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Effect of changing land use scenario in Kolkata Metropolitan on the variation in volume of runoff using multi-temporal satellite images

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The city of Kolkata has happened to grow in an unplanned manner expanding towards the southern and the eastern part. The changing land use pattern of the city was studied using Landsat imageries, which were collected for the year 1987, 1997, 2007 and 2017. A study on the variation in runoff is ideal to understand the effect of urbanization on the environment. This paper attempts to study the effect of the changing land use scenario on the amount of runoff in Kolkata. The multi-temporal images were downloaded from USGS site and verified with topographical maps of scale 1:50,000 obtained from Survey of India. The runoff curve number is an empirical parameter used for predicting the direct runoff. The widely used NRCS-CN method was used to determine the runoff. Hydrology based mathematical expressions were used for direct conversion from Antecedent Moisture Condition I (dry) to Antecedent Moisture Condition III (wet). The runoff was estimated from the curve number which was determined from land use map of the area over time. It is seen that over the years there has been a considerable change in the land use pattern of the city. The built up area rose to as high as 75% in the year 2017, which in turn raised the volume of runoff from 798387 m^3 in 1997 to 861197 m^3 in 2017.

Keywords: Land use pattern, antecedent moisture content, curve number, runoff.

Introduction

The city of Kolkata located on the left bank of the river Hooghly is the capital of the State of West Bengal, India. The study area is situated in the Kolkata district of West Bengal, consuminga geographic area of 187.33 km^2 [1].

The district lies between 22.037°–22.030° North latitude and 88.023°–88.018° East longitude. Kolkata is bounded in the north and east by North 24-Parganas district and in the south by South 24-Parganas district along with Howrah district in the west. The area experiences a tropical climate with maximum temperature of around 40°C and a minimum temperature of around 10°C, accompanied by an average rainfall of 1647 mm. The city had seen an early start in development process during the British Regal Rule[2]. The city has a huge population base and a high density of road network as seen in Fig. 1.

The population of the city has always been on the rise. During the post-Independence period the city saw a huge influx from Bangladesh the then East Pakistan and due to this huge influx of refugees, the city happened to grow in an unplanned manner and mainly the city started expanding towards the southern and the eastern part[3]. If we closely monitor the population of the city since 1901 as shown in Fig. 2, it is seen that the population of Kolkata has always been on the rise. From 1931 there has been a sharp rise in its population. Kolkata is the largest metropolis in eastern India, having a mixed land use pattern with a pre-dominating residential land use. The city is facing the problem of overcrowding, as a result of high residential areas with high density of houses and population. The scarcity of land in the city has led to its vertical expansion, exerting pressure on basic amenities. The land use map of the city is a clear reflection of the increasing built up area and hence the rising population which is encroaching upon the water bodies and open spaces. A close monitoring of the land use is needed for taking effective administrative decision[4]. The land use of the place has a direct influence on the water requirement. With increasing population the demand for water supply increases and with increasing built up, the rain water infiltration decreases and runoff increases. Thus, it is affecting the ground-

