of 22 years (Table 2).

#### 3.2 Change in impervious surfaces

There has been a remarkable increase in ISA from 1989 to 2011 as naturally vegetated areas have been replaced by construction of roads, residential units, industries, etc., as a result of urbanization.



**Fig. 3** Land use land cover in **a** 1989, **b** 2011

*Baner* has seen a shift in IS from a range of 17–30% in 1989 to the 75–85% range in 2011. This clearly indicates that the urban sprawl in this catchment has led to the deterioration in the urban surface cover. In *Kharadi*, rapid urban growth has led to an increase in IS from 30 to 85%, with major impervious cover in the south-central region. *Kondhwa*

**Table 2** Per cent area change in land use type for the catchments

Class name	Area in percentage									
	Baner		Kharadi		Kondhwa Ghorpadi		Wadgaon Budhruk		Wadgaon Sheri	
	1989	2011	1989	2011	1989	2011	1989	2011	1989	2011
Agricultural land	0.58	0.74	1.10	1.36	0.40	0.87	0.65	0.51	0.76	0.41
Barren land	66.07	37.87	78.21	59.72	49.81	26.82	43.93	23.67	84.14	18.82
Dense built up	0.00	30.07	0.03	19.35	19.09	45.87	0.00	35.39	0.60	72.66
Fallow land	1.52	2.50	3.53	1.96	1.92	1.63	4.16	2.65	2.52	1.88
Hilly area	8.14	6.98	1.10	1.66	13.25	9.26	34.28	23.29	0.00	0.01
Natural vegetation	18.30	4.17	11.93	0.95	9.71	7.86	11.84	9.47	5.84	1.17
Sparse built up	4.45	15.78	3.73	14.40	5.60	7.24	4.15	2.94	5.44	3.95
Water body	0.95	1.88	0.36	0.61	0.21	0.46	1.00	2.07	0.69	1.11
Total built up	4.45	45.85	3.76	33.75	24.69	53.11	4.15	38.33	6.04	76.61

*Ghorpadi* region has seen a growth in IS from the southern hilly area to the northern part of the catchment and is experiencing maximum urban growth. In 1989, the maximum impervious cover was 47% in the northern and central parts of the catchment, which has increased to almost 95% in 2011. In *Wadgaon Budhruk*, maximum impervious cover is found in the northern and eastern regions. This catchment has seen an increase in IS from 20% in 1989 to 90% in 2011. *Wadgaon Sheri*, had areas covered by 30%–45% impervious cover in 1989, had witnessed high values of ISA (80% imperviousness) in 2011 which can be directly attributed to the urban sprawl in this area.

Overall, it can be observed that there has been a definite increase in the percentage of ISA in the catchment. Negligible or low impervious cover is noticed in and around the water bodies, ridges, and slopes covered with vegetation. Areas experiencing human intervention in the form of construction activity (roof tops or transport routes) appear to have increased in the past decades, thus leading to an overall increase in the impervious cover. Many areas that recorded less than 25% imperviousness in 1989 have exhibited a whooping rise in their impervious cover (IS values above 80%). This change in impervious surface from 1989 to 2011 is represented in Fig. 4a, b.