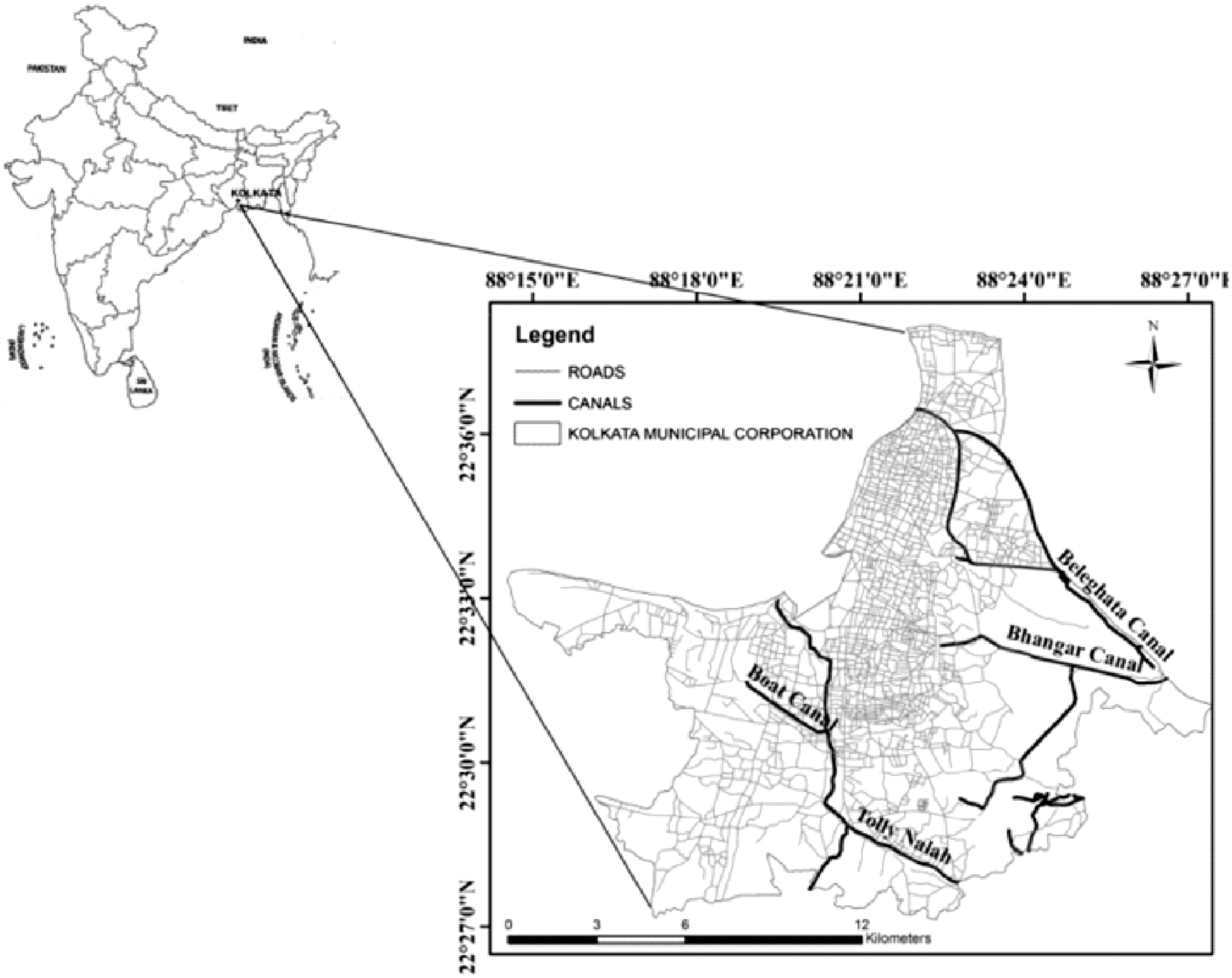

Fig. 1. Location of the study area.

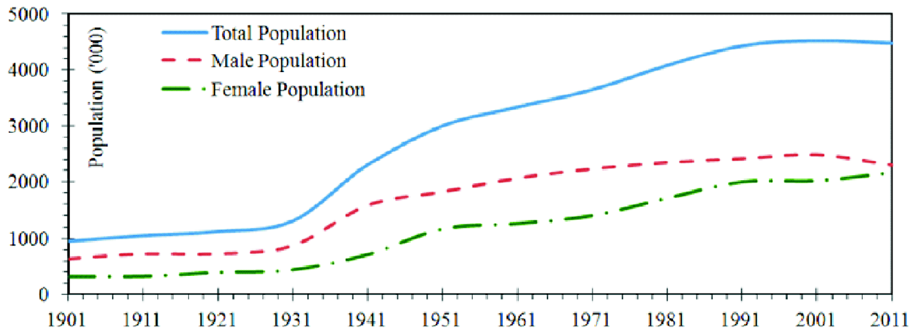

Fig. 2. Trend of population in Kolkata city from 1991-2011 (Census of India).

water level[5,6]. There are several factors affecting runoff, rainfall and land use being important[7].

A proper water resource management requires an acquaintance of the resource availability. An accurate estimation of runoff is necessary for proper decision making. There are many methods to estimate runoff but SCS (also known as Natural Resource Conservation Service Curve Number (NRCS-CN)) method is widely used because of its uncomplicatedness[8]. GIS and Remote Sensing form a very important tool for the construction of inputs readily required for the estimation of CN (Curve Number)[9]. The urban landscape is undergoing a rapid change leading to many environmental risks. An effective management of the same requires an evidence-based technique for ruling out the risk arising from it. Obtaining evidence for such is a very time-consuming process which requires advancement in technologies. Remote sensing offers a platform for a cost-effective management. Satellite imageries are a powerful source of urban land use information[10].

The conventional methods used in the classification of the images are supervised and unsupervised classification. Unsupervised classification is used in thematic mapping and is simple in application. The supervised classification is used to classify pixels according to their reflectance[11]. Image segmentation is subjective and is uncertain. They are strongly application-dependent thus; pixel classification is a challenging task in remote sensing[12].

The objective of this study is to understand the impact of land use on the amount of runoff with the help of Remote Sensing technique and GIS approach. A close monitoring of land use changes and runoff is essential for a better management of the area and flood control.

Materials and methods

The satellite images for the city of Kolkata for the year 1987, 1997, 2007 and 2017 were downloaded from USGS site. The Landsat imageries were then processed and verified from the topographical map of Kolkata (1:50,000) obtained from Survey of India. The details of the satellite imageries are given in Table 1.

Table 1. Details of the satellite imageries

Year	1987, 1997, 2007, 2017
Satellite and sensor	Landsat 5 Thematic Mapper (TM)
Date of acquisition	08.12.1987/03.12.1997/05.05.2007/ 07.12.2017
Spatial resolution	30 m
Path/row	138/044
Datum	WGS 84 (World Geodetic System)
Map projection	UTM (Universal Transverse Mercator)
UTM zone	45
Station Id	BKT (Bangkok, Thailand Ground Station)
Band No.	5

All the imageries were mainly acquired in the month of December because the images were free of cloud cover. Using ERDAS Imagine 2014, the images were processed and classified using supervised classification to obtain the land use pattern in the city as seen in Fig. 3.

Consecutively, the Curve Number (CN) was estimated, which depends on soil type, land use/land cover and antecedent moisture content. The runoff and storage were estimated for the years 1997, 2007 and 2017 using the 30 years rainfall data for each base year. The rainfall data was obtained from Indian Meteorological Department (Alipore). The runoff and storage could not be determined for the year 1987 due to paucity of data.

For the determination of CN values, the hydrological soil classification was adopted. The four classes into consideration are as follows (Table 2).

Antecedent Moisture Condition (AMC) refers to moisture content present in soil i.e. dry condition (AMC-I), average condition (AMC-II) and wet condition (AMC-III), at the beginning of the rainfall event under consideration.

Firstly, the Curve Number for AMC-II condition was determined from the tables provided by SCS[13]. From the value of Curve Number for AMC-II, CN values for other two conditions were determined based on the hydrologic soil cover complexes. Curve Numbers (CN-1 and CN-3) for AMC-I and AMC-III conditions were calculated based on eqs. (1) and (2), respectively.

$$\text{AMC-I: CN-1} = \frac{\text{CN-2}}{2.281 - 0.01281\ \text{CN-2}} \tag{1}$$

$$\text{AMC-III: CN-3} = \frac{\text{CN-2}}{0.427 - 0.00573\ \text{CN-2}} \tag{2}$$

CN-2 value was referred from the table given by Subramanya[14] seen in the Table 3.