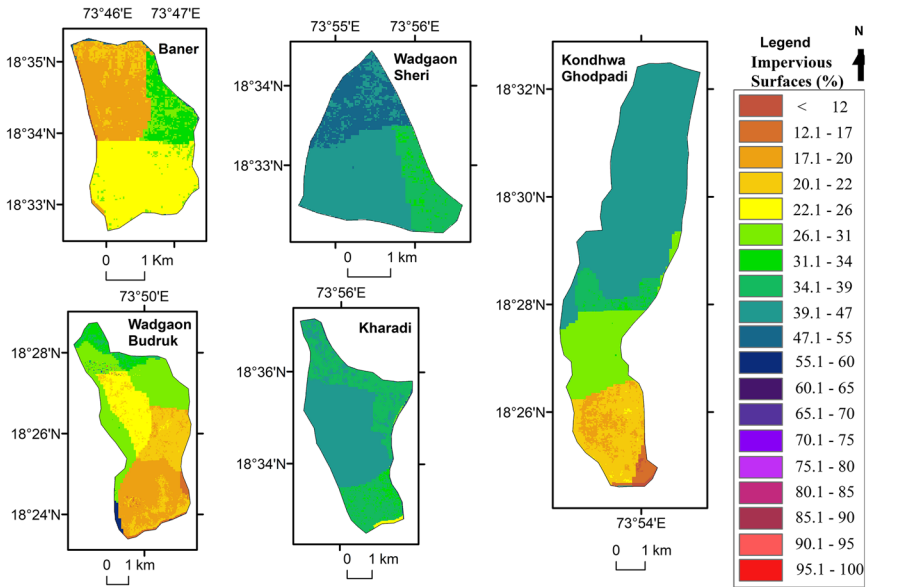
### 3.3 Change in NDVI

NDVI is an indicator of the vegetation cover in the region. NDVI analysis of these catchments shows that in 1989 values were ranging from  $-1$  to  $0.72$ . In 2011, NDVI values are seen to drop to a range of  $-0.25$  to  $0.45$ . This decrease in the NDVI can be attributed to the reduction in natural vegetation and its replacement by urban impervious surfaces.

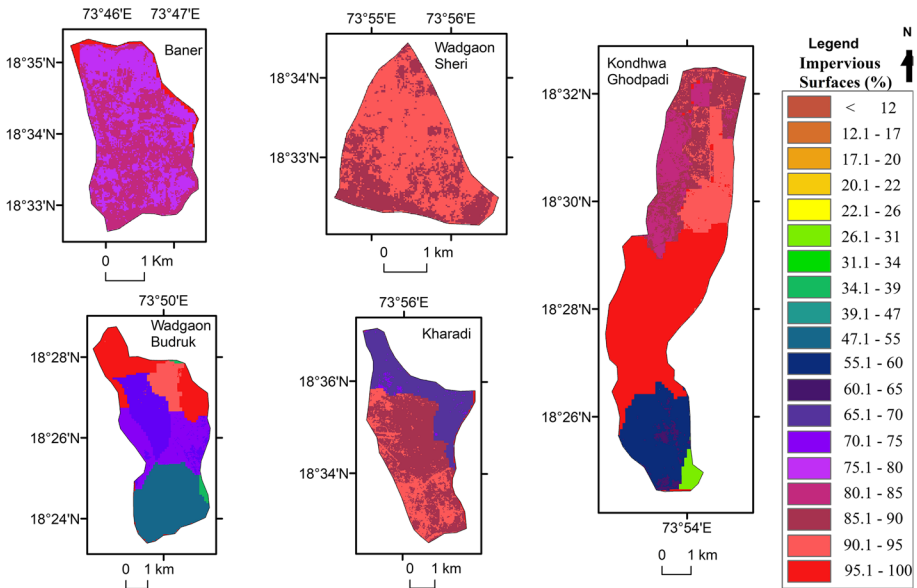
### 3.4 Change in storm runoff

The last 22 years, from 1989 to 2011, have seen a substantial increase in built-up area in each catchment, which has almost doubled in this frame of time. There has been an effect on the soil cover as well, which has been impacted due to increasing construction activity





(a) Impervious Surfaces in 1989



(b) Impervious Surfaces in 2011

Fig. 4 Impervious surfaces in a 1989, b 2011

in the village and city limits. The estimated storm runoff for the five catchments under consideration (for AMC II category) shows runoff and runoff volume displayed in Table 3.

The runoff estimation is based on the fact that the net area for each catchment is constant over 22 years and the rainfall is the average rain (storm event) of 2.35 inches (59.7 mm)

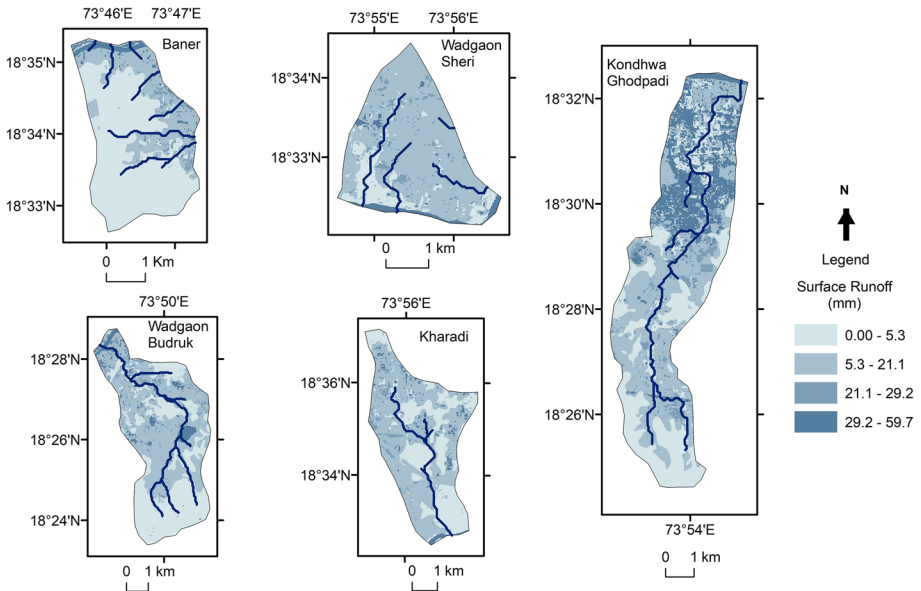
for 1989 and 2.87 inches (72.9 mm) for 2011. This is indicative of how storm runoff is directly impacted by urbanization. Thus, an increase in the amount of storm runoff generated within the catchments during the time period under consideration (1989 and 2011) is clearly visible, as shown in Fig. 5a, b. Overall increase in runoff volume values was observed for all 5 catchments under consideration.

In *Baner*, over these two decades, the runoff values in the winter season revealed an increasing trend from 23.48 mm in February 1989 to 32.9 mm in February 2011. The catchment covers an area of 11.01 km<sup>2</sup>; thus, the runoff volume discharged is low even though the runoff values are high. In terms of runoff volume, a higher range of values are observed ranging from 461.8 m<sup>3</sup> in February 1989 to 1068.5 m<sup>3</sup> in February 2011. In *Kharadi*, the values of runoff show an increase, mostly in the southern part of the region where EON SEZ has come up in recent times, adding to the urbanization and inflow of population in search for better employment opportunities. Runoff in Kharadi has increased from 20.52 mm in 1989 to 30.7 mm in 2011. There has also been a substantial increase in the runoff volume over this span of time, owing to the area of the basin. The catchment of *Kondhwa Ghorpadi* has experienced a similar increase in the storm runoff over this span of time, from 17.9 mm in 1989 to 26.96 mm in 2011, especially in the southern part of the basin where there has been undercutting of hill slopes to make way for newer residential projects. Owing to the large size of the basin, the growing urbanization has resulted in higher values of runoff volume in these 22 years. In *Wadgaon Budhruk*, runoff has increased from 20.74 mm in 1989 to 34.14 mm in 2011. This is observed mostly in the northern part of the region and along the riverbed where most of the urbanization has taken place, the truth of which is reinforced by the increasing values of runoff volume over this time period. *Wadgaon Sheri* also has experienced an increase in the storm runoff from 34.18 mm in 1989 to 40.79 mm in 2011. There has been a great deal of urbanization in this region in 2 decades, resulting to an increase in the impervious cover and thereby the runoff.