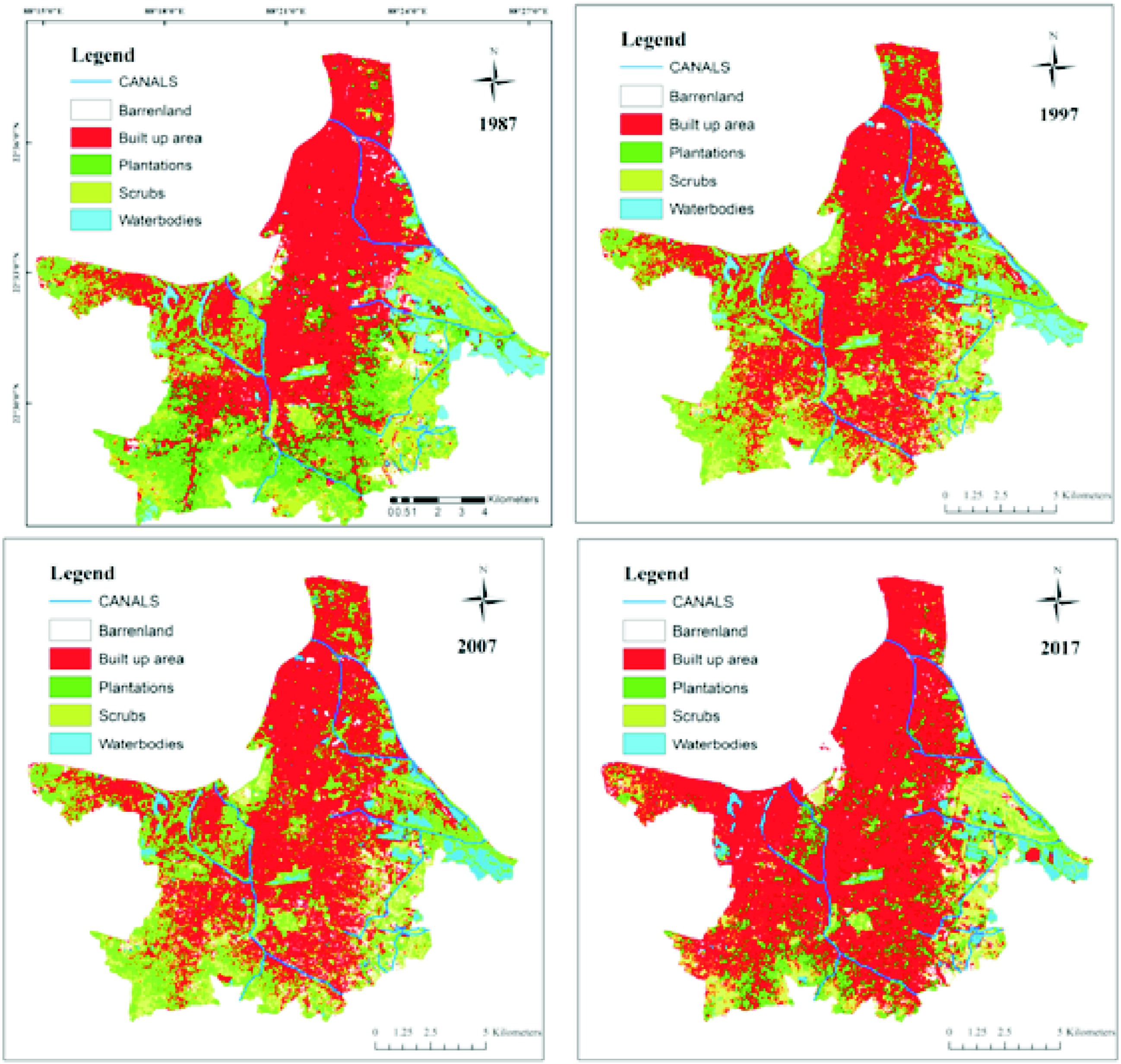

Fig. 3. Land use map of Kolkata city.

Table 2. Hydrologic soil group

Group A	Low runoff potential
Group B	Moderately low runoff potential
Group C	Moderately high runoff potential
Group D	High runoff potential

The potential maximum retention after runoff or storage water (S) of the catchment area for the three different AMC conditions was calculated from the Curve Number values using eq. (3) to determine the runoff of the stream.

$$S = \frac{25400}{CN} - 254 \quad (3)$$

The direct runoff (R) of the study area was determined from the storage (S) value by the formula given in eq. (4).

Table 3. CN-2 values for suburban and urban land uses[14]

Cover and treatment	Hydrologic soil group			
Open spaces, lawns, parks etc.	A	B	C	D
(i) In good condition, grass cover in more than 75% area	39	61	74	80
(ii) In fair condition, grass cover on 50 to 75% area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential, average (65% impervious)	77	85	90	92
Paved parking lots, paved roads with curbs, roofs, driveways, etc.	98	98	98	98
Streets and roads, gravel	76	85	89	91
Dirt	72	82	87	89

$$R = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (4)$$

The above mentioned equation is valid for P > 0.2S. Where P is the rainfall (mm) and *S* is the storage (mm).

Results and discussion

(A) Land use pattern:

To understand the effect of land use on runoff and storage, the land use map for the city was prepared. Kolkata being a metropolitan, it is apparent that the greater percentage of the area will be of concrete cover. The land use pattern of the city was divided into five classes – built up area, water bodies, plantations, scrubs and barren land, respectively (Table 4).

Table 4. Change in land use pattern over the decades

Classes (in %)	1987	1997	2007	2017
Built-up area	49.20	49.42	65.13	75.91
Water bodies	6.26	5.30	4.58	3.77
Plantations	21.97	11.99	13.65	4.57
Scrubs	18.33	28.15	13.32	12.39
Barren land	4.24	5.13	3.31	3.36

Comparing the percentages from graph in Fig. 4, it is seen that the maximum area in Kolkata is under built-up. These concretes have been used for residential as well as for commercial activities. As seen from the land use map maximum concretization is seen around the Central Business District (CBD) area that is around Dalhousie and adjoining area.