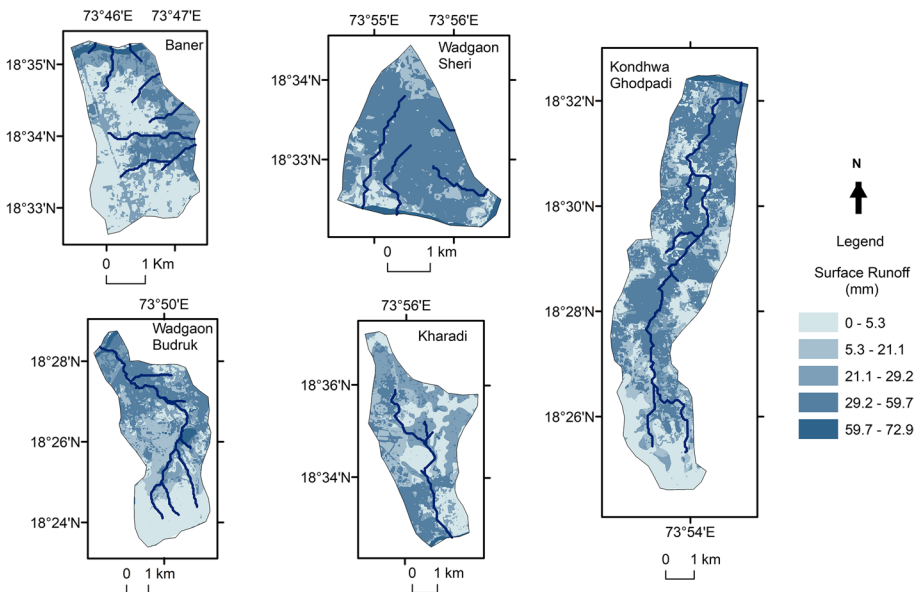
On further analysis of runoff volume of these basins, it was revealed that although there is an increasing trend in the runoff, the basins showing the highest runoff volume were not necessarily the ones showing the highest values of runoff as well. This can be attributed to the fact that catchments with large area tend to generate overall higher runoff volume. Amongst all basins considered for the present study, Kondhwa Ghorpadi has the highest area (34.47 km<sup>2</sup>). Although the runoff in this region is low (17.9 mm in 1989 and 26.96 mm in 2011), the resultant runoff volume generated is the highest (2947.53 m<sup>3</sup> in 1989 and 4736.46 m<sup>3</sup> in 2011), owing to the large size of the basin. Baner on the other hand, having an area of (11.01 km<sup>2</sup>) shows high values of runoff (23.48 in 1989 and 32.9 mm in 2011), but the overall runoff volume is still low (461.80 m<sup>3</sup> in 1989 and 1068.5 m<sup>3</sup> in 2011), which can be attributed to the small size of the catchment.

**Table 3** Runoff and runoff volume generated in each catchment

Basin Name	Feb 1989 runoff (mm)	Feb 1989 runoff Volume (m <sup>3</sup> )	Feb 2011 runoff (mm)	Feb 2011 runoff volume (m <sup>3</sup> )
Baner	23.48	461.80	32.9	1068.50
Kharadi	20.52	2062.35	30.7	3638.73
Kondhwa Ghorpadi	17.9	2947.53	26.96	4736.46
Wadgaon Budhruk	20.74	1021.11	34.14	2039.56
Wadgaon Sheri	34.18	1176.89	40.79	3691.18



(a) Surface Runoff in 1989



(b) Surface Runoff in 2011

Fig. 5 Surface runoff in a 1989, b 2011

Impact of LULC changes on surface runoff using SCS-CN model yielded a positive relationship for the present work. It was observed that that the SCS curve number method, based on an empirical relationship, is an efficient tool for the estimation of direct runoff in

a watershed. The results obtained for the present study, using the ARC CN tool, justify the impact of changes in land use land cover on surface runoff for the suburban catchments of Pune City. The combination of SCS-CN method and the remote sensing data has assisted in estimating the surface runoff. Similar kind of results were obtained by researchers working on the impact of LULC change on runoff (Khare et al. 2015; Guzha et al. 2018). Other studies effectively demonstrated the impact of LULC change in stream flow (Venkatesh and Ramesh 2018; Lei and Zhu 2018).

### 4 Conclusion

Urban sprawl and the related IS growth have considerably impacted the surface runoff generation in the study area. A substantial change in the land use has been observed in all the basins since 1989, with a major shift from barren land and naturally vegetated areas to urban built-up spaces. A reduction in vegetation cover is reflected in the decreasing NDVI values in 2011. Moreover, growing urbanization has led to an increase in the imperviousness of the region, with IS values up to 80% in certain areas. This can be observed in Fig. 6. The prominent findings of the study indicated that:

- i. Per cent built-up area has increased by more than ten times in all the catchments, except Kondhwa Ghorpadi catchment. Only two times increase was noted in case of Kondhwa Ghorpadi catchment during the study period as compared to the rest of the catchments. This is mainly due to the fact that in 1989 while other catchments had a very low per cent area under built-up class (3–6%), Kondhwa Ghorpadi was already experiencing high urban built surfaces (24.69%) as its middle and upper reaches were falling within the then PMC limits. A drastic increase in built-up area in the rest of the catchments was observed by 2011 as a result of their inclusion in the PMC limit, urban sprawl, and development of the new IT hubs. Kondhwa Ghorpadi noted relatively less

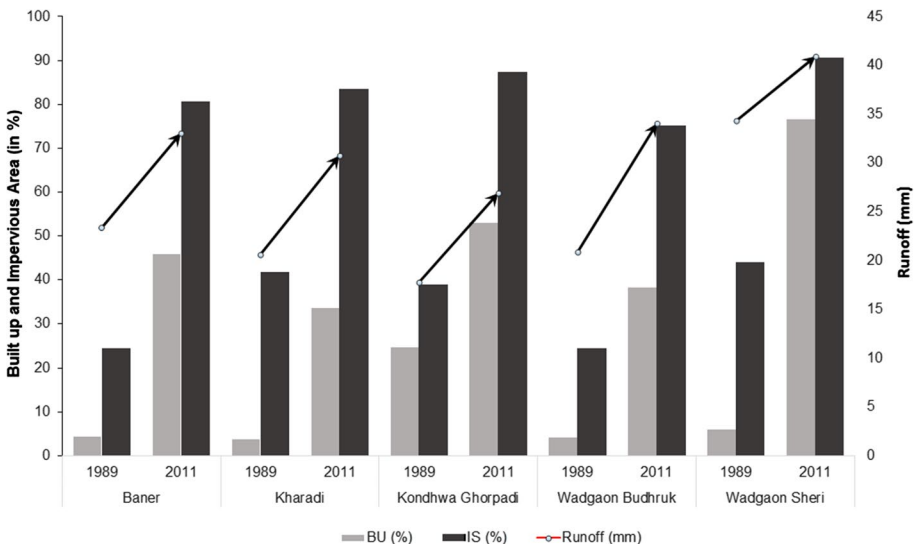


Fig. 6 Comparative chart of built-up, impervious surfaces, and surface runoff

- growth rate during the period under consideration as the built-up sprawl was restricted in certain areas within the catchment which belonged to the Pune Cantonment. Highest per cent built up was noted in Wadgaon Sheri catchment.
- ii. Significant decrease in barren land is noted in all the catchments, as the barren land has mostly been converted to the urban built-up areas. Highest decline in barren area is observed in Wadgaon Sheri catchment (from 84% in 1989 to 18% in 2011). This decline coincides with the rapid growth in built-up areas within Wadgaon Sheri catchment.
  - iii. With the growth in built-up areas within the individual catchments, per cent ISA exhibited significant increasing trend in all the five catchments. All the catchments under consideration had per cent ISA below 50% in 1989, whereas by 2011 all the catchments have per cent ISA above 80%.
  - iv. Surface runoff values generated for these catchments definitely show an increasing trend for the study period. Wadgaon Sheri exhibits the highest potential of generating the surface runoff of all the basins for both the scenarios (1989—34.18 mm and 2011 40.79 mm). However, when it comes to the net runoff volume generated by the catchment area, then Kondhwa Ghorpadi appears to have the highest potential for generating runoff volume. This is basically attributed to the fact that runoff volume is the function of runoff and area, and Kondhwa Ghorpadi has largest catchment area amongst the others.
  - v. In the present study, it was observed that all the catchments indicated significant rise in surface runoff with respect to the changes in LULC. Runoff and runoff volumes are found to be consistently increasing with increase in built-up areas, thus emphasizing the fact that LULC changes, including growth in built-up areas and ISA, are the significant parameters that influences precipitation-runoff relationship.

This study clearly brought out the relationship between increasing built-up area, impervious surfaces and surface runoff. Subbasins which clearly show a growth in built-up structures (impervious surfaces) are seen to yield high runoff values. Transportation routes, mostly with hundred per cent of impervious surfaces, have a greater potential for generating runoff, a fact that is proven to be true in the present study. Increased impervious surfaces have led to increased runoff in all the basins, implications of which are felt in the form of urban flooding during high intensity rainfall events. Thus, urbanization has proved to have a definitive impact on increased ISA and subsequent runoff, and certain mitigation techniques needs to be adopted by the civic bodies.

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