If we compare the land use variation over the years, in this case for 1987, 1997, 2007 and 2017, it is seen that the urban settlement has spread towards the southern and eastern part of the city. Kolkata has a growing population even in the past it had faced the refugee pressure coming from former East Pakistan, to shelter the huge population base the city expanded and to such an extent that it encroached upon the natural vegetation and water bodies.

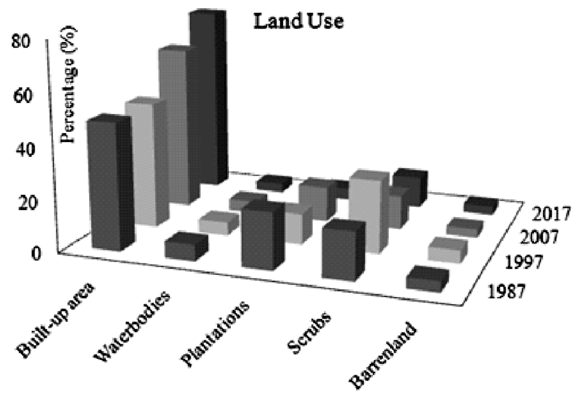

Fig. 4. Change in percentage of land use pattern in Kolkata.

At many places in the city, the water bodies were filled up for construction. In 1987 about 49% of the area was built up which increased slightly in 1997, but in 2007 it rose to 65% and further accelerated to 75% in 2017. Thus, there has been an increase of 26% in the built up area in the last three decades. This had a huge impact on the natural vegetation. Water bodies which were around 6% have come down presently to about 3% even plantations has seen a sharp fall whereas the area under barren land has declined. This clearly indicates a huge degradation of the environment. Huge population base means huge demand for the basic livelihood and the foremost important being water. Treated water is provided to the city from the Corporation but due to huge population and shortage of surface water supply people tend to depend on groundwater. With huge concretization the infiltration rate is decreasing, and since the confined aquifer is tapped in Kolkata due to over exploitation the groundwater is getting depleted and also leading to flood hazards in the city.

The city has turned up to be a fully residential area with huge percentage of commercial sectors. The southern part of the city which was known for its jheels and lakes are seeing it all turning into concrete. With huge population pressure, the wetlands are almost all filled up and buildings are constructed to accommodate the growing population and due to these vanishing wetlands the city also faces the problem of flooding. This concrete structure impedes infiltration of rainwater thus affecting the groundwater recharge. In Kolkata the unconfined aquifer, though present in pockets cannot be utilized as the recharge is not adequate. Thus, a study on the variation in runoff is quintessential to understand the effect of urbanization on the environment.

(B) Soil classification:

The city falls in the lower deltaic plain of the River Ganga basin and so ideally the city has alluvial soil cover. But with development the entire area is concretized which impedes infiltration and increases runoff. So, on this basis the soil cover, the area falls under Group D of the Hydrologic Soil Group.

(C) Determination of curve number:

To determine the Curve Numbers for Kolkata area, firstly, CN for AMC (II) was determined and then from CN-2 and CN-3 was determined for AMC (III). CN-2 was calculated to be 82.15 in 1997, 85.63 in 2007 and 87.65 in 2017.

$$1997\text{: CN-3} = \frac{\text{CN-2}}{0.427 - 0.00573\ \text{CN-2}} = 91.51$$

$$2007\text{: CN-3} = \frac{\text{CN-2}}{0.427 - 0.00573\ \text{CN-2}} = 93.31$$

$$2017\text{: CN-3} = \frac{\text{CN-2}}{0.427 - 0.00573\ \text{CN-2}} = 94.32$$

(D) Determination of storage:

The storage was calculated using the formula given in eq. (3). The storage for the year 1997 is calculated to be 23.56 mm, 18.20 mm in the year 2007 and 15.28 mm in 2017. Thus, there has been a considerable amount of decline in storage for the city (Fig. 5). In the year 2007, there was a fall of 22.75% and in 2017 it further decreased by 16%. Overall there has been a decline of 35.14% since 1997.

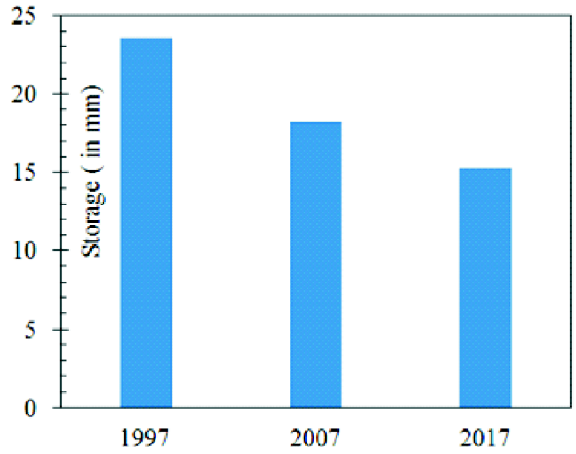

Fig. 5. Storage for years 1997, 2007 and 2017.

(E) Determination of runoff:

The amount of runoff for the city was calculated to have a clear picture of the amount that is drained off without infiltrating into the surface. Had it been infiltrated; it would have had a huge influence on groundwater recharge. The volume of runoff (V_r) is calculated using the following eq. (5):

$$V_r = (A_c \times 10^6) \times (R/1000) \quad (5)$$

where, A_c is the area and R is the sum of direct runoff of all the five wettest days.

The runoff for the year 1997 was calculated to be 7,98,387 m^3 in 1997 which increased to 8,47,927 m^3 in 2007 which further increased to 8,61,197 m^3 in 2017 as seen in Fig. 6.

In the year 2007 there had been an increase of 6.2% in the total volume of runoff which decreased to 1.56% in 2017. This is due to the fact that maximum concretization has already taken place and much change is not noticed presently. Though the actual amount of runoff has increased but the change in percentage is reduced.

Thus, it is evident that the increasing population pressure due to the natural growth of the city and migration, the city is expanding and impacting the environment. The stor-

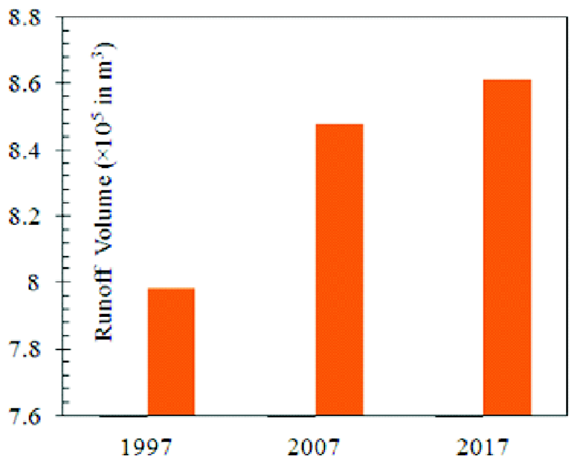

Fig. 6. Runoff hydrograph depicting runoff for the years 1997, 2007 and 2017.

age after the rainfall is decreasing in the city and the runoff is increasing. The CN value for the year 1997 was calculated to be 91.51 and 94.32 in the year 2017. There has been a fall in the storage over the years, thus accelerating runoff.

The runoff volume has increased over the years. The amount of rainfall received by the city has remained more or less constant. Thus, this increase in runoff is quite an indication towards a changed in the land use pattern of the city. We closely observe the runoff pattern in the city, then it is seen that the values for the year 1997 and 2007 is considerable whereas, there has not been much of a difference between 2007 and 2017.

This clearly indicates that the expansion has quite reduced this may be due to the fact that further extension in Kolkata city is not possible and the population is mainly expanding in the adjoining areas of Rajarhat and New Town. A close monitoring of the increasing concretization is essential to check the harmful impact on the environment and it will also help in the planning of the city and for a better management. Even with increasing concretes measures should be adopted for harvesting the water received as rainfall.

Conclusions

The study throws light on the anthropogenic activities impacting the environment. The outcomes clearly reflect the degradation of the environment leading to different stressful event. Over the years the storage capacity (rainwater) of the city is declining. Thus, the increased runoff leads to the problem of water logging in the city. The unplanned growth of the city is another considerate factor adding to the havoc. A close monitoring of the land use pattern is essential for future planning for the sustainable development of the city. The land use for the city has changed noticeably over the period of 30 years from 1987- 2017.

The change in the demography and economic factors are clearly reflected in the land use pattern of the city. The city has expanded over the years but we see that the rate of increase in population is decreasing especially with the development of the adjoining areas namely Salt Lake, New Town and Rajarhat areas. It not only helps in studying the socio-economic factors but also the environmental aspect of it. Runoff estimation is necessary for managing flood and drainage networks. It also opens up the platform for future research in this field.

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